

WORKING PAPER

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Avoiding a Nuclear Wild, Wild West in the Middle East

Edited by Henry D. Sokolski



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Nonproliferation Policy Education Center

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Cover images, from top left clockwise: 1) Illustration of ROK designed SMART reactor planned for Saudi Arabia; 2) worlds largest planned concentrated solar power project located in Dubai; 3) Saudi Aramco natural gas piple in Saudi Arabia; and 4) a nuclear reactor under construction in Barakah, UAE.

Avoiding a Nuclear Wild, Wild West in the Middle East

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*Nonproliferation Policy Education Center
Working Paper 1801*

April 2018
Series Editor: Henry D. Sokolski

Nonproliferation Policy Education Center

The Nonproliferation Policy Education Center (NPEC), a 501(c)3 nonprofit organization, is a nonpartisan, educational organization founded in 1994 to promote a better understanding of strategic weapons proliferation issues. NPEC educates policymakers, journalists, and university professors about proliferation threats and possible new policies and measures to meet them.

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Preface

Most of the research published in this working paper, *Avoiding a Nuclear Wild, Wild West in the Middle East*, is the result of a Nonproliferation Policy Education Center (NPEC) project to implement Title V of the Nuclear Nonproliferation Act of 1978. Title V called on the executive to routinely produce assessments of how developing countries might meet their energy and environmental requirements more economically without additional nuclear power. As part of this project, NPEC commissioned a series of studies focused on Iran and Saudi Arabia. These energy assessments are part of this volume.

The Saudi analyses became all the more relevant when the White House announced in December 2017 that the United States would strike a civil nuclear cooperative agreement with Riyadh. This announcement immediately raised the question how much economic sense it made for Saudi Arabia to invest in nuclear power.

It also raised a number of security questions. Should the United States allow Riyadh to reprocess and enrich even though these activities could bring Saudi Arabia within weeks of acquiring nuclear weapons? If Washington acceded to this demand by Riyadh what would be the implications for the terms of nuclear cooperation with the United Arab Emirates, Egypt, Jordan, Turkey, and Morocco? How would such an agreement impact efforts to tighten the terms of our nuclear understanding with Iran? Would such a permissive deal with Riyadh make it more difficult to say no to Seoul's demand that we allow them to enrich uranium?

All of these questions and more are discussed in this volume's four sections. This working paper is being published in the hope that it will inform not only the debate over what the terms for nuclear cooperation should be for Saudi Arabia but also what Washington's civil nuclear cooperative policy should be in the Middle East and globally after the Saudi deal is struck.

Henry D. Sokolski

Chapter 1

Avoiding a Nuclear Wild, Wild West in the Middle East¹

Henry D. Sokolski

The following is divided into three sections. The first is an overview. The second is a rundown of why Congress should be wary of any U.S. nuclear deal with Riyadh that fails to ban Saudi enrichment and reprocessing as is required in the 2009 nuclear cooperative agreement with the United Arab Emirates (UAE), who's nuclear nonproliferation requirements are referred to as "the Gold Standard." The last section makes the case for proposed legislation that would require a majority vote in both houses of Congress before a U.S. nuclear cooperative agreement with a non-weapon state can come into force if it fails to include these Gold Standard nuclear nonproliferation conditions.

Overview

Failure to require Riyadh to forswear enriching or reprocessing in the text of a U.S.-Saudi nuclear agreement (either by excluding this condition or proposing to put a sunset on it) risks pouring kerosene on the embers of nuclear proliferation already present in the Middle East. Last Sunday, Crown Prince Mohammed Bin Salman threatened to withdraw from the Nuclear Nonproliferation Treaty, insisting in a 60 Minutes interview that "If Iran developed a nuclear bomb, we will follow suit as soon as possible."² The Saudi government also has made it clear that it intends to be "self-sufficient" in nuclear fuel making.³

This is unprecedented. Unlike official public comments made during the negotiation of previous U.S. civil nuclear cooperative agreements, these Saudi statements lay bare for all to see exactly what the security implications of failing to get Riyadh to forswear enriching and reprocessing will be. It's quite clear the Saudis are interested in a nuclear weapons option that can be exercised, if needed, "as soon as possible." That, rather than any economic purpose, is why the Kingdom is seeking U.S. nuclear assistance and is insisting on its "right" to enrich and reprocess.

1. This chapter is from the author's written testimony presented before a Hearing of The House Foreign Affairs Subcommittee on the Middle East and North Africa titled "Implications of a U.S.-Saudi Arabia Nuclear Cooperation Agreement for the Middle East," held on March 21, 2018. A video of the hearing is available from <http://www.npolicy.org/article.php?aid=1381&rtid=8>.

2. "Saudi Crown Prince: If Iran Develops Nuclear Bomb, So Will Saudi," *CBS News*, March 15, 2018, available from <https://www.cbsnews.com/news/saudi-crown-prince-mohammed-bin-salman-iran-nuclear-bomb-saudi-arabia/>.

3. Sylvia Westall, "Saudi Arabia to Extract Uranium for 'Self-Sufficient' Nuclear Program," *Reuters*, October 30, 2017, available from <https://www.reuters.com/article/us-saudi-nuclear/saudi-arabia-to-extract-uranium-for-self-sufficient-nuclear-program-idUSKBN1CZ1ON>. See also, Rania El Gamal and Katie Paul, "Saudi Arabia Should Not Forfeit 'Sovereign' Right to Enrich Uranium: Senior Prince," *Reuters*, December 21, 2017, available from <https://www.reuters.com/article/us-saudi-nuclear-turki/saudi-arabia-should-not-forfeit-sovereign-right-to-enrich-uranium-senior-prince-idUSKBN1EF287>.

If our government green lights such Saudi efforts by failing to uphold the Gold Standard, no one will be fooled as to what we are doing: Instead of upholding the last 73 years of American and international efforts to limit the spread of nuclear weapons by tightening nuclear controls, our government will be doing just the opposite, playing a risky game of nuclear chicken between Riyadh and Tehran. What's worse, this competition will not be limited to just the Saudis and Iranians.

Administration officials may also renew, revise, or cut additional nuclear cooperative agreements with Jordan, Egypt, Turkey, Morocco, and the UAE. As a practical matter, there will be tremendous pressure to have these understandings track whatever we allow the Saudis, turning an already troubled Middle East into a nuclear Wild, Wild West. In this new, nuclearized arena, not just Iran and Saudi Arabia, but their largest neighbors will gain the nuclear technology they need to join the nuclear-armed ranks of the Israelis and Pakistanis. The hope, against almost all experience, is that deterrence will work perfectly in one of the world's most imperfect, unstable regions. As for what might follow if such deterrence fails, the mind boggles—think a nuclear 1914.

To avoid this, it is essential first to hold the line by insisting on the Gold Standard conditions in the U.S.-Saudi nuclear cooperative agreement. Second, the United States must hold the same line with agreements it might negotiate with Riyadh's neighbors and to work with the world's three key nuclear reactor supplier states—France, China, and Russia—and the three key uranium fuel supplier states—France, the British-Dutch-German URENCO consortium, and Russia—to tighten nuclear restraints on their civil nuclear exports as well. Finally, along with others, the United States needs to convince Iran to back off its enrichment efforts. To be sure, this is a tall order. That said, not to try at all assures a failure of the most horrific kind.

As for the proposed legislation, the House Foreign Affairs Committee did the right thing in 2011 when it unanimously approved an earlier version of the bill. Given the nuclear proliferation developments that have transpired since the last major revision of the rules governing nuclear cooperative agreements in 1978, approval of such legislation is long overdue.

Why Congress should be wary of a U.S.-Saudi nuclear agreement that fails to uphold the Gold Standard:

First, it risks igniting a nuclear arms race starting in the Middle East. Language in the current UAE and Egyptian nuclear cooperative agreements with the United States explicitly stipulates that if Washington seals a nuclear deal with any other Middle Eastern state that is more “favorable in scope and effect” than what Cairo and Abu Dhabi were able to secure, the UAE and Egypt have the right to demand “equal terms and conditions.”⁴ In theory, the United States could try to resist such demands. In practice, Washington would be under tremendous pressure to cave. Egypt's nuclear cooperative agreement with the United States is up for renewal in 2021. Then, there is Turkey—its agreement is up for renewal in 2023—and Jordan, which the United States has long sought to strike a nuclear cooperative agreement with. Egypt, Turkey, and Jordan all insist they have a right to enrich and reprocess. Once our government opens the door for the Saudis to do so, these states will demand no less. How this impacts Israel, other than negatively, is unclear. Last week, Prime Minister Netanyahu told the Senate Foreign Relations Committee, the President, and the Israeli cabinet that the United States should cut no nuclear deal with Saudi Arabia unless

4. “Relevant Sections of the Agreement for Cooperation between the Government of the United States and the Government of the United Arab Emirates,” *Nonproliferation Policy Education Center*, 2017, available from http://npolicy.org/US_UAE_Agreement_Relevant_Sections.pdf.

it clearly prohibits enrichment and reprocessing.⁵

Assuming our government goes ahead, it is uncertain what Israel, which already has nuclear weapons, might do.⁶ It is worth noting, however, that every large reactor in the region—Israeli, Iranian, Syrian, and Iraqi—has either been bombed or targeted with aerial attacks. In each case, the attacking state was concerned that weapons plutonium or uranium was either being or might be produced. This worry, perhaps more than any other, is why the United States insisted in 2009 that the UAE forswear enriching or reprocessing in the text of the nuclear cooperative agreement. It was understood that without such a legally binding pledge, the UAE's program would be viewed warily by its neighbors. If the United States is serious about promoting peaceful nuclear power in the region, it needs to get more states in the region to adopt this standard, not fewer.

Finally, states outside the Middle East are watching. South Korean President Moon Jae-in wants to build nuclear submarines. These would require enriched uranium fuel. The current U.S.-ROK civilian nuclear agreement only allows the ROK to enrich uranium if it first secures U.S. permission, which Washington has yet to grant. If the United States allows the Saudis to enrich uranium and reprocess spent reactor fuel, though, Seoul would likely step up its demands, arguing, that as a close security ally, it should be afforded equal treatment for its planned submarines. Needless to say, this nuclear activity could also be used to support a nuclear weapons option.⁷ Assuming Seoul persuaded President Trump to relent and honor its request, the responses of Japan, North Korea, and China could be dramatic.⁸

Second, Riyadh's interest in enriching and reprocessing is difficult to explain—unless it wants a bomb option. In 2012, the Saudis announced their intention to build 16 reactors by 2032. By 2017, Saudi planners had pushed this back to 2040. Shortly thereafter, Crown Prince Mohammed bin Salman backed a national development plan for 2030 that didn't mention nuclear power but instead focused on investing in renewables. Most recently, the Saudis announced that instead of opening bidding on 16 large power reactors, they are only soliciting bids for two. Some analysts contend that this slippage reflects the Kingdom's desire to finance reactor construction with its oil revenues.⁹ With the price of oil dropping from \$100 a barrel several years ago to roughly \$60 a barrel today, the schedule for nuclear construction, they argue, had to slide. A more compelling explanation, however, is that Riyadh doesn't need nuclear power. Recent analyses have determined that the Saudis could more cheaply and more quickly meet their energy and environmental requirements by developing their natural-gas resources and investing in renewables—photovoltaic, concentrated solar power and wind. These analyses also found economic value in the Kingdom

5. "Netanyahu Warns of Mideast Nuclear Arms Race," *The Times of Israel*, March 11, 2018, available from <https://www.timesofisrael.com/netanyahu-warns-of-mideast-nuclear-arms-race/>.

6. It should be noted that the last time the United States made an exception from its nonproliferation policies and legal requirements not to promise to transfer controlled nuclear commodities to another close friend, India, Israel quietly petitioned for equal treatment. See Glenn Kessler, "Israel Submits Nuclear Trade Plan," *The Washington Post*, September 30, 2007, available from <http://www.washingtonpost.com/wp-dyn/content/article/2007/09/29/AR2007092901530.html>.

7. "Moon Gets US to Agree in Principle to Let South Korea Build Nuclear Subs: Report," *Asia Times*, September 20, 2017, available from <http://www.atimes.com/article/moon-gets-us-agree-principle-let-south-korea-build-nuclear-subs-report/>. See also, Lami Kim, "Has South Korea Renounced 'Nuclear Hedging?'," *Bulletin of the Atomic Scientists*, June 27, 2017, available from <https://thebulletin.org/has-south-korea-renounced-“nuclear-hedging”10863>.

8. See *How Dark Might East Asia's Nuclear Future Be?* (Working Paper 1601), Nonproliferation Policy Education Center, August 26, 2016, available from <http://www.npolicy.org/article.php?aid=1322&rid=2>.

9. Dan Yurman, "Saudi Arabia's Ambitious Plans for Nuclear Energy," *Neutron Bytes*, January 15, 2018, available from <https://neutronbytes.com/2018/01/15/saudi-arabias-ambitious-plans-for-nuclear-energy/>.

upgrading its electrical grid and reducing government subsidies that artificially drive up electrical demand. These findings are hardly surprising. The UAE, Riyadh's next-door neighbor, which began construction of four power reactors several years ago, just announced it would not be building any more nuclear plants.¹⁰ Why? Cheaper alternatives: In addition to plentiful natural gas and wind resources, the Emirates are now investing in photovoltaic systems and solar thermal storage systems, which together can operate twenty-four hours a day more cheaply than nuclear.¹¹ These findings also apply to Saudi Arabia, which has begun working on all of these options.¹²

As for the Saudis enriching their own uranium, the economic case, again, is negative. Uranium is plentiful globally from a variety of suppliers and priced at historic lows (less than \$23 a pound)¹³, as are uranium-enrichment services.¹⁴ If the Kingdom is anxious about security of supply, it would make far more economic sense for it to buy long-term contracts for uranium ore and enrichment services than to spend billions on a variety of plants (besides a large centrifuge facility) that would be needed to produce its own nuclear fuel. Even under the most optimistic of scenarios, investing in such an undertaking would only make economic sense after the Kingdom had most or all of its planned 16 large reactors up and running sometime after 2040.¹⁵ It currently has no reactors operating and has only opened a process for buying two. All of these facts help explain Crown Prince Salman's comment that if Iran got the bomb, the Kingdom would "follow suit as soon as possible" and why he insists his country should be allowed to reprocess and enrich. The two points are tightly related: One is the goal (to get a bomb quickly if needed); the other is the means (having the ability to produce and stockpile nuclear weapons uranium and plutonium). This is not something Washington should be a party to. Instead, it should uphold the Gold Standard, help Saudi Arabia with safer nonnuclear energy options, and push these policies throughout the Middle East, including Iran.

Third, failure to secure the Gold Standard with Riyadh, when Washington has the leverage to do so, risks *reducing* U.S. strategic influence in and outside the region. As I've explained in detail elsewhere, the Saudis are unlikely to buy reactors from France, the United States, or China.¹⁶ In each case, the export models being pitched for export have not yet operated and, where they are being built, are dramatically behind schedule and over budget. Meanwhile, the Russians' export reactor (the VVER-1200) has an ex-

10. Peter Fairley, "The United Arab Emirates' Nuclear Power Gambit," *IEEE Spectrum*, January 4, 2018, available from <https://spectrum.ieee.org/energy/nuclear/the-united-arab-emirates-nuclear-power-gambit>.

11. Ali Ahmad, "Economic Considerations of Nuclear Power Deployment in Saudi Arabia," *Nonproliferation Policy Education Center*, November 27, 2017, available from http://npolicy.org/Articles/March%202018%20Drafts/Ahmad_SaudiArabia_Nov17.pdf.

12. Robin Mills, "Saudi Arabia Energy Needs and Nuclear Power," *Nonproliferation Policy Education Center*, February 11, 2018, available from http://npolicy.org/Articles/March%202018%20Drafts/Mills_Saudi_Arabia_Feb18.pdf. See also, Stanley Reed, "From Oil to Solar: Saudi Arabia Plots a Shift to Renewables," *The New York Times*, February 5, 2018, available from <https://www.nytimes.com/2018/02/05/business/energy-environment/saudi-arabia-solar-renewables.html>.

13. "Media – In the Market," *TradeTech*, March 2, 2018, available from http://www.uranium.info/in_the_market.php.

14. Steve Kidd, "Uranium Enrichment – Why Are Prices Now Much Lower and What Is the Impact?," *Nuclear Engineering International*, December 8, 2016, available from <http://www.neimagazine.com/opinion/opinionuranium-enrichment-why-are-prices-now-much-lower-and-what-is-the-impact-5692128/>.

15. Dan Yurman, "What Is Saudi Arabia's End Game for a 123 Agreement?" *The Energy Collective*, March 2, 2018, available from <http://www.theenergycollective.com/dan-yurman/2428621/saudi-arabias-end-game-123-agreement>.

16. Henry Sokolski, "5 Myths about Saudi Arabia's Nuclear Program," *The National Interest*, March 6, 2018, available from <http://nationalinterest.org/feature/5-myths-about-saudi-arabias-nuclear-program-24771>.

tremely limited, troubled safety record. More important, given the Saudis' interest in developing a bomb option, Riyadh will be hard-pressed to trust the Russians to keep their confidences, as the Russians have long provided sensitive nuclear technology to their Iranian adversaries and cooperate with Iran in fighting against the Kingdom's interests in Syria. Who might Riyadh, then, buy from? The Kingdom's original nuclear bid requirements were for two reactors that would produce 2,800 megawatts. There is only one proven, operating reactor that can meet this requirement—South Korea's APR 1400. This reactor is up and running in South Korea, is fully and properly safety certified, and is being built (in the UAE) roughly on time and on budget. The APR 1400 bid also has one other clear advantage: The construction crews finishing their work on the Korean reactors in the UAE are tried and true and can be easily dispatched to complete APR 1400 construction work in the Kingdom. In fact, the Saudis changed their bid requirements to permit reactors other than the APR 1400 *only* after U.S., Chinese, Russian, and French reactor vendors all complained.

In any case, the South Koreans are most likely to win the bid. Given the APR 1400 reactor's American technical content, senior Korean officials are convinced they cannot export it to the Kingdom unless the Saudis first reach a nuclear cooperative agreement with the United States.¹⁷ For this reason (and others besides), Washington has serious leverage over Seoul and what nonproliferation conditions it might choose to place on its Middle Eastern nuclear exports. It would be remarkable if our government chose not to use this leverage. Seoul would surely spot this and would likely demand equal treatment regarding its desire to enrich. As already noted, Egypt, Turkey, Jordan, and the UAE would also take notice. But there's more. Besides the awkward optics of looking like a version of the 2015 Iran nuclear deal (which President Trump says is "the worst deal ever" because it allowed enrichment),¹⁸ a permissive deal with Riyadh that failed to include the Gold Standard would make a hash of the President's announced desire to get Germany, the European Union, the UK, France, Russia, and China to work with Washington to "fix" the Iran deal and its enrichment provisions. I have already noted the concerns of our key ally in the region, Israel, and Netanyahu's request that the United States make a prohibition on enrichment and reprocessing a precondition of any nuclear cooperation with the Kingdom. Clearly, bending to Saudi nuclear ambitions to enrich and reprocess will only reduce, not increase, Washington's "wins" for nuclear influence with all of these states.

The Case for Requiring Congress to Vote to Approve Nuclear Cooperative Agreements that Fail to Include the Gold Standard

It's been 40 years since Congress updated the Atomic Energy Act to reflect the latest insights into what the safety margin should be between "peaceful" nuclear activities and materials and nuclear bomb making. Congress incorporated its first thoughts on this issue in the Atomic Energy Act of 1946. At the time, Congress and the Executive Branch were wary of sharing any nuclear technology, peaceful or military, with any foreign government. With the further development of experimental power reactor designs, though, Congress reconsidered and amended the act in 1954 to promote Eisenhower's Atoms for Peace Program. As a result of this program, the United States actively shared the means to make and separate plutonium, a nuclear weapons explosive, on the mistaken assumption that bilateral and international inspections would be sufficient to prevent its misuse.

17. Jay Solomon, "Saudi Nuclear Talks: Risk and Limitations," *The Washington Institute for Near East Policy*, January 31, 2018, available from <http://www.washingtoninstitute.org/policy-analysis/view/saudi-nuclear-talks-risks-and-limitations>.

18. Morgan Chalfant, "Trump: Iran Nuclear Deal an 'Embarrassment'," *The Hill*, September 19, 2017, available from <http://thehill.com/homenews/administration/351323-trump-iran-nuclear-deal-an-embarrassment>.

India's 1974 nuclear weapons test literally blew this assumption away. Thinking it had clear assurances that New Delhi would not use its help to make bombs, Washington helped India get the reactor, the heavy water to run it, and the reprocessing plant that produced the plutonium New Delhi used in its first "peaceful" nuclear test. At first, State Department officials denied that India had used U.S.-exported heavy water. This, however, proved to be untrue. When Congress found out, it amended the Atomic Energy Act in 1978, tightening controls over reprocessing and enrichment of U.S. nuclear materials and the export of the most dangerous "peaceful" nuclear technology and hardware. Congress also required that a majority of both houses of Congress approve any proposed U.S. civilian nuclear agreement with non-weapons states that did not place all of their nuclear facilities under international nuclear inspections. Experts hoped that these conditions would be sufficient to afford a sufficient margin of safety against the possible diversion of exported civilian nuclear goods to bomb making.

Unfortunately, the last 40 years suggest otherwise. Iraq used its internationally "safeguarded" nuclear program to support its nuclear weapons program. North Korea did the same, openly reprocessing spent fuel and stockpiling plutonium, insisting it had a "peaceful" right to do so. Syria, meanwhile, imported and constructed a covert nuclear production reactor from North Korea even while its nuclear program was supposedly under "full-scope" international nuclear inspections. Iran's insistence on a "right" to enrich and the worrisome practical and diplomatic fallout is too well known to need review. In each of these cases, though, finding a clear violation of any binding commitment was extremely difficult or impossible to make. Finally, in recognition of these developments, the Bush and Obama administrations successfully negotiated a new, tough set of nuclear nonproliferation conditions for the U.S.-UAE deal, known as the Gold Standard.

This history more than recommends yet another adjustment of what the U.S. Atomic Energy Act specifies as a "compliant" nuclear cooperative agreement—i.e., one that automatically comes into force unless Congress passes a veto-proof law after 90 days of continuous executive session. Currently, a joint resolution of Congress is only required to bring a nuclear cooperative agreement into force if the country in question did not have nuclear weapons at the time the Nuclear Nonproliferation Treaty was negotiated and refuses to place all its nuclear activities and materials under international nuclear inspections. This is why a joint resolution of approval was needed in the case of India.

After what we have learned about the inadequacy of such safeguards for countries that want to reprocess or enrich (overtly or covertly), though, it's time Congress updated the act. In specific, if a proposed U.S. civilian nuclear cooperative agreement does not include the nuclear nonproliferation conditions contained in the U.S.-UAE agreement, it ought to require a joint resolution of approval.

The nuclear industry is strongly opposed to this. Having Congress vote on agreements that do not contain the Gold Standard, the nuclear industry argues, could jeopardize significant nuclear commerce. This is the same complaint industry made against the 1978 amendments, which the nuclear industry also opposed. This concern turned out to be unfounded, and now the industry backs those changes. Given the fall in U.S. nuclear exports and the decline of nuclear power's fortunes internationally, there is even more reason to believe the industry's complaints today are also unfounded.¹⁹

But perhaps industry has things right and nuclear cooperative agreements are important trade agreements. Assuming this, though, it hardly strengthens the nuclear industry's case against the proposed legislation.

19. Jodi Lieberman, "Nonproliferation, Congress, and Nuclear Trade: Plus ça Change, Plus C'est la Même Chose," *Center for Strategic and International Studies*, November 15, 2011, available from <https://www.csis.org/analysis/nonproliferation-congress-and-nuclear-trade-plus-%C3%A7a-change-plus-c%E2%80%99est-la-m%C3%Aame-chose>.

Congress, after all, must approve all significant trade agreements by joint resolution. Given the security equities now at play with U.S. civil nuclear cooperative agreements—where they are serving more and more as the equivalent of high-tech mutual security pacts (with emerging security partners such as the UAE, Vietnam, India and, now Saudi Arabia)—treating nuclear cooperative agreements that fail to include the Gold Standard as being at least as important as normal trade agreements, then, only makes sense.

Section I: Does Nuclear Power Make Sense for Iran?

Chapter 2

The Enigma of Resource-Rich Iran's Pursuit of Nuclear Energy

Geoffrey Styles

When Iran agreed to the Joint Comprehensive Plan of Action (JCPOA) in July 2015, it cleared a path for the Islamic Republic to achieve an ambition that predates that government's existence, at least for the non-military applications of nuclear energy.¹ The terms of Iran's agreement with China, France, Germany, Russia, the United Kingdom, United States and European Union permit it to build civilian nuclear power plants while continuing to develop uranium enrichment under UN supervision.

However, the JCPOA left unaddressed the larger question of the appropriateness of nuclear power in a country with the world's second-largest reserves of natural gas, along with abundant, untapped renewable energy resources, all of which appear to be more economical in the Iranian context than the envisioned fleet of nuclear power plants.

Iran has already paid a high price for its lengthy pursuit of nuclear energy. That price has included both direct costs in the form of foregone oil exports under international sanctions, along with substantial indirect costs resulting from reduced or restricted access to foreign direct investment, lending, and the settlement of dollar-denominated transactions.²

The Iranian nuclear program attracted international scrutiny from its inception, particularly in light of Iran's decision to pursue not just the deployment of nuclear power plants, but of the nuclear fuel cycle starting with enrichment. Over many years, intelligence gathered by the United States and other nations raised concerns that Iran's nuclear ambitions extended beyond civilian applications to include the development of a nuclear weapons capability. These suspicions were bolstered by periodic discoveries of undeclared nuclear facilities such as the Arak heavy water reactor and Natanz uranium enrichment plant in 2002 and the underground enrichment facility at Fordow in 2009.³

The prospect of Iran becoming a nuclear weapons state alarmed the international community and prompt-

1. Zachary Laub, "International Sanctions on Iran," *Council on Foreign Relations*, July 15, 2015, available from <https://www.cfr.org/background/international-sanctions-iran>.

2. Aki Bayz, Nicholas J. Spiliotes, Thomas L. Eldert, and Marysol Sanchez Velamoor, "OFAC Strengthens Iranian Embargo by Revoking Authorization of 'U-turn' Transactions," *Morrison & Foerster LLP*, November 11, 2008, available from <https://www.jdsupra.com/legalnews/ofac-strengthens-iranian-embargo-by-revo-81420/>.

3. On Arak, see "Arak Nuclear Complex," *Nuclear Threat Initiative*, July 11, 2017, available from <http://www.nti.org/learn/facilities/177/>. On Natanz, see "Accusing Iran," *The Economist*, September 25, 2009, available from <https://www.economist.com/node/14529841>. On Fordow, see "Factbox: Iran's Fordow plant," *Reuters*, May 24, 2012, available from <https://www.reuters.com/article/us-nuclear-iran-fordow-plant/factbox-irans-fordow-plant-idUSBRE84N0MB20120524>.

ed successive rounds of increasingly strict United Nations sanctions, beginning in 2006.⁴ At their most restrictive point, the sanctions targeted Iran's oil industry and oil exports, the country's principle source of foreign exchange and the engine of its economy. Other sectors and designated groups were also affected, including entities closely linked with the economic interests of Iran's leadership.⁵

From late 2011 the combination of U.S. and UN sanctions had a severe effect on Iran. As seen in Figure 1 below, the Iranian economy contracted in three of the four years the strictest sanctions were in place. During this period the country significantly underperformed the broader Middle East and North Africa region, which otherwise enjoyed steady, moderate growth.⁶

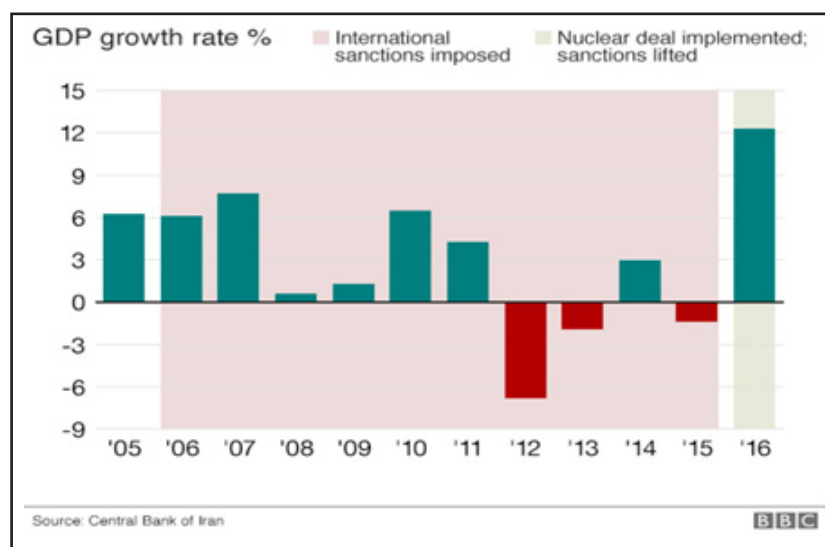


Figure 1: Economic Growth in Iran⁷

Considering only the impact on Iran's global sales of crude oil, its oil exports were cut by around 1.3 million barrels per day.⁸ An accurate estimate of total foregone oil profits on these volumes is impractical, since some of this oil was produced and stored for later sale, while other production was shut in, some of which may have been lost permanently. However, as reported by OPEC, the cumulative reduction in Iran's oil revenues in 2012-15, compared to 2011, came to \$215 billion.⁹ Even after excluding the portion of that attributable to lower international oil prices in 2014 and 2015, the cost to Iran's economy still exceeded \$175 billion, equivalent to around 5 months of current GDP.

4. Zachary Laub, "International Sanctions on Iran."

5. Mark Dubowitz and Saeed Ghasseminejad, "Hit Ayatollah Khamenei in His Pocketbook," *The Wall Street Journal*, July 22, 2018, available from <https://www.wsj.com/articles/hit-ayatollah-khamenei-in-his-pocketbook-1516666405>.

6. Valentina Romei and Hannah Murphy, "Election to dictate fate of Iran's recovery: In charts," *The Financial Times*, May 18, 2017, available from <https://www.ft.com/content/b6994c78-36f3-11e7-bce4-9023f8c0fd2e>.

7. "Six charts that explain the Iran protests," *BBC*, January 4, 2018, available from <http://www.bbc.com/news/world-middle-east-42553516>.

8. Kenneth Katzman, *Iran Sanctions*, Washington DC: Congressional Research Service, 2018, available from <https://fas.org/srg/crs/mideast/RS20871.pdf>.

9. *OPEC Annual Statistical Bulletin 2016*, available from http://www.opec.org/opec_web/static_files_project/media/downloads/publications/ASB2016.pdf.

Nor were sanctions the only pressure exerted on Iran in conjunction with its nuclear program. From the mid-2000s until 2013's "Joint Plan of Action," nuclear negotiations with Iran ebbed and flowed without a clear prospect of reaching resolution.¹⁰ The determination of the Iranian government not to give up or sharply constrain the activities in question fueled speculation that Iran's nuclear ambitions could only be curbed through military strikes, whether by the United States, an international coalition, or regional powers.¹¹ This prospect appeared sufficiently likely to influence global oil markets by means of an "Iran risk premium" that helped to push oil prices above \$100 per barrel on their way to an all-time high of \$148 in 2008.¹²

Iran's agreement in 2015 finally to limit its efforts, particularly with regard to enrichment, has been rewarded with the lifting of the nuclear-specific sanctions on the oil and gas industry along with many of those affecting other sectors. Some sanctions related to other aspects of Iran's policies and regional actions remain in place, but commercial ties, particularly with European countries and companies, have rebounded. Foreign direct investment increased to \$12 billion in 2016, or roughly five times the average of 2003-2010. More than two-thirds of that investment was in oil and gas exploration, production, and processing.¹³

Meanwhile, Iran's single existing light-water reactor is in operation at Bushehr, with technical assistance from Russia. The facility is essentially a Russian modification of the previously uncompleted, pre-Iranian Revolution design and construction by Siemens of Germany, completed in 2011 by Russian contractors.¹⁴ Under the terms of Iran's nuclear power agreement with Russia, the latter is responsible for fueling this reactor and will receive all spent fuel from its operation. The second of as many as eight additional Russian reactors is reportedly under construction at the same site.¹⁵

Iran's history of extraordinary costs incurred in pursuit of nuclear energy, along with its ongoing dependence on foreign nuclear expertise and fuel supplies, raises serious questions about the suitability of nuclear energy for the country. The country's economy has been built around its prodigious endowment of hydrocarbon resources, which meets the bulk of Iran's domestic energy needs and provides most of its income from international trade. At this point, nuclear power and even renewable energy still represent merely asterisks in its energy balances. Does Iran really need nuclear power plants to fuel its economic growth, or does it have better, more economical and less controversial options? That is the fundamental question this chapter seeks to answer.

10. Kelsey Davenport, "Implementation of the Joint Plan of Action At A Glance," *Arms Control Association*, October 2015, available from <https://www.armscontrol.org/Implementation-of-the-Joint-Plan-of-Action-At-A-Glance>.

11. David E. Sanger, "Why Not a Strike on Iran?" *The New York Times*, January 22, 2006, available from <https://www.nytimes.com/2006/01/22/weekinreview/why-not-a-strike-on-iran.html>.

12. Mark Gongloff, "Nymex Crude Gushing Toward \$100, Partly Because of Iran," *The Wall Street Journal*, November 8, 2011, available from <https://blogs.wsj.com/marketbeat/2011/11/08/nymex-crude-gushing-toward-100-partly-because-of-iran/>.

13. Valentina Romei and Hannah Murphy, "Election to dictate fate of Iran's recovery: In charts."

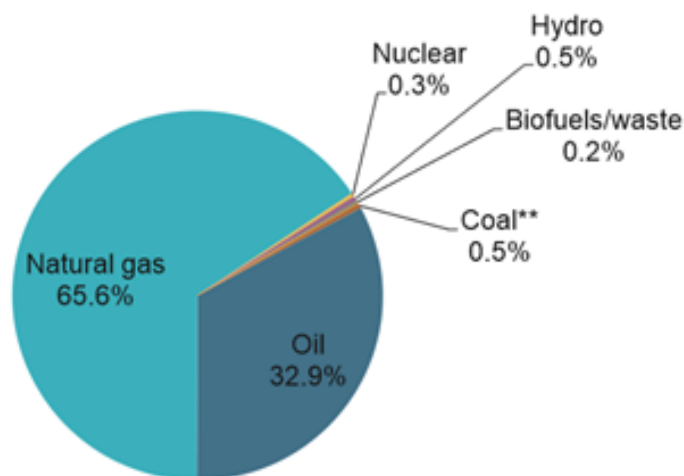
14. "Nuclear Power in Iran," *World Nuclear Organization*, April 2017, available from <http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/iran.aspx>.

15. "Iran, Russia start construction of new Iranian nuclear plant," *Reuters*, September 6, 2016, available from <https://www.reuters.com/article/us-iran-russia-nuclearpower/iran-russia-start-construction-of-new-iranian-nuclear-plant-idUSKCN11G0EB>.

Energy Demand

As indicated in the chart below (Figure 2) the energy mix of the Islamic Republic of Iran is dominated by two related fossil fuels: Petroleum and natural gas. Together these meet 98% of the country's energy demand, supplemented by modest contributions from coal, hydropower, and other renewables, and the output of country's only commercial nuclear power plant.

Islamic Republic of Iran



Source: International Energy Agency

Figure 2: Share of Total Primary Energy Supply in 2015

As discussed in greater depth below, Iran has large reserves of both oil and natural gas. However, more than half of Iran's crude oil production is exported, while nearly all gas production is consumed internally. Gas is the mainstay of the domestic economy, with a 66% share of energy demand in 2015.¹⁶ It is used directly in the commercial and industrial, residential, and transportation sectors. Iran is unusual among oil exporters in having nearly a quarter of its automobiles running on compressed natural gas (CNG).¹⁷ Gas also fueled the bulk of Iran's electricity supply in 2015.¹⁸

In considering the current and potential future role of nuclear power in Iran's energy market, it is essential to examine where and how it competes with other energy sources. The main output of commercial nuclear power is electricity. In this respect nuclear power does not compete with the consumption of fossil fuels by motor vehicles or for process heat in industry. Space heating, transportation and other applications are amenable to electrification, but not to direct fuel substitution by nuclear energy.

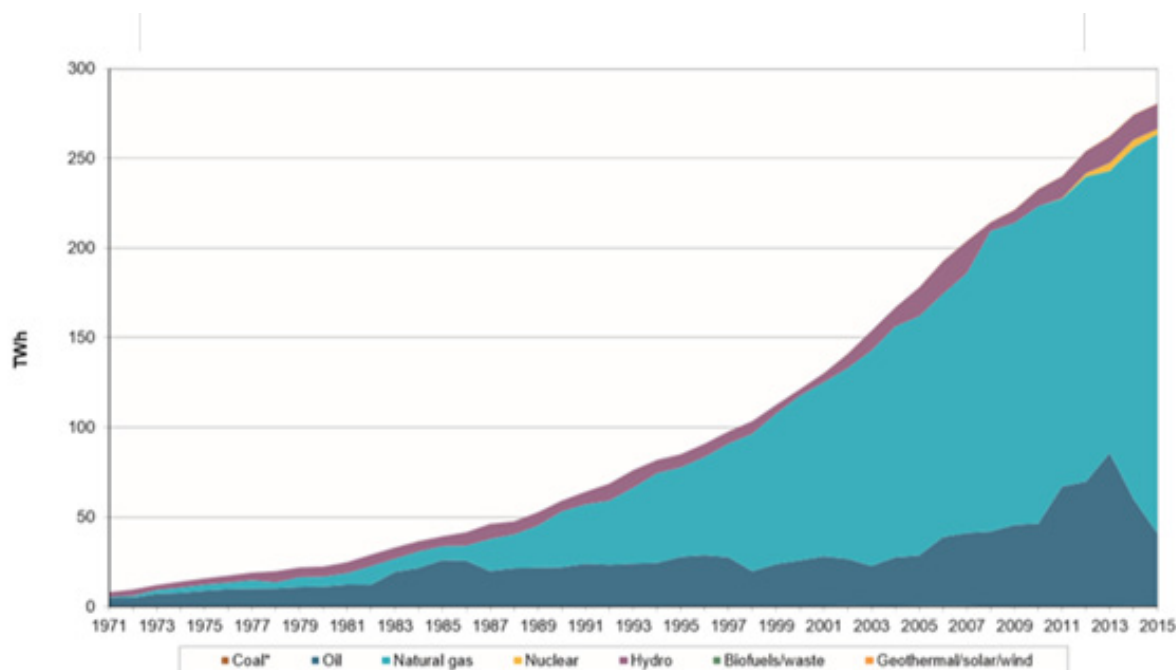
Iran consumed 221,000 Gigawatt-hours (GWh) of electricity in 2015. As shown in Figure 3 below, facilities burning natural gas supplied 79% of that electricity. Another 14% was generated from oil—mainly

16. International Energy Agency, "Iran, Islamic Republic of: Balances for 2015," available from <http://www.iea.org/statistics/statisticssearch/report/?year=2015&country=IRAN&product=Balances>.

17. Italian Trade Agency, "Market Overview of Automotive Sector in Iran," PowerPoint Presentation, available from <http://www.ra.camcom.gov.it/eurosportello/allegati-pina-newsletter/iran-automotive>.

18. International Energy Agency, "Iran, Islamic Republic of: Electricity and Heat for 2015," available from <http://www.iea.org/statistics/statisticssearch/report/?year=2015&country=IRAN&product=ElectricityandHeat>.

seasonal use of petroleum products such as high-sulfur fuel oil—with all other sources contributing just over 6%. Within that, nuclear power stood at 1% of supply. Iran’s record for seasonal peak electricity demand is approaching 56,000 Megawatts (MW), or 56 Gigawatts (GW) in summer.¹⁹



Source: International Energy Agency

Figure 3: Iran Electricity Generation by Fuel

The chart above also indicates the remarkably rapid growth rate of electricity generation, and thus demand, in Iran prior to the imposition of the most restrictive UN oil sanctions. From 1995-2012 demand grew by a compound average rate of over 6.5% per year, while from 2012-15 growth slowed below 2% per year, based on data reported to the International Energy Agency (IEA).²⁰ The growth of natural gas consumption other than for electricity generation during these periods, at 8% and 3.8% per year, respectively, is similar enough to the pace of electricity demand growth to suggest that Iran’s economy was not electrifying more rapidly than the overall growth of domestic energy consumption in the economy in the last two decades. If anything, electrification may have slowed relative to total energy demand while the tightest sanctions were in place and the economy contracted.

It is also evident that during the period of strongest sanctions, a pronounced shift toward oil-burning power plants occurred, and away from gas. This might be explained by depressed internal oil prices, relative to gas, if fuels were priced at market rates in Iran. However, Iran’s fuels markets have been heavily distorted by subsidies of various kinds for many years. It seems equally plausible to conclude that a shift in the domestic energy mix was required to provide an outlet for oil—or its byproducts—that had to be produced due to reservoir integrity concerns or other factors, but could not practically be stored until sanctions would end at some future date.

The implementation of the JCPOA and the end of most nuclear-related sanctions, along with subsequent

19. “Iran Electricity Consumption Near All-Time High,” *Financial Tribune*, July 4, 2017, available from <https://financialtribune.com/articles/energy/67589/iran-electricity-consumption-near-all-time-high>.

20. International Energy Agency, “Iran, Islamic Republic of: Electricity and Heat for 2015.”

improvements in GDP growth, do not necessarily signify a return to the previous long-term trajectory of electricity growth. Post-JCPOA analysis of Iran's future energy supply and demand by the Stanford-Iran Project arrived at an implied rate of forecasted electricity demand growth of 2-2.5% through 2040.²¹ This was based on a sector-by-sector buildup of demand, including much more rapid growth in the energy-intensive industrial sector. That is broadly consistent with an earlier forecast by BMI Research, which saw Iran expanding its power generation by 2.7% per year from 2016-23.

The Iran Project's report also found significant scope for efficiency improvements in Iran's existing gas-fired power plant fleet, through a combination of upgrading simple-cycle gas turbine plants to combined-cycle operation, and through replacement of gas-fired steam power plants by new combined-cycle plants. These upgrades would result in higher net generation of electricity, as well as significant fuel savings. When added to the expected increases in Iran's natural gas production over this period, the study found ample supplies of gas to sustain or even increase the high share of gas in power generation in Iran, depending on the level of future natural gas exports.

Recent reports indicate that Iran is continuing its legislated program of privatizing state-owned power generation assets.²² The Thermal Power Plants Holding Company will apparently sell another 11,570 MW of generation to private companies, in keeping with plans to reach private ownership of 80% of the power sector, by capacity.

Resource Endowment and Availability

Continued expansion of Iran's gas-fired power generation capacity from its already substantial installed base requires long-term access to reliable sources of natural gas on a commensurate scale. Unlike countries that must rely on imported gas from distant producers, transported either by pipeline or as liquefied natural gas (LNG) via ocean-going tankers, for Iran this consideration is reduced to a simple question of the size and accuracy of its domestic natural gas reserves.

Iran is a substantial net exporter of energy but most of that is in the form of crude oil and petroleum products.²³ Although its state-owned energy industry aspires to become a significant exporter of LNG in the future, current gas exports are modest, consisting of pipeline deliveries to neighboring Turkey, Armenia, and Azerbaijan. The latter volumes are largely offset by imported gas from Turkmenistan.²⁴

Despite low levels of gas trade, since 2013 Iran's reported "proved reserves" of natural gas have ranked as the largest in the world, following a substantial downward revision in Russian gas reserves.²⁵ The new

21. Pooya Azadi, Arash Nezam Sarmadi, Ali Mahmoudzadeh, and Tara Shirvani, *The Outlook for Natural Gas, Electricity, and Renewable Energy in Iran*, Working Paper 3, Stanford Iran 2040 Project, Stanford University, April 2017, available from https://iranian-studies.stanford.edu/sites/default/files/publications/the_outlook_for_natural_gas_electricity_and_renewable_energy_in_iran_2.pdf.

22. "Iran Gov't Divesting Stake in Thermal Power Plants," *Financial Tribune*, February 4, 2018, available from <https://financialtribune.com/articles/energy/81327/iran-govt-divesting-stake-in-thermal-power-plants>.

23. International Energy Agency, "Iran, Islamic Republic of: Balances for 2015."

24. Benoît Faucon, "Iran Seeks Rapid Reboot for Natural Gas Exports," *The Wall Street Journal*, January 26, 2016, available from <https://www.wsj.com/articles/iran-seeks-rapid-reboot-for-natural-gas-exports-1453821547>.

25. "UPDATE 3-BP cuts global gas reserves estimate, mostly for Russia," *Reuters*, July 12, 2013, available from <https://www.reuters.com/article/bp-reserves/update-3-bp-cuts-global-gas-reserves-estimate-mostly-for-russia-idUSL5N0EO1I720130612>.

figures put Iran ahead of Russia and the United States, even though both these countries produce a multiple of Iran's annual gas output.

As defined, proved gas reserves include only identified resources that are economic to produce at current prices, using current practices and technology.²⁶ Changes in price or improvements in technology can result in large shifts in proved reserves, such as the 45% increase in U.S. natural gas reserves from 2006 to 2016, resulting from improved capabilities to extract shale gas and other "tight" gas resources economically on a large scale.²⁷

One measure of the sufficiency of a country's natural gas reserves is implied reserve life. This metric does not consider future field production rates or logistics, but simply divides reserves by annual production (R/P). Iran's gas reserve life stands at 166 years at current production. By comparison, Russia's reserve life equates to 56 years at current production, while that of the U.S., now the world's largest producer, is just under 12 years.²⁸

That comparison suggests that, barring any obstacles to obtaining the necessary investment or access to technology, the scale of Iran's gas reserves should provide significant headroom to expand output without running into resource constraints. A 2015 forecast released by the National Iranian Gas Company indicated that with all economic constraints removed, and with large investments in new gas fields, Iran could increase its gas production to 450 billion cubic meters (BCM) per year by 2022, more than double reported 2016 production of 202 BCM.²⁹

Iran's long-term gas potential ultimately hinges on the reliability of its published reserves. A 2005 study by the Society of Petroleum Engineers (SPE) found good agreement in the treatment of the three categories of resources traditionally included in "proved reserves"—"proved developed," "proved non-producing," and "proved undeveloped"—among the agencies responsible for reserves accounting standards in the United States, Canada, UK, Norway, Russia and China.³⁰ All three categories represent gas that is both economically and technically recoverable with additional investment.³¹ As long as Iran adheres to similar standards in its self-reported reserves, then those figures should be comparable to—and as reliable as—those of other major producers.

The largest area of potential uncertainty in this regard is in the category of "proved undeveloped" (PUD) reserves. In Iran's case, those account for at least 85% of stated gas reserves.³² In other words, most of

26. U.S. Energy Information Association, "Oil and natural gas resource categories reflect varying degrees of certainty," July 17, 2014, available from <https://www.eia.gov/todayinenergy/detail.php?id=17151>.

27. BP Statistical Review of World Energy 2017, available from <https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf>.

28. Ibid.

29. Ibid and Ali Golara, Hamid Bonyad and Hedayat Omidvar, "Forecasting Iran's Natural Gas Production, Consumption," *Pipeline and Gas Journal* 242, no. 8, available from <https://pgjonline.com/magazine/2015/august-2015-vol-242-no-8/features/forecasting-irans-natural-gas-production-consumption>.

30. Oil and Gas Reserves Committee, "Comparison of Selected Reserves and Resource Classifications and Associated Definitions," *Society of Petroleum Engineers*, December 2005, available from http://www.spe.org/industry/docs/OGR_Mapping.pdf.

31. U.S. Energy Information Association, "Oil and natural gas resource categories reflect varying degrees of certainty."

32. U.S. Energy Information Association, "Natural Gas Exports from Iran," October 2012, available from https://www.eia.gov/analysis/requests/ngexports_iran/pdf/full.pdf.

Iran's future natural gas appears to reside in fields for which a discovery well has presumably been drilled, but that may not have been delineated through additional drilling, nor have they produced a cubic meter of commercial gas. That is not necessarily a serious cause for doubt, but it is indicative of the relative immaturity of Iran's gas sector, when compared to its oil industry, which has been producing since 1908 and is now rather mature.

If anything, Iran's reliance on PUD gas reserves suggests there may be further upside in its estimates, since reserves customarily grow as fields are developed through further drilling. Historical data on U.S. natural gas provide a good example of how reserves and eventual production can multiply over time through development. Based on data from the U.S. Energy Information Administration (EIA) cumulative U.S. dry natural gas production (excluding gas liquids and reinjection) totaled 1,200 trillion cubic feet (TCF)—nearly 35 trillion cubic meters, or roughly Iran's current gas reserves—even though U.S. proved natural gas reserves have never exceeded 368 TCF and were for many years estimated to be below 200 TCF.³³ Improved technology and higher prices were also important factors in that reserve expansion, and both could play a role in the future growth of Iran's reserves.

Another indication that Iran has substantial gas reserves available to develop is that 47% of current reserves are attributable to the enormous offshore South Pars Field, which extends across Iran's maritime border with Qatar, where it is called the North Field.³⁴ Together South Pars and the North Field form the world's largest non-associated natural gas field, i.e. gas not produced in conjunction with producing crude oil.

Qatar's production from this structure currently exceeds Iran's. In 2017 Qatar ended a self-imposed moratorium on further development of the field and is in the early stages of a significant expansion of output.³⁵ For its part, Iran signed an agreement³⁶ with French energy company Total, which will take a majority stake in the next stage of its South Pars development for an investment starting at \$1 billion.

That announcement, the first such deal following the signing of the JCPOA, meets an important need. At this point the most important constraints on realizing future production growth from Iran's gas reserves are financial. Production technology, geology and geography all appear to be in hand.

Even without much foreign investment, Iran has managed to expand its gas production at a 6% compound average growth rate since 2006 (EIA data through 2014), in line with the rise of domestic demand for the product. That result has of necessity been achieved with local talent and technology, due to the direct and indirect impact of sanctions.

It is also worth noting that Iran's oil and gas production are still essentially all from conventional reservoirs. Shale gas and oil resources have been discovered in several parts of the country, but particularly for

33. "U.S. Dry Natural Gas Production," *U.S. Energy Information Administration*, March 30, 2018, available from <https://www.eia.gov/dnav/ng/hist/n9070us2a.htm>.

34. "Natural Gas Exports from Iran: A report required by section 505(a) of the Iran Threat Reduction and Syria Human Rights Act of 2012," *U.S. Energy Information Administration*, October 2012, available from https://www.eia.gov/analysis/requests/ngexports_iran/pdf/full.pdf.

35. Pratap John, "Qatar's North Field expansion 'moving full steam ahead,' says al-Kaabi," *Gulf Times*, January 3, 2018, available from <http://www.gulf-times.com/story/576882/Qatar-s-North-Field-expansion-moving-full-steam-ah>.

36. Alanna Petroff, "Iran Signs \$2 Billion Gas Deal with France's Total," *CNN Money*, July 3, 2017, available from <http://money.cnn.com/2017/07/03/news/iran-total-sign-2-billion-gas-deal/index.html>.

gas its development is likely to remain uneconomic for many years.³⁷ The focus of the U.S. oil and gas industry on shale gas in the previous decade, and on shale or “tight oil” in the current decade, was largely a function of the maturity and decline of most conventional U.S. oil and gas fields. Iran still has a full menu of conventional gas discoveries to exploit at lower cost.

Finally, in addition to large hydrocarbon reserves, Iran’s territory includes significant renewable energy resources. Their current contribution and future potential will be explored in the section below.

Iran’s Alternative Energy Options

At one time “alternative energy” encompassed a wide array of possible energy sources, including some that were far from commercial availability or competitive cost. And since “alternative” mainly conveyed choices to alleviate what was then regarded as an excessive reliance on expensive and presumably scarce oil and gas, even coal qualified in certain forms. Today, with coal under intense environmental pressure and nuclear power in either economic or regulatory retreat in much of the developed world, alternative energy and renewable energy have become more or less synonymous as the former term falls into disuse.

Hydropower still accounts for by far the largest renewable contribution to Iran’s electricity generation. Dams and other hydroelectric installations made up roughly 17% of Iran’s electric utility generating capacity in 2015.³⁸ However, due to factors including persistent drought, hydro supplied only 5% of Iran’s electricity that year.³⁹

These facilities exist at various scales, but more than 90% are larger than 10 MW. Their output has been highly variable over multi-year periods, but the trend has been generally downward, with hydropower in 2015 generating a quarter less annually than in 2007.⁴⁰ For this reason, further meaningful expansion of hydropower in Iran appears unlikely.

By contrast, so-called non-hydro renewables, mainly wind and solar power, accounted for much less than 1% of both electrical capacity and generation in Iran as of the latest available statistics (2015), despite both potential and plans for substantial growth.

Iran’s Sixth Five-Year Plan targets the addition of 5,000 MW of renewable energy by 2021⁴¹ out of a total

37. Rakesh Upadhyay, “Why Iran’s Shale Oil Discovery Won’t Add to the Glut,” *OilPrice.Com*, May 2, 2016, available from <https://oilprice.com/Energy/Crude-Oil/Why-Irans-Shale-Oil-Discovery-Wont-Add-To-The-Glut.html>.

38. “Electricity, net installed capacity of electric power plants,” UN Data, available from <http://data.un.org/Data.aspx?d=EDATA&f=cmID%3aEC>.

39. Eric Wheeler and Michael Desai, “Iran’s Renewable Energy Potential,” *Middle East Institute*, January 26, 2016, available from <http://www.mei.edu/content/article/iran’s-renewable-energy-potential> and “Iran, Islamic Republic of: Electricity and Heat for 2015,” *International Energy Agency*, available from <http://www.iea.org/statistics/statisticssearch/report/?year=2015&country=IRAN&product=ElectricityandHeat>.

40. “Renewable Energy Statistics 2017,” *International Renewable Energy Agency (IRENA)*, 2017, available from http://www.irena.org/DocumentDownloads/Publications/IRENA_Renewable_Energy_Statistics_2017.pdf.

41. Joshua S. Hill, “Iran Approves \$3 Billion Worth of Foreign Renewable Energy Investments,” *Clean Technica*, February 8, 2017, available from <https://cleantechnica.com/2017/02/08/iran-approves-3-billion-worth-foreign-renewable-energy-investments/>.

of 25 GW of generation of all types to be added.⁴² This appears to be based on previously announced targets from 2014, anticipating 5,000 MW of renewables by 2018.⁴³ This appears to be focused mainly on wind and solar power with, with 500 MW of the latter as an initial target.

It is unclear whether any of these targets can be met within the planned timeframe. However, even if they were, this would very likely fall short of the goal of getting 10% of Iran's electricity from all renewable sources, including hydro, by 2021. If total generation grows from 2015 levels at the 2.7% per year rate cited above, the expected yield from another 5,000 MW of wind and solar installations might push renewables to 8% of all power generated, assuming no further deterioration of hydro output since 2015.

At least \$3 billion of foreign investment has reportedly already been committed to renewable energy projects in Iran, equivalent to only around 1,500 MW of combined new wind and solar capacity.⁴⁴ However, both that figure and the five times larger target set for 2030 represent just a small fraction of Iran's renewable energy potential, which has been estimated at 100,000 MW (100 GW) for wind alone, roughly equivalent to China's 2014 wind power capacity.⁴⁵ In this respect the development of Iran's renewable energy resources other than flowing rivers is even less mature than its exploitation of its enormous natural gas reserves.

Iran's location and climate render it especially suitable for generating electricity from sunlight. Iran's renewable energy agency, SUNA, reports average annual solar intensity ranging from 4.5-5.5 peak-sun-hours per day (equivalent to 4.5-5.5 kWh/m²/d).⁴⁶ This is an indication of excellent solar resources, with the high end of that range approaching some of the most attractive locations for solar power in the U.S. southwest.

The higher the peak-sun-hours at a given location, the more electricity can be generated annually from the same quantity of solar photovoltaic (PV) panels or from a concentrating solar power (CSP) facility. Thus a solar installation in southern Iran might generate, on average, over 70% more electricity yearly than one in southern Germany, with much less monthly variability.⁴⁷

The latter point is especially important for integrating grid-connected renewables without stressing the existing power grid. Wind and solar energy are intermittent power sources, varying across daily, seasonal, and annual scales. The lower the variation in peak sunlight, the more solar generation a power grid can integrate without requiring significant quantities of storage or other fast-reacting sources.

Intermittent renewables such as wind and solar power have useful synergies with natural gas, even as they compete for demand at the margin. Iran's current heavy reliance on natural gas for electricity generation

42. "Iran approves the Sixth Development Plan to boost investment," *CMS Law-Now*, April 21, 2017, available from <http://www.cms-lawnow.com/ealerts/2017/04/iran-approves-the-sixth-development-plan-to-boost-investment>.

43. Ian Clover and Hans-Christoph Neidlein, "Iran reveals 5 GW plans for solar and wind," *PV Magazine*, May 8, 2014, available from https://www.pv-magazine.com/2014/05/08/iran-reveals-5-gw-plans-for-solar-and-wind_100015040/.

44. Joshua S. Hill, "Iran Approves \$3 Billion Worth of Foreign Renewable Energy Investments."

45. Houman Liaghati, "The Potentials of Wind Energy Investment in Iran," *Iran National Environmental Fund*, 2015, available from http://archiv.windenergietae.de/WT24/24WT12_F9_1010_Iran.pdf.

46. "The Emerging PV Market in Iran," *Federal Foreign Office*, December 2015, available from https://www.solarwirtschaft.de/fileadmin/media/pdf/AA_Report_BSW_Iran.pdf.

47. "Solar Irradiance," *Solar Electricity Handbook*, 2017 Edition, available from <http://solarelectricityhandbook.com/solar-irradiance.html>.

is an advantage in this regard. Simple-cycle gas turbines in peak-power service can adjust quickly for fluctuations in supply due to changes in wind and cloud cover. The country's newer combined cycle power plants should have similar capabilities if they were designed to provide short "ramp" times, a measure of how quickly their output can increase or decrease.

Large-scale baseload generators, including nuclear power plants, typically cannot respond as quickly to such changes, if they can respond at all. This has become an important concern in markets with a high penetration of intermittent renewables, such as California, where the daily summer peak of solar generation is growing large enough to displace baseload generation, unless the renewable "overgeneration" is "curtailed," or taken off-line.⁴⁸

To put Iran's renewable energy targets and investments in perspective, its neighbor across the Persian Gulf, Saudi Arabia, has its own goal of achieving 10% of its generation from renewables by 2023, but starting from nearly zero without the equivalent of Iran's head-start in hydropower.⁴⁹ The Kingdom plans to invest up to \$7 billion in solar and wind installations in 2018 alone. Similarly aggressive developments are under way among the countries of the Gulf Cooperation Council. A single solar project in Dubai, the Mohammed bin Rashid Al Maktoum Solar Park, is intended to grow in phases from an initial scale of 13 MW, completed in 2013, to 5,000 MW by 2030—matching the ambition of Iran's entire renewable energy target.⁵⁰

A key driver of the wave of renewable energy installations across the Middle East and elsewhere is the rapidly falling cost of the associated technologies, particularly solar PV. This will be addressed in the following section.

Reducing Greenhouse Gas Emissions

Based on 2015 emissions of 630 million metric tons, Iran ranks eighth among countries for carbon dioxide (CO₂), the main greenhouse gas implicated in climate change, below Canada but above South Korea and Saudi Arabia. It ranks fifth on national emissions per unit of GDP, below China and Russia but above relatively carbon-intensive Canada and Australia.⁵¹

Iran is a signatory to the Paris Agreement, joining most other countries of the world in the voluntary commitment to reduce its emissions of CO₂ and other greenhouse gases (GHGs). As of this writing, Iran has not yet ratified the agreement.⁵²

In preparation for the late-2015 Paris climate conference of the United Nations Framework Convention

48. Paul Denholm, Matthew O'Connell, Gregory Brinkman, and Jennie Jorgenson, "Overgeneration from Solar Energy in California: A Field Guide to the Duck Chard," *National Renewable Energy Laboratory*, available from <https://www.nrel.gov/docs/fy16osti/65023.pdf>.

49. "From oil to solar energy: Saudi Arabia plots a shift to renewables," *The Straits Times*, February 6, 2018, available from <http://www.straitstimes.com/world/middle-east/from-oil-to-solar-energy-saudi-arabia-plots-a-shift-to-renewables>.

50. "Key Solar Projects and Programmes in Dubai," Government of Dubai, available from <https://www.dubaisolarshow.com/views/key-solar-projects-programmes-dubai.aspx>.

51. "Trends in Global CO₂ Emissions, 2016 Report," *PBL Netherlands Environmental Assessment Agency*, available from http://edgar.jrc.ec.europa.eu/news_docs/jrc-2016-trends-in-global-co2-emissions-2016-report-103425.pdf.

52. "Paris Agreement – Status of Ratification," United Nations Climate Change, available from <https://unfccc.int/process/the-paris-agreement/status-of-ratification>.

on Climate Change, Iran submitted its Intended Nationally Determined Commitment (INDC), spelling out its planned levels of emissions reduction and the conditions attached to them. In this document, Iran's government indicated it would reduce emissions unconditionally by 4% by 2030, relative to a "business-as-usual scenario."⁵³ This relatively modest level of reductions would be achieved by reducing emissions from its electric utility sector, reducing natural gas flaring, improving energy efficiency, diversifying its economy, and participating in national and international "market-based mechanisms." That term usually refers to emissions trading and other means of shifting emissions reductions between companies, economic sectors, or governments.

Iran also committed to a higher level of emissions reductions, up to an additional 8% of baseline emissions, conditioned on receiving international assistance, including technology transfer and capacity building. The estimated cost of the promised 4-12% emissions reductions was \$18-53 billion.⁵⁴

In the introduction of its INDC, the Islamic Republic referenced the country's need for continued hydrocarbon development to meet social and economic goals. Many of the specific technologies it identified as candidates for transfer relate to mitigating the greenhouse gas impact of oil and gas development, as well as in power generation, including natural gas combined cycle (NGCC) and combined-heat-and-power (CHP) generation, nuclear power and renewables.

Since the electricity sector is a primary contributor to the country's current emissions, its modernization should align with Iran's emission-reduction goals. In fact, all of the main strategies for updating generation in Iran—replacing gas-fired steam plants with NGCCs, deploying wind and solar power, and building nuclear power plants—contribute to meaningful emissions reductions. However, the extent and effective cost of the resulting emissions reductions varies significantly.

One particularly useful strategy not mentioned or implied in Iran's INDC is the displacement of oil from power generation. As noted in section II above, 14% of the electricity generated in Iran in 2015 was derived from oil, mainly high sulfur fuel oil and other petroleum products. Unlike in Saudi Arabia, little or none of the petroleum used by the power sector is in the form of crude oil. This is an important distinction when it comes to considering the alternate disposition of the petroleum that might be freed up by fuel switching or alternative generation.

The direct substitution of natural gas for residual fuel oil in even an inefficient steam power plant should result in a 29% drop in CO₂ emissions per Megawatt-hour (MWh), based on the relative emission factors of the two fuels when combusted.⁵⁵ Replacing the steam plant with a modern NGCC could result in CO₂ reductions of at least 46%, due to lower heat rate of the gas turbine, compared to a boiler-driven steam turbine, resulting in less fuel used for the same output.⁵⁶

This is analogous to the emissions reductions achieved in the U.S. utility sector as lower-priced natural gas has displaced electricity generated from coal-fired power plants. U.S. CO₂ emissions from electricity generation have fallen by roughly one-fifth since 2008 as coal's share of the electricity market fell from

53. "Intended Nationally Determined Contribution," *Islamic Republic of Iran Department of Environment*, November 19, 2015, available from <http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Iran/1/INDC%20Iran%20Final%20Text.pdf>.

54. Ibid.

55. "Emission Factors for Greenhouse Gas Inventories," *Environmental Protection Agency*, April 4, 2014, available from https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf.

56. "Average Tested Heat Rates by Prime Mover and Energy Source, 2007 – 2016," U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report, available from https://www.eia.gov/electricity/annual/html/epa_08_02.html.

48% to 34% in 2015, while the share of generation from gas increased from 21% to 32%.⁵⁷

Figure 4 shows that even larger emission reductions can be achieved by displacing the output of steam generation, which has characteristics similar to coal, with renewables like wind and solar power. Iran's existing hydropower facilities also qualify as low-emission on this scale, as does Iran's sole nuclear power plant. However, nuclear power is hardly the only tool with which Iran could reduce its GHG emissions, nor, as we will see shortly, is it the least expensive.

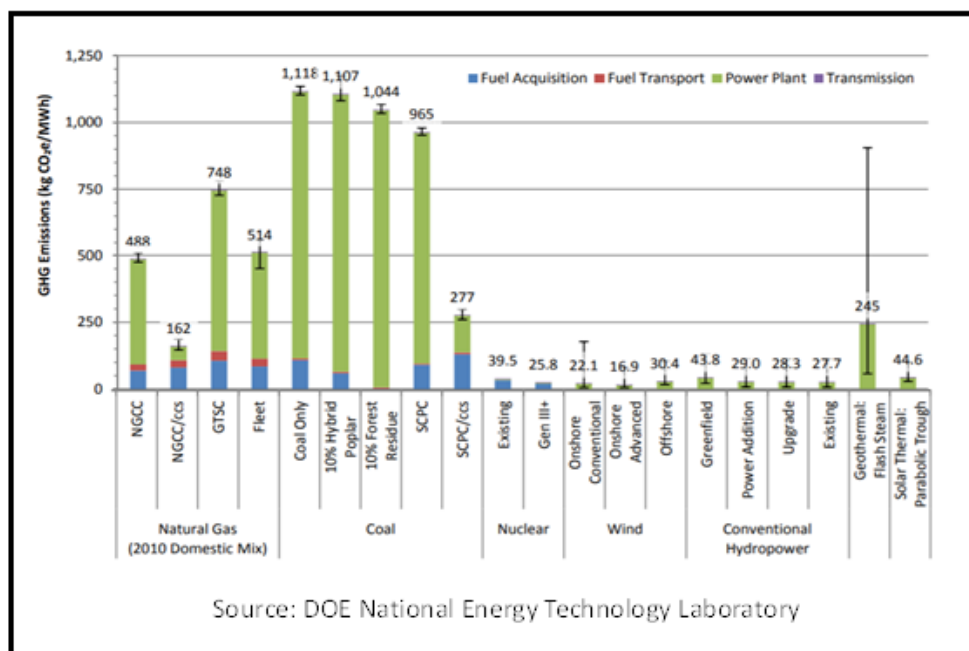


Figure 4: Lifecycle GHG Emissions in Power Generation

The chart also illustrates the emission-reduction potential of pairing gas power generation with carbon capture and sequestration, denoted as NGCC/ccs. CCS installations capture and concentrate CO₂ from the power plant exhaust for injection into a long-term storage site,⁵⁸ utilization in industrial processes, or for enhanced oil recovery as demonstrated by the PetraNova project in Texas.⁵⁹ CCS on natural gas is a simpler proposition than for coal-fired power plants, with their inherent complexities of solids handling. Chevron's Gorgon liquefied natural gas (LNG) plant⁶⁰ in Australia captures and stores over 3.4 million tonnes per year of CO₂ from the natural gas feed to the plant, equivalent to the emissions from a 1,500 MW

57. "Carbon dioxide emissions from electricity generation in 2015 were lowest since 1993," *U.S. Energy Information Administration*, May 13, 2016, available from <https://www.eia.gov/todayinenergy/detail.php?id=26232>.

58. Suzanne Goldenberg, "Canada switches on world's first carbon capture power plant," *The Guardian*, October 1, 2014, available from <https://www.theguardian.com/environment/2014/oct/01/canada-switches-on-worlds-first-carbon-capture-power-plant>.

59. Sonal Patel, "Capturing Carbon and Seizing Innovation: Petra Nova is POWER's Plant of the Year," *POWER Magazine*, August 1, 2017, available from <http://www.powermag.com/capturing-carbon-and-seizing-innovation-petra-nova-is-powers-plant-of-the-year/>.

60. "Gorgon CO₂ Injection Project," *Zero CO₂*, available from <http://www.zero.co2.no/projects/gorgon>.

NGCC plant.⁶¹ Similar facilities have operated in the North Sea since 1996.⁶²

Iran's power sector consumed 11.6 million tonnes of fuel oil in 2015—equivalent to around 200,000 barrels per day—resulting in approximately 37 million tonnes per year of CO₂ emissions.⁶³ If that figure could be cut in half by shifting demand away from Iran's oil-burning steam plants and onto new, efficient NGCC power plants, it would go a long way to meeting the country's 4% emissions reduction pledge under the Paris Agreement. Eliminating oil power generation by substituting an equivalent capacity of wind or solar power would exceed that pledge.

Ending Iran's inefficient oil-based power generation would provide other significant benefits, especially in reducing local pollution. For Iran today, air quality is a more acute problem than climate change. Four of the 10 worst cities in the world for air pollution are in Iran, and despite clean-up efforts, Teheran's air is still labeled as "unhealthy" a third of the year.⁶⁴ A 2004 paper published in the Iranian Journal of Health Science and Engineering found that merely substituting natural gas for fuel oil virtually eliminated the SOx emissions of four of the country's power plants, while reducing smog-forming NOx by 45-80%. New NGCC power plants have very low emissions of such local pollutants.⁶⁵

However, even if Iran were inclined to take this step, it must secure the additional gas supply, requiring additional upstream gas development, as well as an outlet for the displaced oil. As discussed in the next section, the latter concern is far from trivial, even for an oil-exporting nation like Iran.

The Export Factor

Prior to the imposition of the UN sanctions that were lifted after the signing of the JCPOA, Iran had the second-highest oil exports within the Organization of Oil Exporting Countries (OPEC), shipping over 2.5 million barrels per day (MBD) as recently as 2010.⁶⁶ Its recovery, post-sanctions, has been gradual, and conditions had changed in the interim. Iran's exports reached 2.1 MBD in 2017,⁶⁷ but that would only rank fourth, at best, within OPEC,⁶⁸ since the exports of both Iraq and the United Arab Emirates have grown in the meantime.

61. David Wogan, "Running the numbers on EPA's new CO₂ regulations: combined cycle stacks up well," *Scientific American*, September 20, 2013, available from <https://blogs.scientificamerican.com/plugged-in/running-the-numbers-on-epa-e28099s-new-co2-regulations-combined-cycle-stacks-up-well/>.

62. "Sleipner CO₂ Storage," Global CCS Institute, available from <https://www.globalccsinstitute.com/projects/sleipner-co2-storage-project>.

63. "Iran, Islamic Republic of: Balances for 2015," International Energy Agency, available from <http://www.iea.org/statistics/statisticssearch/report/?year=2015&country=IRAN&product=Balances>.

64. Caroline Mawer, "Air Pollution in Iran," *The BMJ*, 2014, available from <https://www.bmj.com/content/348/bmj.g1586>.

65. M. Ghiasseddin, "Comparison of Iran Power Plants Air Pollutants Before and After Shifting to Natural Gas," *Iranian Journal of Health Science and Engineering*, 2004, available from <http://www.bioline.org.br/pdf?se04008>.

66. "Oil Trade," Organization of the Petroleum Exporting Countries, available from <https://asb.opec.org/index.php/interactive-charts/oil-trade>.

67. Irina Slav, "Iran Oil Exports Hit 777 Million Barrels in 2017," *OilPrice.Com*, January 2, 2018, available from <https://oil-price.com/Latest-Energy-News/World-News/Iran-Oil-Exports-Hit-777-Million-Barrels-In-2017.html>.

68. "Annual Statistical Bulletin," Organization of the Petroleum Exporting Countries, 2017, available from http://www.opec.org/opec_web/static_files_project/media/downloads/publications/ASB2017_13062017.pdf.

Moreover, when sanctions ended, global oil markets were experiencing a severe slump caused by the rapid growth of U.S. shale oil production. Iran's resurgent exports compounded this situation until OPEC joined with Russia and other non-OPEC producing countries to restrain output and attempt to rebalance the global market and thereby shrink the significant bulge in global oil inventories that had accumulated.⁶⁹ Following the lifting of a decades-old restriction limiting exports of all but a select few U.S. oil grades, the U.S. has become a significant oil exporter in its own right, adding another new factor to the global market.⁷⁰

With the oil market so delicately balanced, at least for the moment, and OPEC's members bound by their agreement with Russia, Iran would not necessarily be free to export additional oil liberated from power generation by a shift to other fuels or energy sources, even though the quantities are equivalent to roughly 10% of Iran's current oil exports. The fact that the fuel burned in Iran's steam plants is not crude oil, but rather a grade of residual fuel oil, complicates matters further.

Under a new regulation adopted in 2016, the International Maritime Organization (IMO) will restrict the global use in ocean-going vessels of high-sulfur fuel oil of the kind produced by Iran's refineries, starting on January 1, 2020.⁷¹ The regulation cuts allowable sulfur content of the fuel from the current 3.5% to 0.5%, requiring very significant changes in refinery operations in order to meet these new specifications or supply the marine market with other types of fuel that already conform.

Few other outlets exist for such high-sulfur fuels, beyond continuing to burn them domestically. As described in a 2016 report by Platts, the global refining industry has several options for complying with the IMO's new rule, including the diversion of higher-quality fuel from other markets, shifting refinery inputs to higher quality crude oil, and investment in new process equipment to substantially reduce the sulfur content of this material or convert it into other, more acceptable products.⁷² At this point the response appears to be a work in progress, with several of the above solutions having lead times that exceed the time remaining before implementation.⁷³

So in order for Iran to displace enough fuel oil from power generation to make a material difference in its CO₂ emissions, or to create a new high-value product stream for domestic consumption or export, its refineries would have to install sufficient upgrading capacity to process these volumes, at a cost of billions of dollars. The potential returns on such an investment might be attractive, at least initially, but it would compete with desired investments in oil and gas development and production facilities. The alternative would be to attempt to sell this material at distressed prices to refiners elsewhere that already have such capacity.

Thus, in Iran's case, the rationale for justifying investments in renewable energy or nuclear power on the

69. Anjali Raval and David Sheppard, "Non-OPEC producers agree to cut oil output," *Financial Times*, December 10, 2016, available from <https://www.ft.com/content/4cd8dce2-beec-11e6-9bca-2b93a6856354>.

70. John Siciliano, "Oil exports climbing two years after 40-year-old ban lifted," *The Washington Examiner*, October 30, 2017, available from <https://www.washingtonexaminer.com/oil-exports-climbing-two-years-after-40-year-old-ban-lifted/article/2638865>.

71. "IMO sets 2020 date for ships to comply with low Sulphur fuel oil requirement," International Maritime Organization, October 28, 2016, available from <http://www.imo.org/en/MediaCentre/PressBriefings/Pages/MEPC-70-2020sulphur.aspx>.

72. Ned Molloy, "The IMO's 2020 Global Sulfur Cap: What a 2020 Sulfur-Constrained World Means for Shipping Lines, Refineries, and Bunker Suppliers," *S&P Global*, October 2016, available from <https://www.platts.com/IM.Platts.Content/InsightAnalysis/IndustrySolutionPapers/SR-IMO-2020-Global-sulfur-cap-102016.pdf>.

73. Melissa Manning, "New Low-Sulfur Requirements for Marine Bunker Fuels Causing Scramble for Refiners and Shippers, HIS Markit Says," *BusinessWire*, August 28, 2017, available from <https://www.businesswire.com/news/home/20170828005198/en/New-Low-Sulfur-Requirements-Marine-Bunker-Fuels-Causing>.

basis of freeing-up oil currently used in power generation for export at a favorable economic uplift looks highly questionable. Under the circumstances, it appears that at least until significant investments have been made in Iran's oil refineries, new generation from either renewable or nuclear sources would instead compete directly with gas-fired power generation, and ultimately with the economics of future gas development and exports.

Iran is already a modest net exporter of gas. As noted in the above section, all of Iran's present gas exports occur via pipeline. Any significant increase in exports would likely have to be in the form of LNG, requiring investment in liquefaction facilities, in tandem with investment in additional production to provide the large, stable supply of natural gas necessary to support the multi-decade economics of LNG development.

Several LNG projects have been proposed for Iran but some have subsequently been withdrawn, including one with India's state oil and gas company, ONGC.⁷⁴ Russian company Gazprom reportedly signed an agreement for LNG with Iran in late 2017.⁷⁵ Other possibilities such as floating LNG facilities have also been raised, yet all of these potential projects face significant uncertainties as the global market absorbs the output of new LNG facilities in Australia and the onset of LNG exports backed by U.S. shale gas.¹²⁹ Significantly, French oil major Total's agreement to invest in the development of the South Pars gas field is intended to supply Iran's *domestic* market.⁷⁶

Fundamentally, Iran has gas to export, whether from reserves still in the ground or liberated from current power generation needs. For more than a decade the key to large-scale gas development—and hence exports—by Iran has been access to the necessary technology and finance, and by far the largest impediment to both has been Iran's nuclear program and the suspicions that have surrounded it. In principle, the JCPOA addressed those. However, doubts about the sustainability of the agreement, particularly with regard to continued U.S. participation under the current administration, leave a cloud over the attractiveness of international investment in Iran's energy sector.⁷⁷

Nor are these investment needs small. In August 2017 Iran's oil minister Zanganeh cited a figure of \$200 billion over five years to revitalize Iran's oil and gas industry and capitalize on its opportunities.⁷⁸ Up to three-fourths of that should come from foreign investment. In this context recent deals with companies like Total represent only a down payment.

Gathering the required sums could prove challenging. The global oil and gas industry has more potential opportunities today than it appears to have the appetite to pursue. A bruising oil price slump from 2014-16 caused most international oil companies to reduce their capital budgets. The rapid post-slump recovery of U.S. shale

74. "OVL Drops Plan to Build Iran LNG Facility," *The Hindu*, February 26, 2018, available from <http://www.thehindu.com/todays-paper/tp-business/ovl-drops-plan-to-build-iran-lng-facility/article22853465.ece>.

75. "Gazprom in Iran LNG Cooperation Deal," *LNG World News*, December 13, 2017, available from <https://www.lngworld-news.com/gazprom-in-iran-lng-cooperation-deal/>.

76. Karen Thomas, "Iran Ponders LNG," *LNG World Shipping*, November 8, 2017, available from http://www.lngworldshipping.com/news/view.iran-ponders-lng_49826.htm.

77. Najmeh Bozorgmehr and Michael Stothard, "Iran to Sign \$4.8bn Gas Deal with Total," *Financial Times*, July 2, 2017, available from <https://www.ft.com/content/3b530f02-5f1d-11e7-8814-0ac7eb84e5f1>.

78. Jeremy Diamond, "Trump issues warning, but continues to honor Iran deal," *CNN*, January 12, 2018, available from <https://www.cnn.com/2018/01/12/politics/president-donald-trump-iran-deal-waiver/index.html>.

79. "Foreign funds for Iran's oil sector a top priority: Zanganeh," *Iran Daily*, August 21, 2017, available from <http://www.iran-daily.com/News/199102.html?catid=3&title=Foreign-funds-for-Iran-s-oil-sector-a-top-priority—Zanganeh>.

drilling is a factor, as well, moderating near-term prices while offering quicker returns on investment, compared to most large conventional oil and gas projects, such as those on offer in Iran. The result is something of a buyer's market in "upstream" opportunities. That may explain why BP, the 5th largest international oil company by market capitalization, has opted out of investment in Iran at this point.⁸⁰

Comparing the Costs of Iran's Electricity Options

The global energy industry is experiencing change on an enormous scale, particularly when it comes to the shifting future mix of generation that will meet growing demand for electricity. The most recent forecasts from organizations like the International Energy Agency and U.S. Energy Information Administration have increased the share likely to be taken by wind, solar and other renewable energy sources, along with slower but steady growth for natural gas, while moderating their view of the future market share of nuclear power. (See Figure 5)

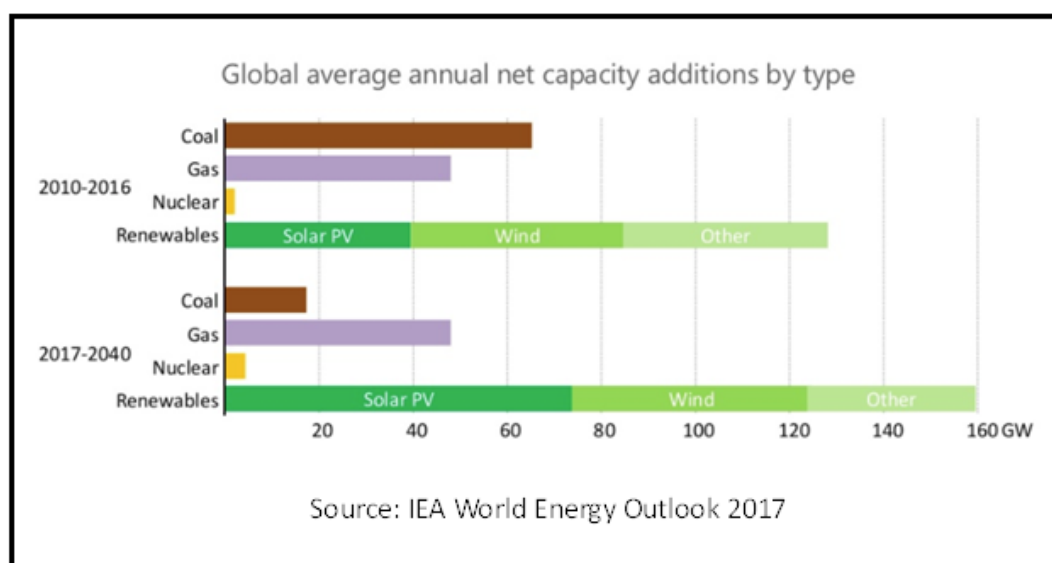


Figure 5: Renewables and Gas Lead World Electricity Capacity Growth

These shifts reflect sharp changes in conventional wisdom since the middle of the last decade. Notions of "peak oil" and its corollary, "peak gas," have wilted under a wave of production from conventional and non-conventional oil and gas resources, depressing prices and instilling a new sense of abundance. Meanwhile, renewables seemed likely to remain expensive well into the future have become competitive with conventional power plants, at least where the resources they tap are plentiful.

By contrast, after the recent cancellation of a flagship nuclear power project in South Carolina, the expected U.S. "nuclear renaissance" has dwindled to a pair of reactors under construction in Georgia. Projects in France, Finland, and the UK have experienced severe cost and schedule over-runs, while Germany is abandoning nuclear power even as it's policy of "Energiewende"—literally "energy turn"—seeks to reduce GHG emissions by increasing the share of wind and solar power.⁸¹

80. Andrew Ward, "BP O opts out of Iran deals ahead of Trump hard line on Tehran," *Financial Times*, January 2, 2017, available from <https://www.ft.com/content/b73c0e9e-ce7b-11e6-b8ce-b9c03770f8b1>.

81. Rebecca Staudenmaier, "Germany's nuclear phase-out explained," *DW*, June 15, 2017, available from <http://www.dw.com/>

The result of these developments has been a surprising rearrangement of the relative cost of the main electric generation options. The “gold standard” for comparing the economics of these technologies is the “levelized cost of energy,” or LCOE. It takes into account the differences among power sources with low capital but high lifetime fuel costs, and others with high capital costs but low or even essentially zero fuel expenses, along with differences in the timing of construction or installation.

Figure 6 below depicts ranges of LCOEs in U.S. dollars per MWh for a broad array of generating technologies on a consistent set of assumptions concerning fuel prices, interest rates, and policies—in this case in the absence of technology-specific subsidies such as the tax credits or “feed-in tariffs” that renewables have enjoyed in a number of markets. The analysis was performed by Lazard in 2016. The range bars for solar PV, gas combined cycle, and nuclear power have been highlighted for clarity.

Unsubsidized Levelized Cost of Energy Comparison

Certain Alternative Energy generation technologies are cost-competitive with conventional generation technologies under some scenarios; such observation does not take into account potential social and environmental externalities (e.g., social costs of distributed generation, environmental consequences of certain conventional generation technologies, etc.), reliability or intermittency-related considerations (e.g., transmission and back-up generation costs associated with certain Alternative Energy technologies)



Source: Lazard “Levelized Cost of Energy Analysis - Version 10.0”

Figure 6: Unsubsidized Levelized Cost of Energy Comparison

As shown here both NGCC (gas combined cycle) and utility-scale solar power appear to be considerably cheaper than nuclear power in the absence of subsidies, even without considering local factors like Iran’s abundant sunshine and effective natural gas prices much lower than the U.S. prices on which this analysis was based.

The analysis is also sensitive to the cost of capital. With inflation as high as in Iran, and high interest rates, capital-intensive projects that require investment over a period of years, such as nuclear power plants, would see their LCOE shift to the right (higher).⁸²

Recent solar power bids in Saudi Arabia, coming in below the LCOE range at an effective price less than

[en/germanys-nuclear-phase-out-explained/a-39171204](https://www.reuters.com/article/germanys-nuclear-phase-out-explained/a-39171204).

82. “Iran – Economic Forecasts – 2018-2020 Outlook,” *Trading Economics*, available from <https://tradingeconomics.com/iran/forecast>.

\$20/MWh, suggest how much solar prices have fallen just in the last two years.⁸³ It also highlights the advantage of regions with very high annual “insolation” or solar intensity.

In addition to the helpful decline in the cost of solar power, the deployment of renewables in Iran benefits from policies instituted by the government to promote it, directly and indirectly. These include a five-year feed-in-tariff (FIT), paying solar developers an above-market rate for their electricity production, equivalent to \$0.15 per kilowatt-hour (kWh).⁸⁴

Another policy advancing renewables less directly is the legislated privatization of Iran’s state-owned generators.⁸⁵ The government aims to increase private ownership of the power sector from the current 60% to 80%, while increasing annual renewable energy installation to 1,000 MW. With few of Iran’s utility customer paying enough for electricity to cover the cost of generating it, renewables could become the most profitable generating assets, as long as the FIT remains in place.

Conclusions

Iran’s energy economy is fueled by a few crucial inputs and driven to meet a relatively small set of needs. On the supply side of this ledger, the hydrocarbon resources within its territory are abundant and, in the case of natural gas, unsurpassed. On the demand side, the country’s economy requires rising energy production to provide export revenue, sustain GDP growth, and meet the needs of consumers. Increasingly, the energy supplied within the country must be cleaner, both to reduce endemic urban air pollution and to meet the commitments Iran made under the Paris climate agreement.

However, when it comes to the other crucial input to the energy sector, the investment needed to develop Iran’s resources and convert them into usable domestic energy or exportable goods, the industry is capital-constrained. That is not unusual when the government owns the oil and gas reserves, pipelines, refineries, and export facilities, as well as deciding how the significant cash flows generated by oil exports will be spent. Funds that in a publicly traded oil company would be reinvested in future production are often diverted to other purposes for which the government needs cash.

This explains why, despite external oil sales of around \$36 billion in 2016, Iran must seek foreign investors to participate in the continued exploitation of its share of the massive South Pars gas field and the revitalization of its oil fields.⁸⁶ It also explains why the sanctions imposed by the UN and the United States were effective in coercing Iran into the negotiations that led to the Joint Comprehensive Plan of Action on its nuclear program.

If the goal of Iran’s energy sector is to produce as much energy as affordably possible for the growth of its domestic economy and energy exports, then the country’s government appears to have better, more cost-effective options available than to spend scarce capital on a robust build-out of nuclear power plants and

83. Travis Hoium, “Middle East’s Low Solar Prices are a Game Changer,” *The Motley Fool*, October 10, 2017, available from <https://www.fool.com/investing/2017/10/10/middle-east-low-solar-prices-are-a-game-changer.aspx>.

84. Ian Clover and Hans-Christoph Neidlein, “Iran reveals 5 GW plans for solar and wind.”

85. “Iran Gov’t Divesting Stake in Thermal Power Plants,” *Financial Tribune*, February 4, 2018, available from <https://financialtribune.com/articles/energy/81327/iran-govt-divesting-stake-in-thermal-power-plants>.

86. “OPEC net oil export revenue streams in 2016, by member country,” *Statista*, available from <https://www.statista.com/statistics/223231/opec-net-oil-export-revenue-streams-by-country/>.

fuel enrichment.

There is every indication that renewable energy and modern gas-fired power plants can supply the foreseeable electricity needs of Iran's domestic economy, while reducing emissions of both local pollutants and greenhouse gases like CO₂. And because these technologies are cheaper in terms of both up-front investment and the levelized cost of their energy output, compared to nuclear power, this would leave more money to be invested in developing oil and gas fields for export purposes, compared to the convoluted and costly path of using nuclear power to displace for export some of the oil and gas currently burned there for electricity.

Iran has ample resources of natural gas and renewable energy—wind and sunlight—with which to grow its energy economy, while its nuclear ambitions have functioned as a large and sustained impediment to obtaining the foreign direct investment needed to undertake such growth. At least from an energy perspective, the continued pursuit of the government's nuclear program can only be described as an enigma.

Chapter 3

Meeting Iran's Energy Requirements without Nuclear Power

Patrick Clawson

This study is about how Iran can meet its electricity requirements without nuclear power. To be clear, let us explain what this study is *not* about. Most of Iran's energy needs are met with natural gas and oil, which is used for transportation, space heating, and the like. Nuclear power is of little relevance to meeting those needs. Where nuclear power comes into play is in Iran's generation of electricity. Therefore this paper is only about supplying Iran's electricity without nuclear power.

This study is also not about the proliferation risks posed by Iran's nuclear choices, be that for power plants, a full nuclear fuel cycle, or various research programs. While the effectiveness of various international agreements and the potential for Iran to weaponize its nuclear capabilities are extremely important questions, they are not the subject of this chapter. Instead, this study examines to what extent Iran has a legitimate civilian purpose for nuclear power, which is in many ways a precursor to those weapons issues. Bear in mind that its nuclear power program is the principal explanation Iran has given for its robust nuclear activities (while Iran also cites medical, agricultural, and scientific purposes, those are distinctly secondary to the power program).

This chapter examines where nuclear power fits in Iran's electricity situation. The paper begins by examining the current electricity generation situation in Iran and the likely prospects if there is no change in policies—prospects which include additional nuclear power plants. The bulk of the chapter considers policies more appropriate than nuclear power—policies which would save Iran vast sums while at the same time offering as good or better environmental results as nuclear power. The policies considered include, in order of their potential savings to Iran: Cutting subsidies and therefore electricity demand; relying on more renewable energy; replacing much single-cycle gas generation with combined-cycle; and relying on natural gas for much additional capacity. The chapter concludes with a discussion of institutional factors which contribute to the decision to pursue additional nuclear power plants.

The Current Electricity Generation Situation

Given the many clandestine activities of the Iranian government (e.g., support for terrorism and subversion), its history of misleading international inspectors about its nuclear program, its record of election manipulation (most blatantly in the 2009 presidential election), and its authoritarian government with only a democratic veneer, it is not surprising that many Westerners assume that little information is available from Iranian government. In fact, quite the opposite is true. On the whole, the Iranian government provides more data on the internet about its activities than the U.S. government does (with obvious exceptions about national security). In particular, the data available about electricity in Iran is exhaustive—and much

of it is in English.

In 2015—meaning the Iranian year which ends on March 20 of the next Western calendar year—Iran generated 280 billion kilowatt-hours (KwH) of electricity.¹ Of that total, 123 billion KwH came from facilities owned by the Ministry of Energy (MOE); note that MOE is largely concerned with electricity, since the separate Ministry of Oil is responsible for all aspects of oil and natural gas production and distribution (see Table 1.21, Gross Power Generation). Of the non-MOE electricity, 153 billion KwH came from facilities owned in theory by the “private sector”—which is not very private—and connected to the national grid, 6 billion KwH from facilities connected to and owned by large industries, and less than 1 billion KwH from other facilities not connected to the national grid – those being in isolated regions.

Year	Steam		Gas Turbine		Combined Cycle		Diesel	Hydro	Nuclear & Renewable Energy		Total		
	MOE	non-MOE	MOE	non-MOE	MOE	non-MOE	MOE	MOE	MOE	non-MOE	MOE	non-MOE	Overall
1967	0.732		0.056				0.396	0.658			1.842		1.842
1978	6.316		3.928				0.893	6.249			17.386		17.386
1996	62.364		15.475	0.35			0.61	7.376			85.825	0.35	86.175
2010	90.348	3.725	33.646	24.75	70.658		0.128	9.523	0.212		204.303	28.475	232.778
2015	61.66	25.299	21.339	54.084	22.961	77.975	0.065	14.087	3.094	0.115	120.112	157.358	277.47

Table 1: Gross Power Generation, 1978-2015 (billion KWh)²

Even more so than in most countries, the “private sector” facilities are highly dependent on government policies, as discussed below. These facilities are a recent phenomenon. The first non-MOE generation was only in 2000.³ As late as 2010, non-MOE facilities were only 17% of total operational capacity; 2015 was the first year in which non-MOE operational capacity exceeded that of MOE (see Figure 1, Operational Capacity of Power Plants by Ownership). Most of the growth of private facilities has come from privatization of facilities built by MOE, not new construction. Consider that between 2010 and 2015, the capacity of non-MOE grew 23,596 MW while total national capacity—MOE plus private—grew 10,639 MW.

1. “Detailed Statistics of Iran’s Electricity Industry - 1395 [2016/17]” in Persian, MOE/Tavanir, p. 1, available from <http://isn.moe.gov.ir/getattachment/05b65404-b61f-4dd3-9490-2ef35c6a965f/تـيـريـدمـهـژيـو،نـارـيـاقـرـبـتـعـنـصـلـيـضـفـتـرام> -س.ی.دربار. This very lengthy report has, as the title indicates, detailed statistics.

2. *Statistical Report on 49 Years of Activities of Iran Electric Power Industry (1967-2015)*, Tavanir Holding Company and Islamic Republic of Iran Ministry of Energy, 2016, p.10.

3. All of the data in the rest of this section, unless otherwise noted, are from the MOE/Tavanir Statistical Report on *29 Years of Activity of Iran Electric Power Industry (1967-2015)*.

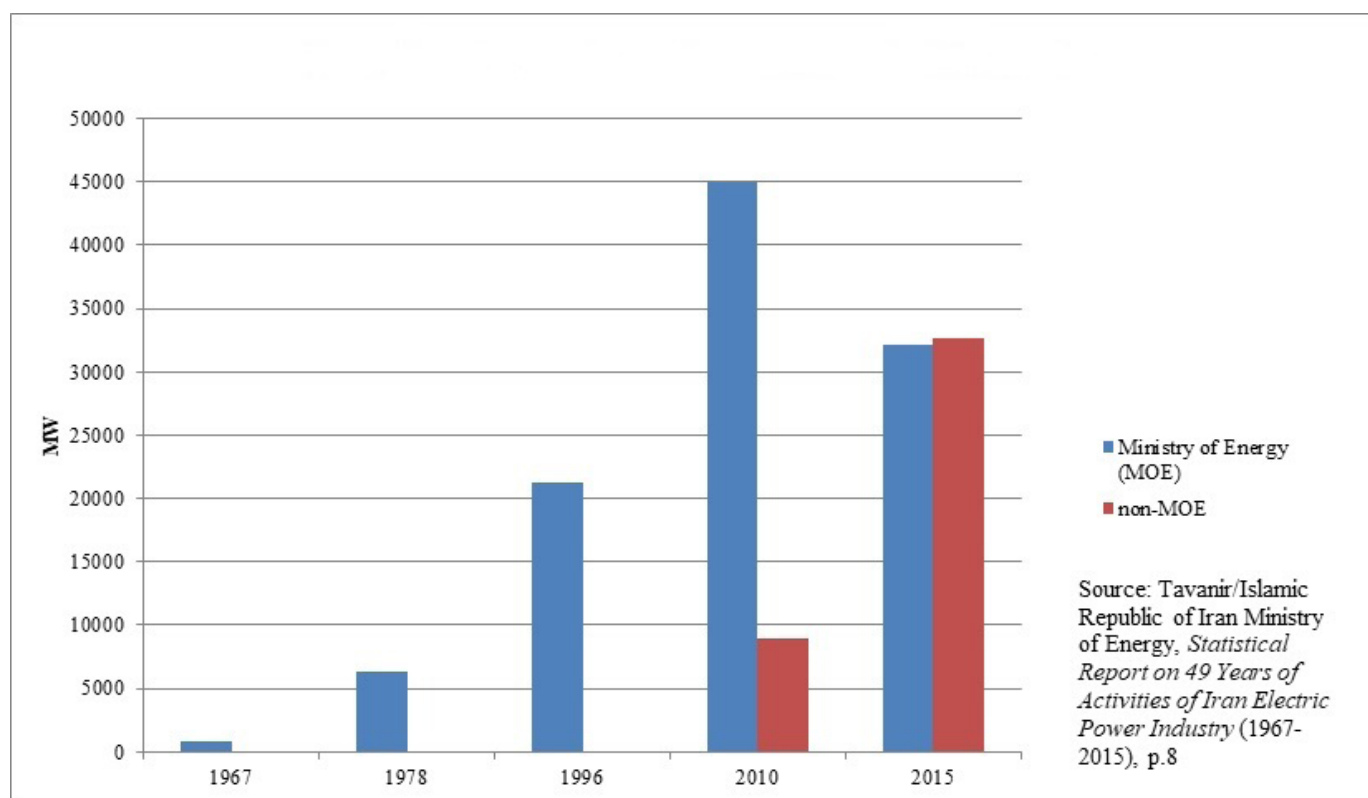


Figure 1: Operational Capacity of Power Plants by Ownership

Gas has long predominated in the Iranian power-generation mix. At the time of the 1978 revolution, Iran's capacity was 6,362 MW of which hydro was 1,804; diesel, 447; and gas 4,111, with 1,606 steam and 2,505 single-cycle gas turbine (see Table 2, Operational Capacity of Power Plants, and Figure 2, Operational Capacity of Power Plants by Fuel Type). In recent years, Iran is increasingly moving towards combined-cycle technology. The first combined-cycle facilities became operational in 1997, and by 2015, such facilities made up 23% of national operational capacity. In 2015, the operational capacity of Iran's power plants was 64,708 megawatts (MW), of which 61,992 used natural gas, 284 used diesel, 11,278 were hydro facilities, 1,140 were nuclear, and 53 were renewable MOE owned 32,119 MW; others, 32,589 MW. Of the natural gas facilities, 15,210 were steam (10,942 MOE and 4,268 non-MOE); 21,630 single-cycle gas turbine (5,086 MOE and 16,544 non-MOE), and 15,112 combined cycle (3,389 MOE and 11,723 non-MOE).

Year	Steam		Gas Turbine		Combined Cycle		Diesel	Hydro	Total		
	MOE	non-MOE	MOE	non-MOE	MOE	non-MOE	MOE	MOE	MOE	non-MOE	Overall
1967	324		62				154	309	849		849
1978	1606		2505				447	1804	6362		6362
1996	11456		7379				412	1963	21210		21210
2010	14560	661	9959	8332	11698		279	8486	44974	8993	53967
2015	10942	4268	5086	16544	3389	11723	284	11278	30979	32535	63514

Table 2: Operational Capacity of Power Plants (MW), 1967-2015⁴

4. *Statistical Report on 49 Years of Activities of Iran Electric Power Industry (1967-2015)*, Tavanir Holding Company and Islamic Republic of Iran Ministry of Energy, 2016, p.8

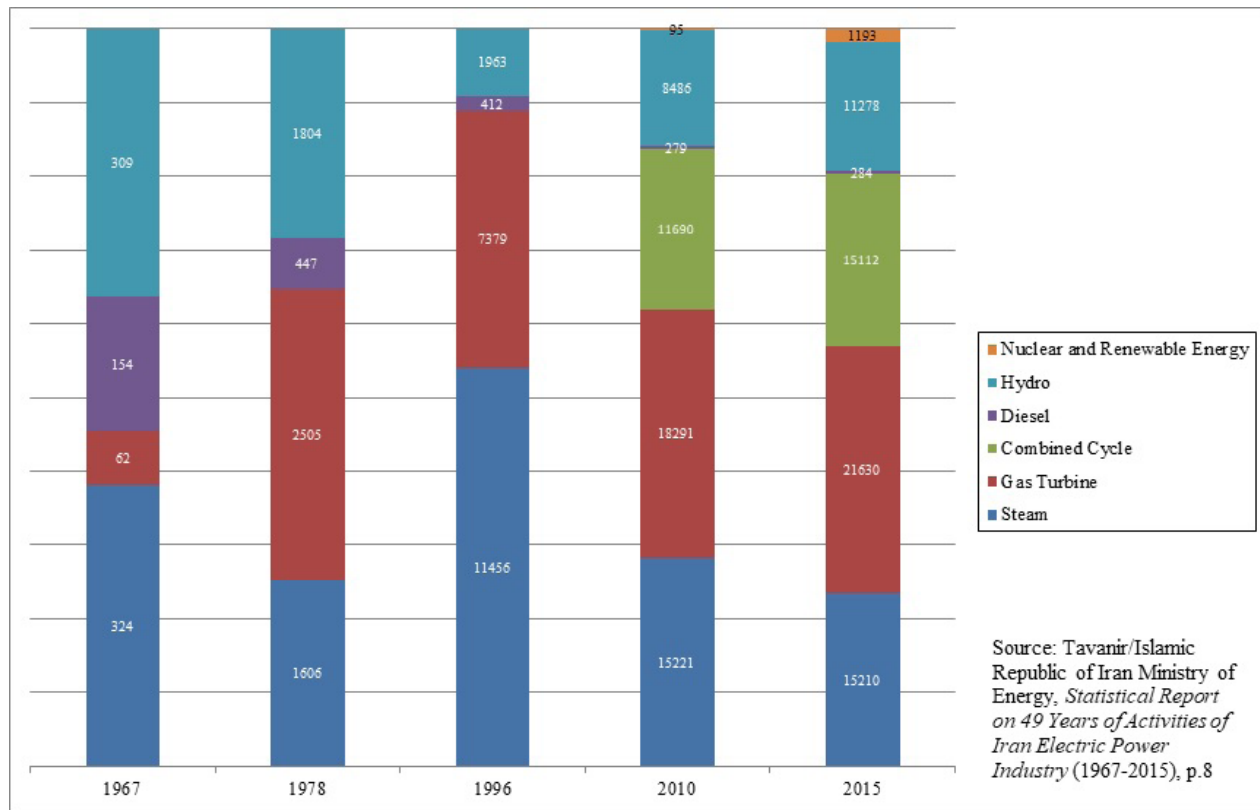


Figure 2: Operational Capacity of Power Plants by Fuel Type

Iran has been rapidly expanding its operational capacity for many years. From 1967 to 1978—the Shah’s last year—operational capacity rose 650%, an average annual increase of 18%. More recently, capacity has almost tripled since the first combined-cycle facilities started about twenty years ago, going from 23,050 in 1996 to 64,708 in 2015, an average annual increase of 5.58%.

Whereas the additional capacity under the Shah was mostly single-cycle gas turbine, the revolutionary government in its first decades mostly built steam plants. Of the 14,848 increase in operational capacity from 1978 to 1996, 9,850 was steam and 4,874 was single-cycle gas turbine; there was little change in hydro or diesel. More recently, the pattern has shifted, with a burst of hydro dam construction, considerable combined-cycle gas, and continued considerable addition of single-cycle gas turbine. In the period 1996-2015, of the 41,658 MW capacity increase, 15,112 has been combined cycle; 14,251 single-cycle gas turbine; 3,754 steam; 9,279 hydro; 1,140 nuclear; and 53 renewable, while diesel shrank 194.

Of the fuel consumed for electricity generation, gas predominates. In 2015, gas provided 525.81 million tons of oil equivalent (MTOE), while fuel oil provided 5.85 MTOE (see Table 3, Fuel Consumption of Power Plants). Note that because gas supply is insufficient to meet all demand during the peak consumption period in the winter, gas is provided for heating and industrial use while electricity generators have to shift to using fuel oil. One Iranian study comparing the economics of differing fuel sources used as an assumption that fuel oil would be burned three months a year.⁵ From the Iranian data, it would appear that the shift takes place primarily at MOE facilities; the non-MOE facilities use very little fuel oil or diesel, even though some of the operational capacity of such facilities is steam, which can handle the fuel switch

5. M. Khakbazan-Fard et al., “Generation Expansion Planning for Iran Power Grid,” *Iranian Journal of Science and Technology – Transaction B: Engineering* 34, no. B3, 2010.

over more readily than can turbine facilities. That said, even the most recently built gas-fired turbine generating facilities have to include large storage facilities for fuel oil, and news reports treat as a matter of fact that fuel oil will be burned in the winter. The Iranian data show that the problem became worse after 2009 as natural gas use for electricity generation actually fell (see Figure 3, Trend of Power Generation of Thermal and Non-Thermal Power Plants by Fuel Types, taken directly from an Iranian report).⁶

Year	Diesel		Fuel Oil		Natural Gas		Total		
	MOE	non-MOE	MOE	non-MOE	MOE	non-MOE	MOE	non-MOE	Overall
1967	114648		262173		11700		388521		388521
1978	1240896		855645		1242000		3338541		3338541
1996	854802		6276978		12098700		19230480		19230480
2010	3799401	1189473	7468137		33664500	6736500	44932038	7925973	52858011
2015	1098429	4029540	5221542	633936	19413000	33168600	25732971	37832076	63565047

Table 3: Fuel Consumption of Power Plants (tonnes of oil equivalent), 1978-2015⁷

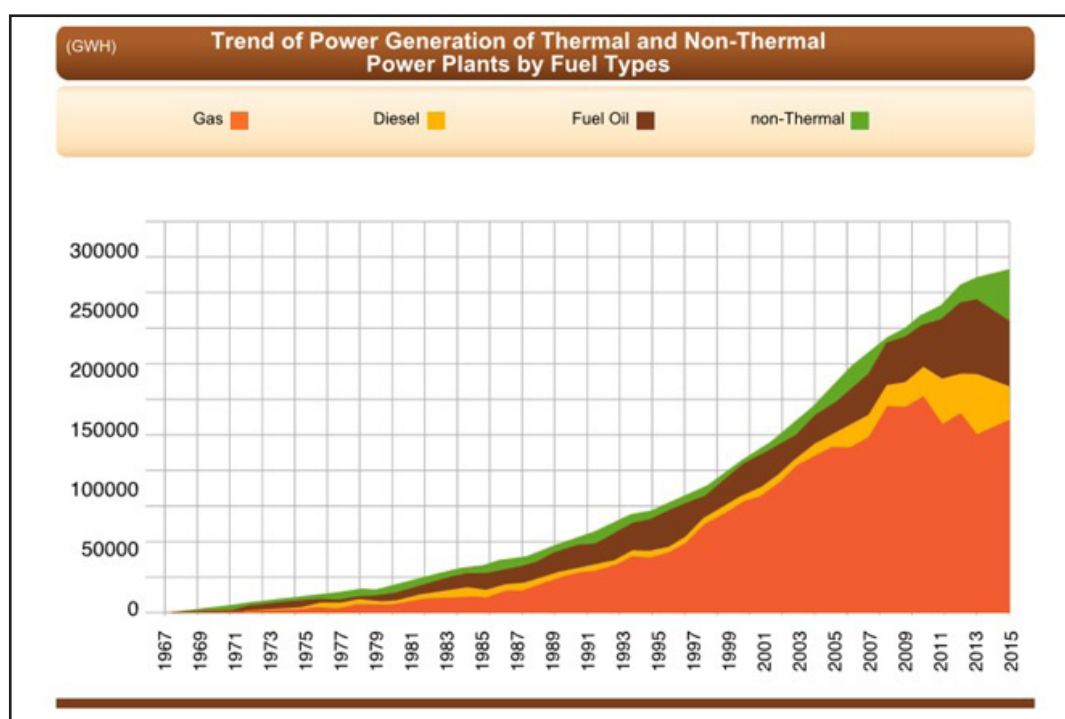


Figure 3: Trend of Power Generation of Thermal and Non-Thermal Power Plants by Fuel Types⁸

6. Note that the Iranian data use convert the fuel types with slightly different conversion factors than the BP factors used elsewhere in this study.

7. *Statistical Report on 49 Years of Activities of Iran Electric Power Industry (1967-2015)*, Tavanir Holding Company and Islamic Republic of Iran Ministry of Energy, 2016, p.14

8. *Statistical Report on 49 Years of Activities of Iran Electric Power Industry (1967-2015)*, Tavanir/Islamic Republic of Iran Ministry of Energy, p.9

Electricity is transported and distributed to consumers nearly entirely by one nationalized company, Tavanir, which is effectively part of MOE. There do not appear to be any plans to change that situation.

A brief word is in order about the place of electricity in Iran's overall energy scene. Iran is a heavy consumer of energy. In 2016, according to the widely-used BP *Statistical Review of World Energy*⁹ an annual report with accompanying spreadsheet showing historical data going back many decades, Iran's primary energy consumption (271 million tons of oil equivalent) was nearly twice that of Turkey's (138 million tons of oil equivalent), a country of similar population and larger national income. Such heavy use of energy is common among the Gulf oil producers. In 2016, primary energy consumption per capita was 3.37 tons of oil equivalent in Iran, 8.26 in Saudi Arabia, 10.19 in Kuwait, and 12.28 in the United Arab Emirates—compared to 3.21 in the European Union and 7.03 in the United States.¹⁰ Iran and the Gulf oil producers countries suffer from many of the same wasteful energy policies, be it regarding electricity or such matters as subsidized gasoline.

Likely Prospects Without a Change in Government Policy

The policies presently in place are likely to lead to robust growth in electricity demand. While nearly all increased demand will be met by natural gas, Iranian authorities are determined to add additional nuclear power plants, though these plants will provide only a small portion of the additional capacity. Part of the reason that these plans are likely to come to pass is the sad record of past reform efforts.

Current Plans

As part of the Stanford Iran 2040 Project, in April 2017, four scholars presented a paper entitled “The Outlook for Natural Gas, Electricity and Renewable Energy in Iran.”¹¹ They argue that through 2040, Iran is likely to add capacity at the rate of 1,300 MW per annum, compared to 3,000 MW per annum in the recent past (in actuality, operational capacity increased on average 2,400 MW per annum in the period 2006-2015). Given that Iran's operational capacity in 2015 was 64,708 MW, it would imply a growth rate of 1.6% per annum in the period 2015-2040. Other estimates are much higher. A late 2015 estimate by the respected private firm BMI Research forecast that electricity generation would grow at an average 2.5% per annum from 2015 through 2024.¹² At the 2013 9th International Energy in Tehran, Hamed Shakouri and Allyah Kazemi from the University of Tehran presented a complex model forecast 6.3% annual growth in Iranian electricity demand for the foreseeable future.¹³ The Iranian government's forecast growth rate is

9. *Statistical Review of World Energy*, British Petroleum, June 2017, available from <http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>.

10. Author's calculations based on energy consumption data from the BP source cited above and population data from the World Bank.

11. Pooya Azadi (Stanford), Arash Nezam Sarmadi (National Grid), Ali Mahmoudzadeh (U British Columbia), and Tara Shirvani (World Bank), “The Outlook for Natural Gas, Electricity, and Renewable Energy in Iran,” Stanford Working Paper No. 3, April 2017, available from <https://iranian-studies.stanford.edu/iran-2040-project/publications/outlook-natural-gas-electricity-and-renewable-energy-iran>.

12. BMI Research, *Iran Power Report*, Q4 2015, pp. 13-14 (note: the author has a copy of this report, which is available on line only at extremely high cost).

13. Hamed Shakouri and Allyeh Kazemi, “Electrical Energy Demand Forecast of Iran,” available from <https://www.research->

higher than any of these outside predictions. Iran's Sixth Five-Year Development Plan, covering 2017-21 and approved by the Majlis in April 2017, calls for adding 25,000 MW over the five years, which would be an average annual rate growth rate of 6.75%.¹⁴ A major driver of investment decisions is peak consumption, rather than average annual consumption. According to a May 2017 statement by Iran's Deputy Energy Minister, Sattar Mahmoudi, peak electricity consumption is expected to grow 7% in summer 2017 over the previous year.¹⁵ Maximum power demand occurs in the summer, typically in July and August. The maximum demand in 2015 was 53,654 MW, which MOE calculates as a 65.2% generation load factor.¹⁶ Not all of that was met; the maximum supplied power was 49,351 MW. That said, Iran has much less of a problem than many other Middle East countries about how to meet peak load. Whereas in Saudi Arabia, for instance, peak summer load is vastly higher than winter load, in Iran a fair amount of power is used for winter heating (most Iranians live in the northern cities, which are quite cold in winter), so the winter load is a respectable fraction of the summer load.

Atomic Energy Organization of Iran (AEOI) President Dr. Ali Akbar Salehi has noted that the Majlis (parliament) has charged the government to have 20,000 MW of nuclear power in a long-term horizon, and 8,000 in the medium-term, defined as 15 years.¹⁷ In 2015, Salehi said that within the next 10-15 years, the number of nuclear power plants should reach eight and make up about 8-10% of electricity production. Salehi claimed that the cost per kWh of electricity generation from nuclear power was cheapest among all sources: Nuclear – 10 U.S. cents, combined cycle – 12 cents; steam – 14 cents; and single-cycle gas – 19 cents. However, the validity of his claim is questionable. Salehi frequently refers to older studies, including some from the 1970s, which enthusiastically endorsed nuclear power, especially since Iran's oil fields had already markedly aged by the 1970s (since then, technological advances have done wonders to sustain production from oil fields which had been expected to have been exhausted long ago).

More immediately, Russia and Iran signed a nuclear power cooperation agreement in November 2014 which was followed by a September 2016 agreement, signed in a grand ceremony in Moscow, for the construction of two additional nuclear power plants at Bushehr which also envisaged a further two, and four more at locations yet to be determined.¹⁸ The plants at Bushehr would be imports from Russia; the others would be Iranian-built with Russian assistance. The agreement specified that all eight would use Russian fuel. Continuing the leisurely pace of implementing the 2014 agreement, a ceremony was held in Bushehr

gate.net/publication/280573416_Electrical_Energy_Demand.

14. Amir Kordvani and Poulad Berenjforoush, "Iran approves the Sixth Development Plan to Boost Investment," *Lexology*, available from <http://www.lexology.com/library/detail.aspx?g=9a25e9cc-44d0-45fa-9a54-905de434fc66>.

15. "Prediction of Increase in Peak Electricity Consumption for Summer," *Donya-e Eqtesad*, May 3, 2017, available from <http://donya-e-eqtesad.com/SiteKhan/1203157>.

16. *Statistical Report on 49 Years*, MOE/Tavanir, p 16.

17. "Production of 20,000 MW of Nuclear Power in the Long-Term," *Hamvatan*, September 11, 2016, available from <http://www.hamvatansalam.com/news210307.html> and "Plan to Produce 20,000 MW of Atomic Electricity," *Donya-e Eqtesad*, April 30, 2016, available from <http://donya-e-eqtesad.com/SiteKhan/824089>.

18. Andrew Kramer, "Russia Reaches Deal with Iran to Construct Nuclear Plants," *The New York Times*, November 11, 2014, available from <https://www.nytimes.com/2014/11/12/world/europe/russia-to-build-2-nuclear-plants-in-iran-and-possibly-6-more.html>; "Iran, Russia to Start Building Two Nuclear Power Plants," *Radio Free Europe/Radio Liberty*, September 2, 2016; and "Iran to Produce 2,000 MW of new nuclear power on the Persian Gulf," *Tasnim News*, September 10, 2016, available from <https://www.tasnimnews.com/fa/news/1395/06/20/1182687/>.
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to mark the formal start of construction on March 14, 2017¹⁹—a week before the Iranian New Year, at a time when Iranian large-scale projects are frequently proclaimed to have begun when actual work does not get going for many months or even years later. At that ceremony, it was announced that the first 1,000 MW WWER reaction would be completed in October 2024 and the second in April 2026. It is worth noting that construction of the first Bushehr reactor took more than three times as long as the schedule announced when the project was launched. Even if the ambitious announced schedule for completion of two additional nuclear power plants is met, their additional 2,000 MW capacity would be a small part of the additional capacity Iran is likely to build in the next decade. The Stanford study forecasts that additional capacity as 15,000 MW; the BMI study, as 30,000 MW; the Iranian government's plan is for even more. An additional 2,000 MW of nuclear power would be 13.4% of the lower estimate and 6.7% of the higher estimate.

Ineffective past reform efforts

Any discussion of Iran's electricity sector should include a frank evaluation of the loudly proclaimed reform efforts over the last decade. While much heralded at the time—including by the International Monetary Fund (IMF) and World Bank—as models of how to move from wasteful to efficient policies, the reforms can in retrospect be called at best modest and more accurately failures.

For years, debate raged in Iran about the vast sums being devoted to subsidizing energy, including electricity (gasoline subsidies drew most of the attention). To the surprise of many, populist President Mahmoud Ahmadinejad embraced the far-reaching reforms recommended by international economists, namely, raising energy prices to world market levels and replacing energy subsidies with cash grants to families and firms to cushion the impact of the higher prices. A version of the reform passed the Majlis on January 5, 2010, which covered the full range of energy subsidies, including gasoline and natural gas as well as electricity.²⁰ The plan, developed in large part in consultation with the World Bank, was much heralded by the International Monetary Fund. In a September 2010 press release, the IMF noted that the suspension of oil and gas subsidies “should remove distortions and restore efficiency in the economy.”²¹

However, the actual results differed considerably from the design intentions. For one thing, many Iranians live in apartment buildings, and it was common for the building to have only one meter—with the result that individual unit-dwellers had little incentive to be more efficient in using electricity. Even if that problem were resolved—and anecdotal evidence suggests progress on that front—the dramatic change from ending extensive subsidies hit hard at “legacy” consumers, that is, those consumers who made decisions on the basis of the past policies. An industrial firm whose cost structure is based on cheap electricity could well become unprofitable if forced to suddenly pay an unsubsidized electricity rate. For that reason, the original plan was to devote 30% of the higher revenue from the new rates to subsidized loans or grants to

19. “Construction begins on Iran's Bushehr 2 Nuclear Power Plant: Rosatom,” *Tehran Times*, March 15, 2017, available from www.tehrantimes.com/news/4122015/Construction-begins-on-Iran-s-Bushehr-w-Nuclear-Power-Plant.

20. “Putting an End to the Subsidy Trap,” *Financial Tribune*, January 20, 2015, <https://financialtribune.com/articles/economy-domestic-economy/9392/putting-an-end-to-the-subsidy-trap>.

21. “IMF Survey: Iran to Cut Oil Subsidies in Energy Reform,” *International Monetary Fund*, September 28, 2010 and “Case Studies on Energy Subsidy Reform: Lessons and Implications,” *International Monetary Fund*, January 28, 2013, available from <http://www.imf.org/external/np/pp/eng/2013/012813a.pdf>.

firms to invest in energy-savings.²² But little if any of that money materialized. What funds were generated by the reform were insufficient to cover the generous grants to families that Ahmadinejad grandly announced—especially since he abandoned the overly ambitious plan to determine each family’s income and then tailor the subsidies to the amount of income (a plan remarkably at odds with Iran’s circumstances, given that few families file income tax returns and little is done to enforce the income tax laws). His political opponents suggested that Ahmadinejad’s interest in the energy reform was motivated by his desire to claim credit for sending each Iranian family a large check each month.

The result of charging higher rates without compensating firms was that many industries would have gone bankrupt if forced to pay the new energy rates. It would appear that some firms simply did not pay—a strategy adopted by many consumers as well. The government has not published systematic data on unpaid electricity bills, but anecdotal accounts suggest that faced with soaring bills, consumers reacted with outrage and did not pay.²³ Given the many press reports about higher bills and given Iran’s vigorous press, had there been numerous disconnections for non-payment, it would certainly have been reported and would have been deplored by populist politicians. Since no such thing occurred, it seems more likely that there were few disconnections and instead many arrears.

In the event, the new higher electricity rates were largely reversed by the collapse of the Iranian rial. Under the pressure of crippling international sanctions—the European cut-off in fuel purchases and U.S. measures which effectively prevented banks anywhere from handling payments for Iranian oil—the rial collapsed, first on the semi-legal open market and then at the official exchange rate. The official rate went from 10,616 rials to the dollar in 2011 to 18,414 rials in 2013.²⁴ At the new value of the rial, the post-reform rates for gas and oil were suddenly well below international market rates, meaning that electricity generated with these fuels was once again heavily subsidized.

Added to which, the Ahmadinejad government reacted to the sanctions-induced shortfall in government revenue by resorting to the printing press. As the money supply soared, so did inflation. Consumer prices, by the official index, rose approximately 17% in 2014 alone and a cumulative 157% from 2011/12 through

22. “Initially, the benefits were to be paid in cash, while in a second phase, some of the additional revenues were to be used to support higher social benefits and public goods. Thirty percent of the additional revenues were to be used to assist Iranian companies restructure to adjust to the new, dramatically higher energy costs. The remaining twenty percent of the additional revenues would go to the government to cover government’s own higher energy bill. Article 15 of the Reform Act authorized the government to establish a new Subsidy Targeting Organization to ensure efficient centralized management of the reform.” Available from <https://www.imf.org/en/Publications/WP/Issues/2016/12/31/Iran-The-Chronicles-of-the-Subsidy-Reform-25044>.

23. According to Tabnak of August 15, 2010, available from <http://www.tabnak.ir/fa/news/114238/%D9%82%D8%A8%D8%B6-%D8%A8%D8%B1%D9%82-%D8%B3%D8%A7%D8%B1%D9%88%DB%8C%D9%87%D8%A7-%D8%B1%D8%A7-%D9%82%D8%A8%D8%B6-%D8%B1%D9%88%D8%AD-%DA%A9%D8%B1%D8%AF>, electricity consumers in the city of Sari, Iran protested the high electricity bills they received in the wake of the reforms. One consumer claimed that the price of power consumption was estimated to increase by 50-60% despite the fact that the Deputy Energy Minister said that electricity tariffs would be capped at a 10% increase. The same consumer claimed that his electricity tariff had increased 25% from the tariff he had paid previously. In less than two months, his electricity tariff had risen from 150,000 rials to 2,090,000 rials. Another resident of Sari noted that that number was wrong, however, claiming that his electricity bill had only risen from 180,000 rials to 1,610,000 rials. A third resident described a 40-50 percent increase in the price of electricity bills.

24. Official exchange rate (LCU per US\$, period average), The World Bank, available from <http://data.worldbank.org/indicator/PA.NUS.FCRF?locations=IR>.

2015/16.²⁵ The electricity rates were barely adjusted. From 2010-2011, they rose from 160 to 450 rials;²⁶ since then, they have barely budged, with the average 2016 rate being about 500 rials. The impact has been that electricity is once again heavily subsidized as it was before the reform. The International Energy Agency estimated that Iran's 2015 electricity subsidies were among the highest in the world, matched only by those in Russia and Saudi Arabia (see Figure 4, Energy Subsidies by Country 2015). Note that the same estimate shows Iran as providing such large subsidies for other types of energy that its overall energy subsidies were the largest in the world.

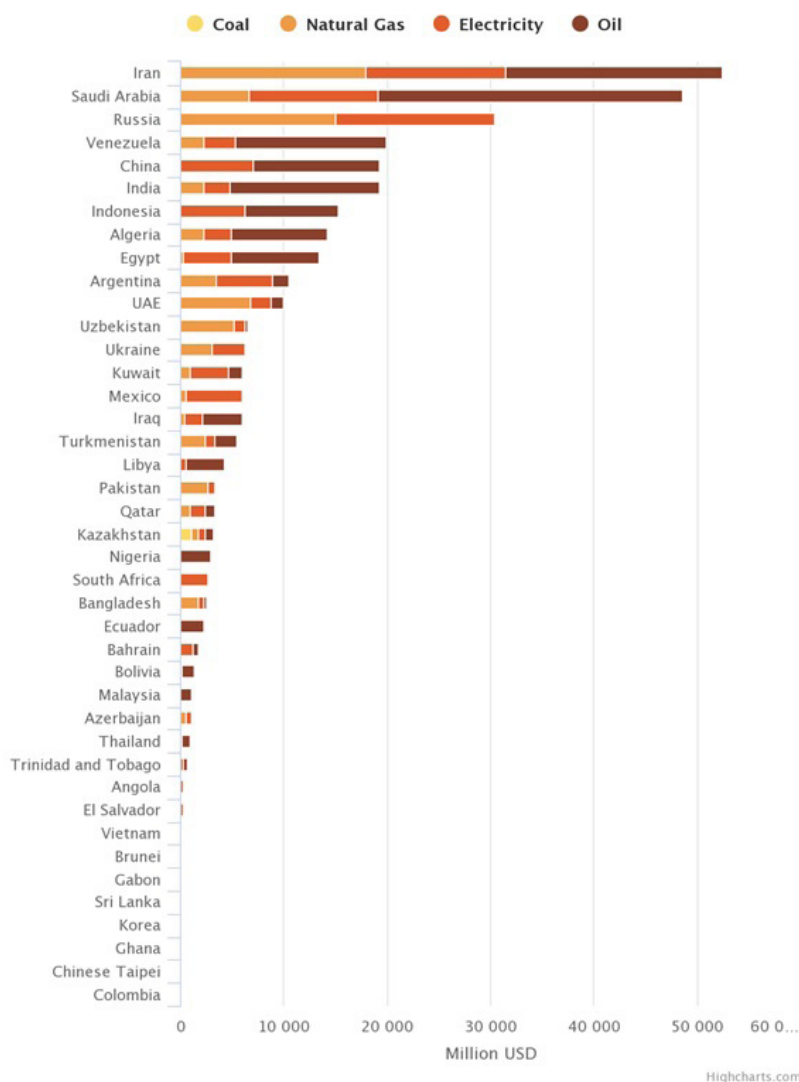


Figure 4: Energy Subsidies by Country 2015²⁷

25. Consumer price index (2010 = 100), The World Bank, available from <http://data.worldbank.org/indicator/FP.CPI.TOTL?locations=IR>.

26. Saeed Moshiri, "Energy Price Reform and Energy Efficiency in Iran," *International Association for Energy Economics*, 2013, available from <https://www.iaee.org/en/publications/newsletterdl.aspx?id=197>.

27. IEA World Energy Outlook, available from <http://www.worldenergyoutlook.org/resources/energysubsidies/>.

An additional evidence the reform was not as far-reaching as initially envisaged is that demand for electricity was little affected by the reform, despite the dramatic increase in announced rates. Gross power generation did not fall any year in the last decade; in the year of the maximum reform (2011), it rose 3.0%, little different from the growth in other years of the decade. In the period 2010-2015, the average increase in gross power generation was 3.8%.²⁸ One could argue that a price reform would take a while to show up in consumption data, as consumers have few alternatives the day after the new rates take effect. But in a relatively short time—certainly within a couple years—consumers could shift habits and invest in energy saving technologies. The failure of demand to show much such effect certainly reinforces the view that the new rates were not effectively collected.

This dramatic and unsuccessful reform effort has left Iranian politicians with little enthusiasm for energy reform—and has made Iranian consumers highly skeptical that any announced reforms will in fact be implemented. Both politicians and consumers seem largely resigned to a continuation of current policies with only minor modifications implemented slowly. That said, it is worth pointing out the extraordinary opportunities for Iran to save money through a variety of non-nuclear avenues. Cutting subsidies is the most obvious but most difficult measure. Other steps involve changing the investment decisions, such as relying more on renewable energy and moving more towards combined cycle generation rather than single cycle. And even if those steps are not taken, it still remains the case that Iran would do better to generate in natural gas-fired facilities rather than in nuclear power.

Cutting Subsidies

The failure of earlier reform efforts has left Iran with heavily subsidized electricity rates. The most obvious way to meet Iran's future electricity needs is to reduce those subsidies and therefore reduce consumption. This is entirely unlikely, especially given the experience of the earlier dramatic reform effort.

One element in the subsidized electricity rate is the subsidized price of fuel. Consider natural gas. In theory, electricity producers pay about the same rate for natural gas as do other consumers, as explained by the Stanford Iran 2040 paper:²⁹

“In rough terms, natural gas in Iran is uniformly priced at \$34,000/mcm for residential, power, and industrial consumers (including petrochemical plant fuel) despite the profound differences in the price sensitivities of these consuming sectors. For the sake of comparison, the above price is almost 50% lower than the Henry Hub gas spot price (\$71,000 in 2016) and 90% lower than the average residential gas price in the United States (\$355,000/mcm in 2016).”

While there is only an imperfect world market in natural gas, the price paid for natural gas by different consumers around the world has been converging. The differences were as much as five-to-one a few years ago what with the U.S. gas glut driving down prices in mid-America and with Japanese firms locked into long-term contracts.³⁰ Now, prices differentials are generally less than two-to-one. Even at the low end of that price range, Iranian electricity companies are paying less than half the market value of gas.

28. *Statistical Report on 49 Years*, p. 10. Net power generation (p. 12) followed the same pattern.

29. Azadi, et al., “The Outlook for Natural Gas, Electricity and Renewable Energy in Iran,” p. 11.

30. BP, *Statistical Review of World Energy 2017*, p. 33.

But that is not the end of the subsidies for electricity. Even if the fuel used were free, the price of electricity in Iran to consumers does not cover the cost of generation and distribution. Iranian press reports, citing government officials, refer to the cost of generation and distribution—without any allowance for the fuel—as 1,000 rials per kilowatt-hour while the average price paid by consumers is 500 rials.³¹ The end result is that the average price for electricity in Iran at 500 rials per kilowatt-hour is one-eighth the U.S. average: 1.5 cents compared to about 12 cents in the United States.

One would think that the privatization of much of the electricity generation capacity would create a powerful lobby group for more realistic electricity rates. After all, it is hard to see how the private generators make a profit if the average rate is half the cost of generation and distribution even were fuel free. However, Iranian “privatizations” have a peculiar character. For one thing, they are remarkably opaque. In June 2017, President Rouhani said that no more than 13% of the assets privatized went to truly private hands.³² Many “privatized” assets ended up in the hands of those connected to the Islamic Revolutionary Guard Corps (IRGC). In the same speech, Rouhani characterized the privatization to date as transferring assets from “the government without guns” to “the government with guns”—a much quoted comment by Iranian commentators. In addition, other assets went to quasi-government entities, such as the many retirement funds run by ministries and state-owned enterprises, or the funds in each province which are supposed to transfer a large chunk of privatized assets to the poor. Since if those funds actually handed the assets to the poor, the poor would promptly sell them, driving down the price, what has happened in practice is that the central government manages those funds theoretically on behalf of the poor. It would appear that much of the privatization process has been run in a way which allows the politically well-connected to divert government funds into their pockets.

Certainly the non-transparent way in which privatization has worked has been an impediment to attracting the foreign investment Iran claims it wants for infrastructure projects. Added to which, the active role of IRGC-connected figures creates a problem for any foreign investor who does any transactions in U.S. dollars, since the U.S. government retains strict sanctions—including large penalties—aimed at foreign firms that use U.S. dollars in transactions that are linked to IRGC-related firms. These factors will be a significant impediment to attracting foreign or domestic investment for expanding electricity generating capacity. Arguably, the barriers could slow non-nuclear projects—gas or renewable—so much that they could take about as long to build as do nuclear power plants which are fully government financed.

Relying on More Renewable Energy

The main form of renewable electricity generation in Iran is hydropower. The Shah added much to Iran’s hydro operational capacity, which went from 309 MW in 1967—36% of the total operational capacity for all sources—to 1,804 MW in 1978, 28% of total capacity.³³ After making only minor additions to hydro capacity in the first two post-revolutionary decades—hydro capacity going from 1,804 MW at the time of the 1978 revolution to 1,999 in 1998—Iran has built quite a number of hydroelectric dams in the last two decades. From 2001 to 2015, installed operational hydro capacity rose sharply, from 1,999 MW to 11,278

31. “How Much is the Cost of Production of Electricity?” (in Persian; translation by author), *Donya-e Eqtesad* (the Iranian financial newspaper), October 14, 2016, available from <http://donya-e-eqtesad.com/SiteKhan/1129248>.

32. “President of the Republic: Everyone Should Trust the Private Sector,” (in Persian – author’s translation), June 24, 2017.

33. All data in this paragraph are from MOE/Tavanir, *Statistical Report on 49 Years*, p 8.

MW, which meant that hydro went from 8% of total capacity to 17%.

At the same time, the government has encouraged increased irrigation with wasteful technology, with the inevitable result that water shortages have become quite common. Protests about water shortages have broken out repeatedly in various parts of the country, including protests against the building of new hydroelectric dams. It seems very unlikely that Iran would be able to continue increasing the share of hydro in electricity generation; quite the contrary, that share seems slated to decline.

In 2016, a private estimate of the non-hydropower renewable energy sector in Iran—not fully compatible with the MOE/Tavanir data cited elsewhere—was comprised of mainly wind (53.88 MW) and biomass (13.56 MW), with much smaller amounts of solar (0.51 MW).³⁴ In 2016, the head of the Ministry of Energy (the ‘MoE’) stated that Iran was planning to tender 1,000 MW of wind and as much as 3,000 MW of solar projects.³⁵ MOE will purchase all electricity generated from renewable sources by approved private sector projects at specific feed-in tariffs (FiTs). The Sixth Five-Year Development Plan calls for 5,000 MW of renewable generating capacity. Tavanir has forecast that renewables will provide 10% of Iranian power by 2021.³⁶ Both of these forecasts seem implausibly optimistic.

To be sure, Iran has excellent natural conditions for solar power in particular. Iran is an arid country with clear skies much of the year and with large desert areas for which there are few economic uses other than solar power. Given this paper’s focus on Iranian institutional arrangements and economic factors, this is not a subject which will be explored in more detail here.

Updating the Technology Used to Generate Electricity with Thermal Fuels

Iran makes extensive use of steam generation rather than gas turbines. Nearly everywhere else in the world, steam is seen as an inferior technology to gas turbines. Iranian sources are more enthusiastic about steam. Indeed, one Iranian study ranked steam as the cheapest source for electricity generation.³⁷ It is not clear why steam is rated highly in Iran. Perhaps the answer is related to the need to use fuel oil during the winter months in so-called “gas” facilities. Iran’s fuel oil is high in sulfur. Burning high-sulfur fuel oil is presumably not good for a turbine. Also, that fuel oil has few other economic uses and so is presumably cheap. Fuel oil is not in high demand internationally; indeed, what market does exist for the fuel oil will

34. CMS Cameron McKenna LLP, *2016 Report on Renewable Energy in Iran*, available from http://www.satba.gov.ir/suna-content/media/image/2017/02/5196_orig.pdf?t=636219021775330000. The report is sloppy on some matters, e.g., it mischaracterizes the data it presents on hydropower, which on close examination turn out to be data only on micro-hydropower projects.

35. CMS Cameron McKenna LLP, *2016 Report on Renewable Energy in Iran*, available from http://www.satba.gov.ir/suna-content/media/image/2017/02/5196_orig.pdf?t=636219021775330000.

36. Heba Hashem, “Who Will Fund Iran’s First Batch of Renewable Energy Projects?” *Renewable Energy Trade Mission Iran*, September 15, 2016, available from <http://www.retrademissioniran.com/news-articles/2016/9/15/who-will-fund-irans-first-batch-of-renewable-energy-projects>. Among the foreign companies with which Iran had by September 2016 signed agreements to support renewable energy development were British Photovoltaic Association, Genesis of Italy, and Shanxi Energy of China. “Renewable energy projects in Iran: Solar Focus,” October 21, 2016, *Dentons*, available from <https://www.dentons.com/en/insights/guides-reports-and-whitepapers/2016/october/21/renewable-energy-projects-in-iran>.

37. Khakbazan-Fard et al., “Generation Expansion Planning for the Iran Power Grid.” Three of the studies four authors work for Tavanir. They say their analysis is based on the WASP IV software package, which they characterize as “one of the well-known power expansion planning softwares.” They conclude, “For supplying the base load, steam power plants are chosen. The main reason is the lower price of the fuel for steam plants (9 months gas and 3 months HFO [heavy fuel oil]) in comparison to the fuel of gas and combined cycle power plants (9 months gas and 3 months gasoil).”

largely disappear as the global shipping industry makes the shift (required by nearly all countries as part of an international agreement) to phase out use of this type of fuel in ships by 2020.

Anyway, if Iran were able to work out arrangements—perhaps including guaranteed year-round gas supply—to make steam less attractive and were Iran to phase out its large stock of aging steam facilities, it would seem Iran could gain considerable efficiencies in electricity generation.

Another issue is single-cycle versus combined-cycle gas generators. In a single-cycle gas generator, air is filtered in to an air compressor. Natural gas is introduced to a burner, where in the presence of the compressed air, it produces a high temperature and high pressure gas that spins a turbine connected to a generator, producing electricity. In a combined-cycle generator, extra electricity is produced by introducing water, where exhaust gas from the original output is used to heat water into a steam, where it turns a second turbine, generating more power through the generator, after which it is condensed and sent back to the exhaust gas chimney. A combined-cycle generator will produce up to 50% more power than a single-cycle generator.³⁸

Since 2005, single-cycle gas turbine generation has grown 57.4%, while combined cycle has grown 64.1%. In 2015, combined cycle generated 25.3% more power than single cycle gas turbine generation. There may well be scope for more efficiencies from shifting to more combined-cycle facilities, as Iran is doing.³⁹ However, it should be noted that single-cycle facilities are better suited for firing up quickly to meet peak demand, so there will also be room for some such facilities in the best-managed system.

Relying on Natural Gas

Despite some complications, Iran has much potential to continue relying on natural gas as the principal fuel for electricity production, which is precisely what all serious studies recommend and what the government has announced. Even assuming that the government's optimistic schedule for new nuclear power plants and renewable energy comes to pass, Iran will still rely on natural gas for most of the additions to its electrical generating capacity.

In recent decades, Iran has dramatically increased its reliance on natural gas. In 1978/79, Iran's electricity generation capacity was 7,086 megawatts (MW) of which natural-gas-fired facilities were only 2,523 MW. As noted before, in 2015/16, the total capacity was 64,708 MW, of which natural gas fueled 21,630 MW. In other words, of the additional in capacity, was fueled by natural gas.

That fits with Iran's general pattern of making intensive use of its natural gas. In 1979, Iran's overall gas consumption—the vast majority being outside of electricity generation—was 3.6 million barrels of oil equivalent (MBOE) compared to 83.8 MBOE of oil consumption. In 2016, gas was 180.7 MBOE and oil was 83.8 MBOE. In other words, Iran shifted from being a country which used little natural gas to one which uses a great deal.

38. "Iran Increases Combined Cycle Power Output," *Financial Tribune*, July 13, 2016, available from <https://financialtribune.com/articles/energy/45349/iran-increases-combined-cycle-power-output>.

39. "Iran Increases Combined Cycle Power Output," *Financial Tribune*, July 13, 2016, available from <https://financialtribune.com/articles/energy/45349/iran-increases-combined-cycle-power-output>; "Iran Starts Construction of 890 MW Combined-Cycle Power Plant," *Financial Tribune*, January 28, 2017, available from <https://financialtribune.com/articles/energy/58312/iran-starts-construction-of-890-mw-combined-cycle-power-plant>; "Two Combined-Cycle Power Plants Launched in Southern Iran," *Financial Tribune*, February 8, 2017, available from <https://financialtribune.com/articles/energy/59113/two-combined-cycle-power-plants-launched-in-southern-iran>.

Few countries in the world rely as heavily as Iran on natural gas as a proportion of their primary energy consumption. In the BP data, the share of natural gas in primary energy in Iran is 66.7 percent; in the United States, 31.5 percent; in the European Union, 23.5 percent; and in Russia, 52.2 percent.⁴⁰ The only countries in the same league as Iran for relying heavily on natural gas are Turkmenistan, Uzbekistan, Qatar, and Trinidad and Tobago. Natural gas in Iran is used extensively not only in heating and industrial uses, but even in ground transportation: The Iranian vehicle fleet has the world's highest share of vehicles power by compressed natural gas.⁴¹ About 30% of Iranian gas consumption is for electricity generation; 30% is for space heating; 30% is for industrial uses, especially petrochemicals; and 10% is for reinjection into aging oil fields to boost pressure.⁴²

A major reason that Iran makes such extensive use of natural gas is that it has extensive reserves. According to BP, Iran's natural gas reserves in 2017 are 33 trillion cubic meters (TCM), making up 18.2% of the global reserves.⁴³ However, a word of caution is in order about reserve data. There is no agreed international standard for what constitutes reserves, and Iran, like many countries, is less than transparent about it calculates the reserves figures it announces (BP largely relies on figures announced by governments). The U.S. reserve figures are much more cautious than those of most countries, being calculated by strict standards designed to let investors know what companies' prospects are. Furthermore, it is not apparent why a commercial company would invest in finding reserves which are not likely to be used for many years, so it may well be the case that U.S. firms satisfy themselves with a cushion of several years' reserves and do not invest much in looking for additional reserves. In other words, figures on reserves can be a poor indicator of a country's production potential.

In many ways what is more relevant in judging Iran's prospects for increasing gas production is its historical record. As noted earlier, Iran has dramatically increased its production of natural gas from 3.6 MTOE in 1978 to 180.7 MTOE in 2016. This expansion has been particularly marked in recent years; 2011 production was 143.9 MTOE, meaning that production rose in 2011-2016 on average 4.7% per annum. However, Iranian MOE data show an odd 200-2013 dip in use of natural gas as fuel for electricity generation. The data from which Figure 3 is said to be drawn show gas used for electricity generation at 43.4 billion cubic meters (BCM) in 2009 falling to 36.6 BCM in 2013, before then jumping upwards to 50.2 BCM in 2014 and 58.4 BCM in 2015. This is roughly consistent with the BP data on Iranian gas consumption in all sectors, which shows rather slower growth in 2009-2013 before jumping in 2014-2015. But it is by no means clear why this may have happened. Reasons could have included problems in gas production or excessive amounts of fuel oil and diesel which Iran had problems marketing abroad.

The domestic market looks to be the best place to use the increasing Iranian production of gas, given that prospects for exporting gas look poor. Besides political sensitivities with neighbors Turkey and Pakistan, Iran has not offered attractive price terms and has had great difficulties securing financing for pipelines. As for exporting liquefied natural gas (LNG), Iran does not and is not likely to get access to U.S. technology for such key components as gas compressors. Even if that problem can be bypassed as alternative

40. BP, *Statistical Review of World Energy 2017*.

41. Indeed, according to Automotive Megatrends, Iran has the second largest fleet of natural gas vehicles in the world. "Back to business: Iran, a new emerging market," *Megatrends*, July 12, 2016, available from <https://www.automotiveworld.com/analysis/back-business-iran-new-emerging-market/>.

42. Azadi et al., "The Outlook for Natural Gas, Electricity, and Renewable Energy in Iran."

43. BP, *Statistical Review of World Energy 2017*. The data on 1978 consumption compared to 2016 come from the underpinning tables published along with that report.

suppliers develop better LNG technologies, Iran faces the problem of an extraordinary increase in LNG capacity coming in the not-too-distant future from Australia and then a few years later from the United States. In a well-supplied market, Iran would have difficulty competing—both for political reasons and because Iran’s political culture makes it difficult for any Iranian official to agree to terms attractive to foreign purchasers without facing charges at home that they sold out the nation’s interests.

While Iran has had great success over the years at increasing its gas output, it must be acknowledged that Iran has not been able to meet peak demand in the winter—in part because Iran has done a very poor job at constructing storage facilities where gas could be stored in the summer and then drawn down in the winter (reports circulate that Iran’s storage capacity is on the order of a week of consumption, compared to much more in other countries with similarly harsh winters). And Iran will face constraints expanding its gas production because of the high capital requirements and Iran’s limited access to international financial markets. That said, Iran continues to flare large amounts of natural gas rather than gathering the gas for productive use. The Stanford study estimates the flared gas at 33,000 MCM/day.⁴⁴ That matches the estimate from the World-Bank-run Global Gas Flaring Reduction Partnership in conjunction with major energy companies, which uses a satellite to estimate flaring around the world; its estimate of Iran’s flaring in 2015 was 12,000 million cubic meters for the year, or 34,000 MCM/day.⁴⁵ That is equal to about 6% of Iran’s current gas production; alternatively, that is 20% of the 58,154 MCM of gas used by Iran’s power plants in 2015.⁴⁶ The Stanford study places the cost of capturing now-flared natural gas at \$60,000-80,000 per MCM. In other words, by ending flaring, Iran has low-cost means to increase its gas output sufficient to meet the additional needs of electricity generation by efficient combined-cycle facilities.

To be sure, one can make the argument that Iran might do better to use much of the gas it can produce in the next few decades to re-inject into its aging oil fields, thereby boosting oil output while preserving the gas to be used several decades from now. The Stanford Iran 2040 study was only the latest study pointing out that such re-injection is one of the highest return uses of Iran’s gas: It calculated the value per MCM from re-injection as \$200,000 compared to \$50,000 from electricity generation or space heating, which did not even include the value of the gas which can be recovered in future years after oil has been extracted from the field into which the gas is reinjected.⁴⁷ Re-injecting gas has been recommended by Iranian technocrats since the Shah’s days, but Iran has for forty years failed to act meaningfully to take advantage of this obvious way to sustain and increase oil production. Iran has spent many tens of billions of dollars on new investment in oil production which could have been saved had it instead acted to reinject natural gas in the aging fields. The failure to end flaring has been arguably as, if not more costly, than all of the policy decisions Iran has taken about electricity production, including the investment in nuclear energy.

44. Azadi et al., “The Outlook for Natural Gas, Electricity, and Renewable Energy in Iran,” pp. 11-12.

45. Global Gas Flaring Reduction Partnership, available from www.worldbank.org/en/programs/gasflaringreduction#7.

46. Gas production from *BP Statistical Review*; fuel used for electricity generation in 2015 from *Statistical Report on 49 Years*, p. 14.

47. Azadi et al., “The Outlook for Natural Gas, Electricity, and Renewable Energy in Iran,” pp 12-13. Admittedly, the value of CNG for ground transport, at \$450,000 per MCM, and of exported gas, at \$270,000 per MCM, were higher than reinjection, but the study notes the constraints on expanding use of gas for either of those purposes. The value of gas for industrial purposes ranged from \$50,000 to \$155,000 per MCM, with the higher figure being for petrochemical feedstock.

Environmental Considerations

Iran's major cities, especially Tehran, suffer from dreadful air pollution. The vast majority of the pollution comes from the use of oil, especially gasoline and diesel in vehicles. Iran's vehicle fleet has rudimentary pollution control technology, and Iran's gasoline is of a low standard. Because relatively little of Iran's air pollution comes from electricity generation, any measures to reduce electricity demand or produce electricity from less polluting sources than the natural gas now used to produce most of Iran's electricity would have little impact on Iran's urban air pollution problems. Specifically, any benefit from using nuclear power to generate electricity would have modest to negligible impact on Iran's air quality problems.

In many countries, the waste produced by nuclear power has become an environmental headache. That is not and probably would not be the case in Iran. Iran has been and likely will for the near future be dependent on nuclear power plants built by Russia. Under considerable international pressure—not least from the United States—exerted because of concern that reactor waste could provide Iran the basis for reprocessing plutonium for nuclear weapons, Russia requires Iran to surrender in a timely manner all nuclear waste materials to Russia. One could argue that Iran's use of nuclear power contributes to the global problem of nuclear waste disposal, but it is not apparent that Iranian authorities would factor into their decision-making the impact that they may have on a global problem as distinct from an Iran-specific problem.

During the negotiations of the JCPOA, Iranian officials repeatedly stated that Iran intended to design its own power plants which would use the enriched uranium fuel Iran was producing.⁴⁸ That was in response to repeated Russian statements that Russia would only sell power plants to Iran if all the fuel came from, and was returned to, Russia—a pledge meant to reassure Western countries there was little proliferation risk from Russian power plants sold to Iran. However, Iranian officials have said that in the negotiations about two additional power plants, Russia has been willing to consider Iran providing the fuel. This has not been confirmed by the Russian side. But it is possible Iran will provide some supplier—perhaps China—who would be willing to provide Iran a power plant that is to be fueled by Iranian-produced enriched uranium. If so, then Iran would have to consider how to dispose of the fuel. There does not seem to have been any discussion in Iran about this issue. In this context, it is worth noting that Iran has two vast deserts of salt flats—perhaps a fuel disposal site could be located in one of these.

Why the Enthusiasm for Nuclear Power?

Obviously one reason Iranian officials are enthusiastic about nuclear power is the potential it gives for a nuclear weapons option. However, additional factors are also at play. Those include attraction for what is perceived as advanced technology and also the institutional arrangements in electricity generation.

48. "Annex I – Nuclear-related Measures," U.S. Department of State, p. 2, available from <https://www.state.gov/documents/organization/245318.pdf>.

Attraction of Advanced Technology

One of the main themes in Khamenei's public statements is the importance of Iran's scientific advance and what he sees as Western opposition to Iranian scientific progress:

"Colonial countries are quite aware of the fact that in order to keep a country under their political and economic dominance, they should bar its scientific progress."⁴⁹

"They are opposed to the progress and development of the Iranian nation. They do not want an Islamic and independent country to achieve scientific progress and possess advanced technology in the Middle East region, a region which possesses most of the world's oil and which is one of the most sensitive regions in the world. They are worried about anything that can help the regional nations to achieve independence, self-reliance and self-sufficiency. They want this populous region, which is rich in mineral resources, to be in need of them forever. This is why they are opposed to our possessing modern technology and to our youngsters making progress in scientific areas. It is hard for the global arrogance to accept that the talented Iranian nation has been able to take great strides in the field of science and technology, especially in the field of nuclear technology. They want Iran's energy to be always dependent on oil, since oil is vulnerable to the policies of world powers. They aim to control other nations with invisible ropes."⁵⁰

Khamenei sees nuclear power in this light. That is more than a bit peculiar, given that nuclear power is a 60-year-old technology which has not proven particularly successful in the most scientifically advanced countries. But Khamenei is not the most up-to-date in his praise of technology and science; for instance, he rarely refers to software and computer technology.

Besides scientific progress, Khamenei's other fixation is on self-reliance. Khamenei has made numerous statements over the past few years highlighting Iran's need for economic self-reliance, which, in his eyes, will enable Iran to be politically independent. For example, his statement that "Iran should not be pinning its hopes on when the enemy will lift the sanctions...the hell with them. We should look into what we can do ourselves."⁵¹ One might suggest this is a bit odd, given that so much of Iran's economic well-being comes from oil exports. And one might ask how reliance on nuclear power promotes economic self-reliance, given that Iran has no capacity to make the fuel rods needed for a nuclear power station and is not likely to be able to do so for a long time to come. But in Khamenei's mind, nuclear power is connected to economic self-reliance.

Institutional Arrangements Favoring Nuclear Power

Certain institutional arrangements made the original decision to pursue nuclear power more attractive, and other institutional factors proceeded to reinforce the original choice. To start, there was the initial decision to invest in nuclear power. One factor that may have been involved was that the institutional separation between the electricity generator—i.e., at the time, entirely MOE—and the fuel supplier. MOE does not

49. Karim Sadjadpour, *Reading Khamenei: The World View of Iran's Most Powerful Leader*, Washington, DC: Carnegie Endowment for Peace, 2009, p. 11, available from http://carnegieendowment.org/files/sadjadpour_iran_final2.pdf.

50. Ibid, p. 23.

51. "Iran's leader calls for self-reliance in face of sanctions," *Middle East Institute*, 2014, available from <http://www.mei.edu/content/irans-leader-calls-self-reliance-face-sanctions>.

control the supply of gas for the electricity plants. As explained elsewhere, gas supplies are interrupted in the winter when demand is at its peak. Such interruptions are particularly likely to hit large consumers, such as electricity generating stations, rather than the household network; as noted elsewhere, electricity generation takes about 30% of gas used in Iran.

Whereas the electricity generators may not be given priority in gas distribution, by contrast, the Bushehr nuclear power plant does not have to worry about fuel interruptions. Bushehr, which is owned and operated by the Iranian government through the Atomic Energy Organization of Iran, has a guaranteed fuel supply. And Bushehr does not have to worry about being cost-competitive with other electricity generators, since the decisions about its operations do not seem to be much influenced by cost.⁵²

An additional institutional factor which promotes nuclear energy is the momentum created once nuclear power starts. Once authorities made the investment to create a large atomic energy agency, it became a powerful lobby for its self-perpetuation and aggrandizement. In other words, the decision to pursue robust nuclear facilities launched Iran on a path from which departure becomes harder and harder. The organized pressure to sustain nuclear energy comes in no small part from the engineering lobby. Consider that the unemployment for engineering graduates in Iran is, at 22%, high than that for holders of degrees in the humanities and education, which was 15% or less.⁵³ It is not clear what the unemployment rate is for nuclear engineers.

And then there is natural propensity of politicians to validate the decisions they made in the past. Politicians are no more willing than the rest of humanity to acknowledge that they were mistaken. Having spent on nuclear power billions of dollars—and having suffered years of crippling international sanctions which Iran explained (largely incorrectly) as being designed to impede Iran’s nuclear power program—the politicians who made those decisions would have great difficulty bringing themselves to acknowledge that the pursuit of nuclear power was a mistake. The nuclear power plans were supported by every major Iranian politician, including the vigorous support of Supreme Leader Ali Khamenei who has been in that post since 1989 and seems set to hold it until he dies.

Overall Evaluation

This study has shown that Iran has many ways to meet its electricity needs which are economically more attractive than use of nuclear energy. That said, Iran’s electricity system is generally badly run from an economic perspective. While nuclear power is a poor use of resources for Iran, the construction of additional nuclear power plants would not make the list of the most wasteful things Iran has done regarding electricity. Furthermore, the powerful political pressures to continue with nuclear power—to validate past decisions, to provide employment to highly trained engineers, to fit with Khamenei’s “resistance economy” rhetoric—make it extremely unlikely Iran will revisit the decision to proceed with additional power plants.

52. “Iranian-Run Bushehr Plant has IAEA Oversight,” *Voice of America*, November 2, 2009, available from <https://www.voanews.com/a/a-13-2009-06-10-voa60-68826397/413931.html>.

53. Nader Habibi, “Iran’s Overeducation Crisis: Causes and Ramifications,” *Crown Center for Middle East Studies*, Brandeis University, February 2015, p. 4, available from <https://www.brandeis.edu/crown/publications/meb/MEB89.pdf>.

Section II: Does Nuclear Power Make Sense for Saudi Arabia?

Chapter 4

Economic Considerations of Nuclear Power Deployment in Saudi Arabia

Ali Ahmad

Introduction

Saudi Arabia's plans to acquire nuclear power are ambiguous. In 2012, the kingdom announced its intention to build 16 nuclear reactors by 2032, which was later delayed to 2040.¹ More recently, the "Saudi Vision 2030," championed by the now Crown Prince, Mohamad Bin Salman, did not explicitly mention nuclear power as an option for the kingdom, though it emphasized the need to invest in, and localize renewable sources of energy.² The Saudi Vision 2030 was promptly followed by the "National Transformation Program 2020," which included the need to identify and the prepare the construction location of Saudi's first nuclear power plant, localize parts of the nuclear fuel cycle and the SMART small reactor, a South Korean technology.³

Saudi officials offer multiple motivations to construct nuclear power plants in the kingdom. Perhaps the most commonly articulated one is a desire to get away from the near-complete reliance on hydrocarbon resources to produce electricity and desalinated water. Such reliance is seen to lead to the depletion of national oil and gas reserves but is also perceived to have an opportunity cost associated with forgone export revenues. Others suggest that interest in nuclear power is also a response to Iran's acquisition of nuclear technology. It has been argued, for example, that, "GCC states want to show Iran, their own people, and the broader world that Arabs also have the prowess and power attributed to nuclear technology."⁴ Whatever the motivations behind nuclear power might be, the acquisition of nuclear technology will entail major economic and non-economic costs.

This chapter examines the main economic drawbacks and considerations for building nuclear power plants in Saudi Arabia. It focuses on issues such as large vis-à-vis small reactor options, cost of electricity generation, localization potential, and the role of renewables, particularly solar power. The paper also discusses the measures required and investments needed to achieve high penetration of renewables in the kingdom.

1. "Nuclear Power in Saudi Arabia," *World Nuclear Association*, retrieved Oct 2, 2017, available from <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/saudi-arabia.aspx>.

2. "Vision 2030 Kingdom of Saudia Arabia," available from <http://vision2030.gov.sa/en>.

3. "Saudi National Transformation Program, 2016," retrieved October 2, 2017, available from <http://vision2030.gov.sa/en/ntp>.

4. George Perkovich, "Nuclear Developments in the GCC: Risks and Trends," in *Gulf Yearbook 2007 - 2008*, Geneva, Switzerland: Gulf Research Center, 2008, pp. 227–38.

The Electricity Sector in Saudi Arabia

The kingdom's power generation capacity is built on conventional thermal plants fueled by a mix of crude oil, heavy fuel oil, natural gas, and other petro-residuals, as shown in Figure 1.⁵ All of the natural gas produced within the Kingdom is consumed domestically while electricity generation is dominated by gas turbines which offer a cheap way of meeting demand.⁶ The Saudi Electric Company (SEC), a vertically integrated electricity company, controls 71% of the generation capacity and is responsible for transmission and distribution across the country.⁷ More recently, government reforms are pushing for unbundling of the generation, transmission and distribution sectors in order to encourage the entry of new producers thereby increasing efficiency and decreasing government spending.⁸

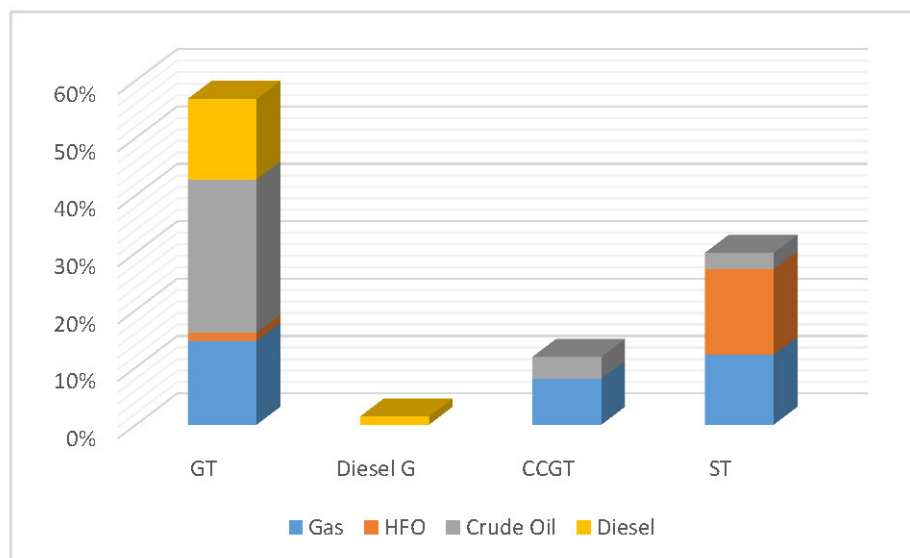


Figure 1: Electricity Generation in Saudi Arabia by Type of Fuel and Generation Technology (ST= steam turbine, CCGT= Combined cycle gas Turbine, GT=Gas Turbine, Diesel Generators)

By 2032, power generation capacity in the kingdom is expected to reach 120 GW.⁹ The increase in electricity demand will be mostly driven by population growth, a fast-growing economy and an increase in consumption fueled by cheap energy prices and high government subsidies.¹⁰

5. It should be noted that Saudi Arabia's oil share in the power sector is higher than most other countries, resulting in significant opportunity cost, particularly when oil prices are high.

6. Segar, Christopher. "Getting it Right: Renewables Augment Gas Saudi Energy Mix." *The Journal of the International Energy Agency - EIA Energy* no. 7, 2014, p. 40 and Rabia Ferroukhi, Arslan Khalid, Diala Hawila, Divyam Nagpal (IRENA), Laura El-Katiri, and Vasilis Fthenakis, *Renewable Energy Market Analysis: The GCC Region*, IRENA, 2016.

7. Nachet and Aoun, *The Saudi electricity sector: pressing issues and challenge*, Institut français des relations internationales, March 30, 2015, available from https://www.ifri.org/sites/default/files/atoms/files/note_arabie_saoudite_vf.pdf.

8. Ibid.

9. The Electricity & Co-Generation Regulatory Authority, Saudi Arabia, *Annual Statistical Booklet for Electricity and Seawater Desalination Industries*, 2016, available from http://www.ecra.gov.sa/ar-sa/MediaCenter/DocLib2/Lists/SubCategory_Library/Statistical2016.pdf.

10. CIA, *The World Factbook* 2016-17.

Based on 2014 data, the maximum peak load reached in Saudi Arabia was approximately 56.5 GW occurring during week 36 (September 1-7, 2014), while the minimum peak reached was 31.88 GW occurring during the first week of that same year (December 30-January 5, 2014). The high peak load occurred in summer and low peak load occurred in winter. The difference between highest and lowest load in summer was 8.77 GW, the difference in the winter was 7.55 GW.¹¹ The summer pattern is specific to a number of countries including the Gulf countries where air conditioning is widely used in summer and barely needed for heating in winter. See Figure 2.

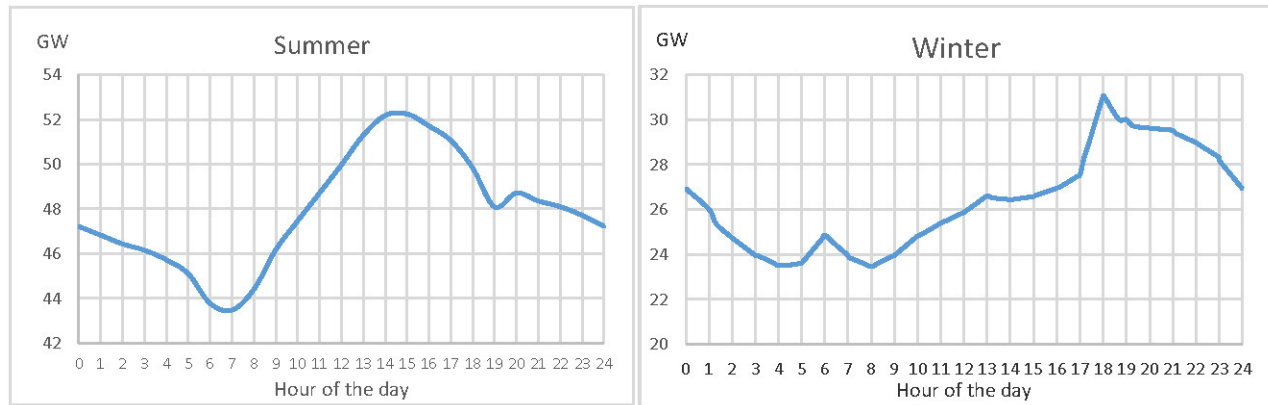


Figure 2: Hourly Load in Saudi Arabia During Summer (left) and Winter (right) – Source: Chite and Ahmad, 2017

Nuclear Technology Options

There are multiple reactor technologies that are available for deployment in Saudi Arabia. Many of the reactors that have already been sold and are being operated or under construction have relatively large power capacities (Table 1).¹² More detailed technical descriptions of reactor technologies and their relevance to the Middle East market can be found in the literature.¹³ In the Gulf Cooperation Council (GCC), the South Korean APR-1400 technology is the only one currently under construction in the United Arab Emirates.¹⁴

11. Philippe Chite and Ali Ahmad, “Requirements for High Solar Penetration in Electricity Production in Saudi Arabia,” *Energy Transitions in the GCC*, Gulf Research Center, forthcoming.

12. There are numerous other designs that are potentially available for sale but these are not listed since they have so far not been constructed or under construction.

13. Mohamed S. El-Genk, “On the Introduction of Nuclear Power in Middle East Countries: Promise, Strategies, Vision and Challenges,” *Energy Conversion and Management* 49, 2008, pp. 2618–28.

14. “Nuclear Power in UAE,” *World Nuclear Association*, retrieved October 2, 2017, available from <http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx>.

Country	Technology	Reactor Design	Capacity (MWe)
South Korea	PWR	APR-1400	1400
France	PWR	EPR	1600-1700
USA/Japan	PWR	AP1000	1110
Russia	PWR	VVER	1000
USA/Japan	BWR	ABWR	1350
India/Canada	PHWR	PHWR/ACR-700	700

Table 1: Current Reactor Designs Available for Saudi Arabia

Saudi Arabia's ambitious plans for nuclear power has attracted a number of nuclear vendors. In 2013 both GE Hitachi Nuclear Energy and Toshiba/Westinghouse signed contracts with Exelon Nuclear Partners (ENP), a division of Exelon Generation, to pursue reactor construction deals with KA-CARE.¹⁵ The reactor designs proposed include the ABWR, the ESBWR and the AP1000. The French companies Areva and EDF have also been aggressively moving into Saudi Arabia. In 2015, KA-CARE signed nuclear cooperation agreement with France to study the feasibility of constructing two EPR reactors while providing training on safety and waste disposal. Saudi Arabia and China signed a MoU in 2016 to build of High-temperature gas-cooled reactors (HTGRs) and in 2017 to study the feasibility of building HTGRs.¹⁶ More recently, Saudi Arabia sent a "request for information" to nuclear reactor vendors around the world, a step perceived as a first step towards opening a formal tender.¹⁷ As a response, Westinghouse, which promotes the AP1000 design, has been reported to be in discussion with U.S.-based companies to form a bidding consortium.¹⁸ With reports of Russian and South Korean companies also planning to bid, nuclear vendors worldwide look at Saudi Arabia as one of the most promising markets, especially with if KA-CARE's plan to build 16 reactors is materialized.

Small Modular Reactors

Saudi Arabia's interest in small modular reactors seems to be serious. In March 2015, the kingdom signed an MoU with South Korea to conduct a three-year study to review the feasibility of constructing SMART reactors in Saudi Arabia. The agreement also calls for the two countries to cooperate on the commercial-

15. "Teaming up for Saudi Bids," *World Nuclear News*, September 9, 2013, available from http://www.world-nuclear-news.org/NN-Teaming_up_for_Saudi_bids-0909137.html.

16. "Nuclear Power in Saudi Arabia," *World Nuclear Association*, retrieved Oct 2, 2017, available from <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/saudi-arabia.aspx>.

17. "Westinghouse discussing group bid for Saudi nuclear tender," *Reuters*, November 21, 2017, available from <https://www.reuters.com/article/us-saudi-nuclear-usa-exclusive/exclusive-westinghouse-discussing-group-bid-for-saudi-nuclear-tender-sources-idUSKBN1DL1BF>.

18. Ibid.

ization and promotion of the SMART reactor to third countries.¹⁹

A number of SMR developers have argued that there are multiple motivations to pursue smaller designs, directed both at large industrialized countries and developing countries. One motivation is the high upfront capital cost of standard reactors, which is beyond the financing capacities of many utilities and countries. Another is to expand nuclear power to countries with relatively small electrical-grid capacities; a gigawatt-scale reactor could destabilize a small grid. What is interesting about the SMART partnership between Saudi Arabia and South Korea is that the kingdom falls outside the “niche” SMR market, as advocated by SMR vendors.

However, other factors that have been offered as motivations for SMRs are claims to potentially greater safety due to the reliance on passive features, and enhancement in public acceptability. In the case of the Saudi SMART venture, the technology is also capable of producing desalinated water besides generation electricity.²⁰

The downside of SMRs deployment in Saudi Arabia, however, is the loss of economies of scale—smaller nuclear reactors are typically more expensive on a per unit cost basis. Detailed and carefully conducted elicitations showed that even experts drawn from, or closely associated with, the nuclear industry expect SMRs to cost more per kW of capacity than currently operating reactors.²¹ Based on the average of expert estimates of the extra per kW cost for SMRs, the percentage increase expected ranged from 12% for 225 MWe reactors to a whopping 120% for 45 MWe reactors.

There are currently dozens of SMR designs under development. Some of these are still in the conceptual design phase, many are still in the R&D phase and only four have been licensed or currently are under construction.²² The details of these SMRs are summarized in Table 2. Thus far, there is no sign that any of the five remaining GCC countries are considering any of these reactors.

19. “Saudi Arabia team up with South Korea on SMART,” *World Nuclear News*, March 04, 2015, available from <http://www.world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html>.

20. “Saudi Arabia and Korea further SMART cooperation,” *World Nuclear News*, September 03, 2015, available from <http://www.world-nuclear-news.org/NN-Saudi-Arabia-and-Korea-further-SMART-cooperation-03091501.html>.

21. Ahmed Abdulla, Inês Lima Azevedo, and M. Granger Morgan, “Expert Assessments of the Cost of Light Water Small Modular Reactors,” *Proceedings of the National Academy of Sciences* 110, no. 24, 2013, pp. 9686–91.

22. Hadid Subki, “Global Trends, Prospects and Challenges for Innovative SMRs Deployment” (presented at the Long-term Prospects for Nuclear Energy in the Post-Fukushima Era, Seoul (Korea), August 29, 2012), available from http://www.iaea.org/INPRO/5th_Dialogue_Forum/Wednesday_29.08.2012/Session_IV_Nuclear_Safety_and_Innovation/2._Hadid_Subki_IAEA_0829_no_distribute.pdf.

Country of Origin	South Korea	Russia	China	Argentina
Reactor Technology	PWR	PWR	HTGR	PWR
Status	Licensed	Under Construction	Under Construction	Under Construction
Electrical Power (MWe)	90-100	35	2X105	27

Table 2: Small Modular Reactors Currently Under Construction or Licensed

The HTGR Option

Saudi Arabia's interest in SMRs extends to the Chinese high temperature gas reactor (HTGR). In March 2017, KA-CARE and China Nuclear Engineering Group (CNEC) signed an agreement to conduct a feasibility study that will consider "the development of system solutions for the investment and construction of HTGRs."²³ The agreement will also examine cooperation in "intellectual property and the development of a domestic industrial supply chain for HTGRs built in Saudi Arabia".

Since HTGRs operate at a higher temperature compared to water-cooled reactors, they can be used to generate process heat and hydrogen production as well as electricity.²⁴ On paper, Saudi Arabia could deploy HTGRs in their industrial regions such as petrochemical compounds and heavy oil recovery systems. Proponents of HTGRs claim that they possess high safety standards.²⁵ However, based on a review of the operational history of HTGRs, they face some serious technical challenges and are prone to a variety of small failures such as air and oil ingress, which could trigger accidents with severe consequences.²⁶ Given the importance of the oil and petrochemical sector for the Saudi economy, the consequences of any accident are likely to be immense. Therefore, the kingdom will be taking on a substantial risk for a return that can be achieved using other sources of energy and technologies.

23. "China, Saudi Arabia begin HTGR feasibility study," *World Nuclear News*, May 17, 2015, available from <http://www.world-nuclear-news.org/NN-China-Saudi-Arabia-begin-HTGR-feasibility-study-1705174.html>.

24. In cooler countries, HTGR's excess heat can be used for district heating for residential and commercial customers.

25. Zhang, Zuoyi, Zongxin Wu, Dazhong Wang, Yuanhui Xu, Yuliang Sun, Fu Li, and Yujie Dong, "Current Status and Technical Description of Chinese 2 × 250 MWth HTR-PM Demonstration Plant," *Nuclear Engineering and Design* 239, no. 7, 2009, pp. 1212–1219.

26. M.V. Ramana, "The checkered operational history of high-temperature gas-cooled reactors," *Bulletin of the Atomic Scientists* 72, no. 3, 2016, pp. 171–179 and Matthias Englert, Friederike Frieß, and M.V. Ramana, "Accident Scenarios Involving Pebble Bed High Temperature Reactors," *Science & Global Security*, 2017, pp. 25 and 42-55.

Cost of Electricity Generation

The conventional way to compare the cost of electricity generated by different sources is to calculate the levelized cost of electricity (LCOE), which can be understood as the ratio of the total cost to the benefits (in this case the electricity produced) with all figures being discounted to the same baseline year. This follows from the standard discounted cash flow methodology, which accounts for the time-value of money. This methodology is used to calculate the life cycle cost of producing electricity.

The calculated LCOE for different energy sources are all busbar costs delivered to the grid; i.e., they take into account auxiliary or in-plant consumption of electricity but do not include transmission and distribution costs. Any large-scale expansion of nuclear power in Saudi Arabia would require an expansion of transmission infrastructure. Such costs are not included here, even though it could be significant.

The cost of electricity generated as well as water produced by desalination from any technology depends on a number of parameters. An important factor is the discount rate. For the case of Saudi Arabia, the chosen discount rate is 5%. Note that this is a real discount rate, and inflation is implicitly taken into account. This choice may seem somewhat low, but many studies do indeed adopt discount rates of around 5 to 5.5% in their evaluations of electricity economics in the GCC.²⁷

¹⁵ Fuel/ Technology	Nuclear	Gas-light oil / GT	Gas- light oil/ CCGT	Heavy Oil/ ST	Diesel/ Diesel
Fixed Cost (\$/MWh)	68.5	10.37	17.35	14.77	66.98
Var. Cost(US\$/MWh)	12.25	37.69	8.70	8.23	21.50
LCOE (cent/kWh)	8.08	4.81	2.60	2.30	8.85

Table 3: Cost of Electricity Generation in Saudi Arabia of Different Technologies Using Subsidized Prices

Estimates of the cost of electricity generation of various sources in Saudi Arabia are shown in Table 3. These estimates were based on a recent study by Chite and Ahmad.²⁸ Estimating the cost of generation using prices of subsidized fuel, as usually entailed from Saudi electricity operators, results in very low generation costs where nuclear (and renewables) cannot compete.

A special case to be considered is the cost of nuclear electricity generated by SMRs. As discussed earlier, SMRs are expected to have higher capital costs per kW by somewhere between 12 and 120%.²⁹ In this analysis, SMRs' capital costs is assumed 25% higher than for current nuclear reactors, i.e., approximately \$7,430/kW.³⁰ MRs would also have higher fueling cost because of higher uranium requirements.³¹ It is also

27. Yasser Al-Saleh, Paul Upham, and Khaleel Malik, *Renewable Energy Scenarios for the Kingdom of Saudi Arabia*, Working Paper, Norwich, U.K.: Tyndall Centre for Climate Change Research, October 2008 and Center for Engineering Research, *Updated Generation Planning for the Saudi Electricity Sector*, Riyadh, Saudi Arabia: Electricity & Cogeneration Regulatory Authority, March 2006.

28. Philippe Chite and Ali Ahmad, "Requirements for High Solar Penetration in Electricity Production in Saudi Arabia."

29. Abdulla, Azevedo, and Morgan, "Expert Assessments of the Cost of Light Water Small Modular Reactors."

30. This cost value is based on the EIA's reported cost for advanced nuclear, which currently stands at 5945 \$/kW.

31. Alexander Glaser, Laura Berzak Hopkins, and M.V. Ramana, "Resource Requirements and Proliferation Risks Associated with Small Modular Reactors," *Nuclear Technology* 184, 2013, pp. 121–29.

not clear what sets of conditions they would be licensed under,³² and depending on the safety and security requirements imposed by regulatory authorities, SMRs could have higher fixed and variable operations and maintenance costs. In contrast to these higher costs, the construction time for SMRs is expected to be shorter.³³ For simplicity, it is assumed that all of the cost variables for current (large) LWRs are the same as SMRs with the exception of the capital cost. Then, with these assumptions, the levelized cost of nuclear power from reactors rises from about \$81/MWh if large reactors are constructed to over \$94/MWh for SMRs.

Baseload Generation: Nuclear Versus Natural Gas

Unlike renewables that have zero fueling costs, the cost of natural gas is an important, perhaps overwhelming, component of the cost of generating electricity in a natural gas plant. Therefore, the cost comparison between nuclear and natural gas could vary from country to country. Natural gas prices in countries that use domestic reserves, such as Saudi Arabia, would be significantly lower than countries that import natural gas at international prices, and this would affect the relative economics of power from nuclear reactors and natural gas plants.

The economic competitiveness of gas-fired power plants decreases as the prices of natural gas increase. Ahmad and Ramana estimated the cross-over value between nuclear and natural gas generated electricity for Saudi Arabia is at a natural gas price of \$13.6/mmBTU.³⁴ In other words, nuclear is less economical if natural gas prices are lower than the cross-over value. The economic prospects for nuclear power in the Kingdom are not favorable in comparison with natural gas, even if the currently low domestic natural gas prices in Saudi Arabia were to rise substantially.

What if Saudi Arabia were to increase its domestic output and start exporting gas instead of using it in natural gas plants? This is related to what is often termed the opportunity cost. The first thing to note is that such exports will most likely be in a liquefied (LNG) form. Consequently, the costs associated with building infrastructure, liquefaction, and shipping should be taken into account. A study on the future of natural gas conducted by the Massachusetts Institute of Technology estimates the cost of liquefaction at \$2.15/mmBTU, shipping of LNG at \$1.25/mmBTU, and regasification at \$0.7/mmBTU.³⁵ The total of these costs amount to \$4.1/mmBTU.³⁶ Because of this additional expenditure, it would make economical sense for Saudi Arabia to build a nuclear reactor in comparison to a natural gas plant only if the price that could be obtained on the international market exceeds \$13.6/mmBTU over the period of the lifetime of the reactor.

32. M.V. Ramana, Laura Berzak Hopkins, and Alexander Glaser, "Licensing Small Modular Reactors," *Energy* 61, 2013, pp. 555–64, available from https://inis.iaea.org/search/search.aspx?orig_q=RN:46018600.

33. Abdulla, Azevedo, and Morgan, "Expert Assessments of the Cost of Light Water Small Modular Reactors."

34. Ali Ahmad and M. V Ramana, "Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia," *Energy* 69, 2014, pp. 682–694.

35. Ernest J Moniz, Henry D. Jacoby, and Anthony J. M. Meggs, *The Future of Natural Gas*, Cambridge, MA: Massachusetts Institute of Technology, 2011.

36. Additionally, LNG plants are very expensive, with long-lead times and significant potential market risks as more countries ramp up to export LNG or as importing countries decide they can boost local gas production using fracking. Since the LNG plants must operate for long periods of time to recover costs, these risk factors ought to further tilt countries without sufficient LNG capacity already built to favor domestic use in power markets instead.

Potential of Solar Power in Saudi Arabia

Aside from meeting the increasing energy demand, integrating solar power in the Kingdom's current energy mix would be both economically and environmentally advantageous. Saudi Arabia has one of the highest potential of solar energy in the region where annual solar radiation is around 2,200 kWh/m².³⁷ Moreover, integrating renewables within the energy industry would drive economic diversification, create jobs and facilitate the implementation of climate change policies. Compared to nuclear, pairing solar power plants with domestic gas turbines can also help with load balancing more effectively.

The Kingdom recently equipped 30 metrological stations able to conduct very accurate measurements including one-minute measurements of Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), and Direct Normal Irradiance (DNI).³⁸ GHI ranged from an average daily total of 5,700 Wh/m² to the highest 6,700 Wh/m² with the higher values found in inland areas and lower values found on the coast. DNI values ranged from an average daily total of over 6,474 Wh/m² found on western inland areas to an average daily total closer to 5,510 Wh/m² found on eastern areas.³⁹ The solar resources outlined above are optimal for the performance of two main solar technologies that dominate current and future energy projects in Saudi Arabia: Photovoltaics (PV) and Concentrated Solar Power (CSP).

The hourly load pattern shown in Figure 2 above should offer an advantage for renewables mainly solar, as the high load occurs in the summer, in step with the maximum output of solar PV or CSP systems. However, PV systems generally suffer from reduced power output during the summer due to high ambient temperature affecting the performance of solar cells. On the other hand, CSP systems are less affected by high ambient temperature but are more sensitive to weather conditions like haze or sandstorms which lower the performance of solar CSP plants.⁴⁰

In terms of costs, PV costs are divided into module costs (direct cost of photovoltaic modules); "hard" (inverter, racking, electrical equipment, etc.); and "soft costs" (labor, permitting fees, etc.). Module prices have followed a learning rate of 20 percent over the long term for the last 10 years.⁴¹ Non-module prices, which are also known as BOS (Balance of System) are also decreasing, nearly at the same rate. Future improvements in the PV technology cost should come from a combination of improving power electronics, reducing supply chain complexity and cost, and decreasing installation costs and margins as markets mature.⁴²

The dramatic decline in solar PV costs is particularly relevant because of the long construction period of nuclear projects, a decade at the very least.⁴³ Even assuming that a nuclear power project is given the go-

37. A. Farnoosh, F. Lantz, and J. Percebois, "Electricity Generation Analyses in an Oil-exporting Country: Transition to Non-Fossil Fuel Based Power Units in Saudi Arabia," *Energy* 69, 2014, pp. 299–308.

38. *Renewable Resource Atlas*, K.A.-CARE King Abdullah City for Atomic and Renewable Energy, available from <https://rratlas.kacare.gov.sa/RRMMPublicPortal/>.

39. Erica Zell, et al., "Assessment of Solar Radiation Resources in Saudi Arabia" *Solar Energy* 119, 2015, pp. 422–438.

40. "CSP Prospects in Saudia Arabia," 2014, available from www.csptoday.com/menasol2014.

41. "Commission imposes duties to prevent imports of dumped and subsidised Chinese solar panel components via Taiwan and Malaysia," *European Commission*, February 12, 2016, available from <http://trade.ec.europa.eu/doclib/press/index.cfm?id=1461>.

42. Ibid.

43. According to the IAEA's figures for construction periods, the global weighted average reactor construction time is 96.6

ahead in 2018, it will likely be 2028 by the time it starts generating electricity. On the other hand, there is little reason to expect the costs of nuclear power to decline substantially. Historically, costs of nuclear power have only increased.⁴⁴

Recent solar PV projects benefit from lower prices. For example, the Dewa project in Dubai rated 260 MW is priced at \$328 million, giving a capital cost of 1,225 \$/kW. The plant is expected to produce electricity at world record of 5.85 cent/kWh. Prices are heavily influenced by the project location. In Saudi Arabia, these costs should be less than those in the United States and Europe. Costs should decrease even further as more PV projects are installed and some parts of the PV system are manufactured locally.

Investments Needs

The total investment for the 2012 KA-CARE plan is expected to reach about \$360 billion by 2030, with CSP technologies representing the highest costs (see Figure 3).⁴⁵ A cheaper scenario involves adding gas turbines and replacing nuclear reactors with CCGT power plants which are cheaper and have a shorter construction time. In that case, the total investments needed are approximately \$150 billion, nearly half the investments needed by 2012 KA-CARE plan (see Figure 4).

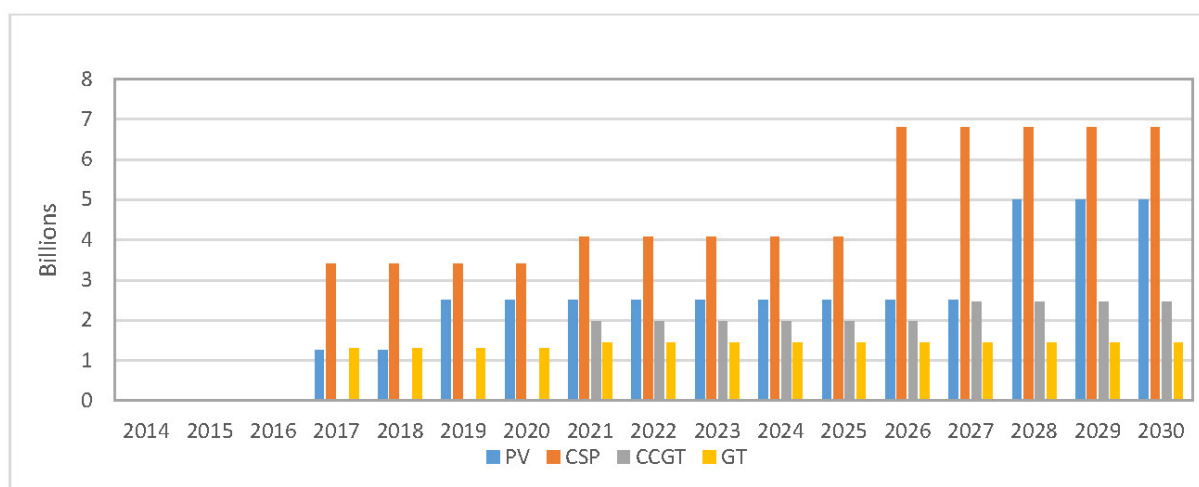


Figure 3: Investment in Billion US\$ Needed to Implement the Original KA-CARE Plan (16 GW PV, 25 CSP and 17.6 GW Nuclear)

months, or about eight years. See IAEA, *Nuclear Power Reactors in the World: 2013 Edition*, Vienna: International Atomic Energy Agency, 2013. In these figures, the construction period is defined as the time between the “first pouring of concrete to the connection of the unit to the grid.” However, some costs that are incurred before the first pour of concrete—for example, money spent on ordering components that take a long time to manufacture. If one were to include those as well, there would be cash flows from a project initiation for about ten years.

44. Hultman and Koomey, “The Risk of Surprise in Energy Technology Costs” and Arnulf Grubler, “The Costs of the French Nuclear Scale-up: A Case of Negative Learning by Doing,” *Energy Policy* 38, no. 9, 2010, pp. 5174–88.

45. Calculations used the following capital costs: 2,500 \$/KW for PV, 6,800 \$/KW for CSP with six hours storage and \$5,530 for nuclear reactor. Olson, Schlag, Patel, and Kwok, *Capital Cost Review of Power Generation Technologies* and Ali Ahmad, and M.V. Ramana, “Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia,” *Energy* 69, 2014, pp. 682–694.

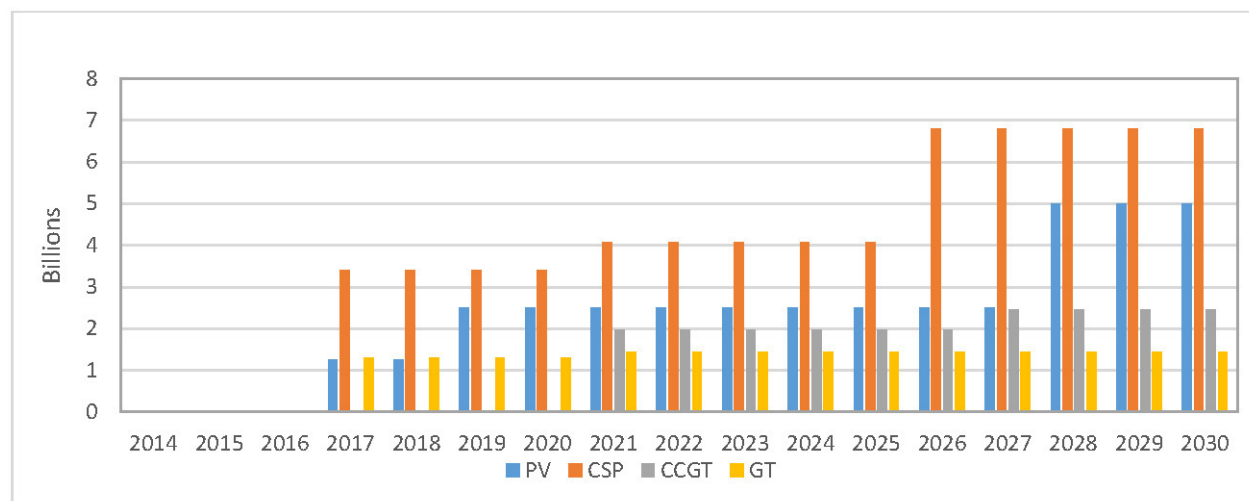


Figure 4: Investment in billion \$ needed to implement the modified plan (16 GW PV, 10 CSP and 17.6 GW CCGT and 30 GW GT)

High solar penetration in the Saudi electricity sector will depend on the support of the political leadership, the type of technology, its capacity and associated costs, the energy market structure, the investment climate and finally, the permitting rules and regulations.⁴⁶ The “Saudi Vision 2030” shows strong interest in renewables among political leaders, but the energy sector is still dominated by oil and remains highly subsidized which further leads to very low fuel and electricity prices encouraging high consumption.

All the existing entities needed for leading the energy transition are still new or yet to be established, however, it is likely that Saudi Aramco will play an important role in implementing this transition. Saudi Arabia will still need further research on the effect of sandstorms, soiling, aging, and high temperatures on renewable energy systems. The country should also promote energy efficiency and storage schemes, smart grid systems and interconnection with neighboring countries. Moreover, the localization of renewables should be a top priority for policy makers since the kingdom can rely on international partnerships for technology transfers that could facilitate its energy transformation.

The Localization Question

Localization has been mentioned as an important theme in the Saudi 2030 vision, and was further emphasized in the National Transformation Plan 2020. In general, countries seek to promote local content requirements to promote public support, support new industries and add new jobs.

According to the National Transformation Plan 2020, the Saudi government aims to promote local content in the nuclear and renewable energy sector simultaneously.⁴⁷ For the nuclear energy sector, the kingdom plans to introduce nuclear power to the energy mix of the kingdom with a target of 25% to 30% local con-

46. *Moving towards 100% Renewable Electricity in Europe & North Africa by 2050: Evaluating progress in 2010*, Price-waterhouseCoopers, 2011, available from <https://www.pwc.at/de/publikationen/klimawandel-nachhaltigkeit/moving-towards-100-percent-renewable-electricity-in-eu-and-africa-by-2050.pdf>.

47. *National Transformation Program*. (2016), retrieved October 2, 2017, available from <http://vision2030.gov.sa/en/ntp>.

tent that includes nuclear fuel cycle activities such as in uranium production.⁴⁸ To support the legislative efforts, building infrastructure, training human capabilities, localizing renewables technology, SMRs, and the nuclear fuel cycle, 5 Billion Saudi Rial will be spent by 2020.⁴⁹

Saudi Arabia's intention to localize nuclear industries and the fuel cycle clearly contradicts attempts by SMR vendors to cut costs through, factory-build, serial production models, unless the kingdom intends to build tens of SMART reactors across its territory. Though this does not seem to be a realistic option given the current lack of economic, industrial and human capacities. Furthermore, the possibility of linking all GCC countries with a one electric grid, makes the economic case for SMRs in the kingdom even weaker since such grid interconnections would be ideal to improve the economics of renewables.

On the other hand, the localization potential for renewables, particularly solar, in the kingdom is high. It is also easier to achieve compared to the complex, and political, nuclear localization. Additionally, it is not surprising that the decentralized decision-making process involved with planning and constructing renewable energy projects plays an important role in advancing its localization potential.

Investments in renewable energy in Saudi Arabia should be accompanied by localization of some part of the value chain in the kingdom. For PV, the localization of BOS (balance of the system) activities can be the first step; this could include manufacturing support structures, trackers, mounting hardware, electric protection devices, wiring, monitoring equipment and installation. As a second setup in localization the kingdom can build a manufacturing facility in the country. The investments needed for localizing a 1GW/yr PV manufacturing facility range between 1 and 2 billion US\$ per plant. By 2030, a 7 GW PV plant should create around 21,000-50,000 direct jobs and 70,000-140,000 indirect jobs in the Kingdom.⁵⁰

Conclusion

Nuclear power has been proposed as part of Saudi Arabia's future energy mix. With recent interest in investing in small modular reactors, the kingdom's strategy is both perplexing and risky. This work shows that nuclear power, large and small, does not meet the criterion of economic competitiveness. First, nuclear electricity is already more expensive than that produced by solar technologies. The coupling between renewables and natural gas offers Saudi Arabia the most economically optimal option. Given that the Kingdom does not export its natural gas, the cross-over value between nuclear and natural gas was estimated at \$13.6/mmBTU. For nuclear electricity to become a cheaper option, Saudi Arabia will have to sell its natural gas at higher prices than that of the cross-over price. On the other hand, renewables, particularly solar power, offers Saudi Arabia real opportunities for meeting its electricity demand incrementally with substantial localization potential.

48. It is not clear for now whether "uranium production" includes enrichment.

49. Ibid.

50. A typical PV plant will need two persons/MW in the construction stage, 7.5 person/MW in the operation stage, and 0.5 person/MW for maintenance. In 2012, the PV industry created 3-7 direct jobs and 10-20 indirect jobs per MW produced. *Energy from the Desert: Very Large scale PV Plants for Shifting to Renewable Energy Future*, International Atomic Energy Agency Photovoltaic Power Systems Program, February 2015, available from <http://iea-pvps.org/index.php?id=316>.

Chapter 5

Saudi Arabia Energy Needs and Nuclear Power

Robin Mills

Introduction

This report, commissioned by the Nonproliferation Policy Education Center, assesses the prospects for Saudi Arabia to meet its energy and environmental requirements without the use of nuclear power.

There are evidently many ways in which those requirements could be defined and met. This study covers the period up to 2040 since this is the period over which the country has defined its current nuclear power target, and with main focus on 2032 given that this was the year for its initial planned mix of nuclear and renewable energy. Reasonable assumptions are made for growth in electricity demand, other industrial energy demand, and transportation, based on official Saudi forecasts with independent checks and scenarios, including those with greater realised energy efficiency. The primary focus is on electricity given that this would be the main output of a civil nuclear power programme, so the other uses of oil and gas in the transportation and industrial sectors are not considered in detail.

Then a comparison is made of the Saudi energy system up to 2040 with nuclear power at current targeted levels; with the current fossil-fuelled mix; and with a number of scenarios with more renewable energy and no nuclear. These three approaches are contrasted on the metrics of economic attractiveness (cost and value); environmental outcomes; reliability and energy security; local economic development. Possible proliferation-related reasons for pursuing civilian nuclear power have been dealt with at length by others and are not considered here.

The main scenarios considered assume that the regional political situation and climate remain broadly similar to today. It is assumed that, over this period, transport (air, land, and sea) will remain fuelled primarily by hydrocarbons (oil and possibly natural gas). In all scenarios, mostly current technologies are assumed, with conservative views on improvements in performance and cost. Of course, more rapid advances in renewable energy, unconventional hydrocarbons, carbon capture & storage, advanced energy storage or other technologies would make it easier to meet the country's energy requirements without nuclear power. Conversely, advances in nuclear power (such as small modular reactors) would make it relatively more attractive.

Environmental requirements are assumed to be, at minimum, compliance with Saudi Arabia's Paris climate change agreement submission, as well as mitigating local environmental impacts of its current energy system.

Current Situation

Objectives

Saudi Arabia's oil and gas are its main natural resource, the foundation of its economy and its political system and international role. With that in mind, the key goals of Saudi energy policy can be defined as:¹

1. Maintain and increase oil and gas output to meet the needs of the domestic population, supply local business with energy and feedstock, and earn export revenues.
2. Maintain its role as one of the world's leading oil producers and the dominant force in the Organisation of Petroleum Exporting Countries (OPEC).
3. Secure markets for its oil by investing in assets and relationships in its main customers.
4. Diversify the economy by developing hydrocarbon-based and energy-intensive industries, as well as, more recently, non-oil industries, with a view towards the long-term diminution of oil's role in the global economy.
5. Build up substantial fiscal reserves to safeguard against oil price volatility.
6. Safeguard the security of its energy industry and country generally via hard security measures, relationships/alliances and "soft power."
7. Delay or minimise environmental measures that would reduce the use of oil in the world economy.

More recently, two other objectives have risen to prominence, even if they do not yet eclipse the objectives above:

1. Improve energy efficiency, introduce non-hydrocarbon energy sources, and reform subsidies to reduce the fiscal burden on government and preserve oil and gas for industrial and export use, while bearing in mind domestic public opinion and preserving the competitiveness of business.
2. Improve environmental performance, including greenhouse gas emissions.

Oil

Saudi Arabia is, of course, one of the world's largest oil producers (12.3 million barrels per day of crude oil, condensate, and natural gas liquids in 2016, second in the world behind the United States and ahead of Russia; of this, 10.46 million bbl/day was crude oil), and the world's largest oil exporter (net 8.4 million barrels per day in 2016²; of this 7.5 million bbl/day was crude oil and 1.5 million bbl/day refined petroleum products, with 0.6 million bbl/day import of refined products).³ It is the world's largest holder of conventional oil reserves with an

1. Author's interpretation based on observable Saudi policies, official statements and development plans such as Vision 2030.

2. *BP Statistical Review of World Energy 2017*, 'Oil – proved reserves,' 'Oil Production – Barrels,' and 'Oil Consumption – Barrels,' available from <https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf>.

3. *OPEC Annual Statistical Bulletin 2017*, p8, available from http://www.opec.org/opec_web/static_files_project/media/down-

official total of 266.2 billion barrels at the end of 2016⁴ (only Venezuela has a larger figure, but the majority of Venezuela's official reserves are extra-heavy oil of uncertain commerciality).

Saudi oil production costs are exceptionally low, probably on the order of \$10 per barrel or less (capital plus operating costs). The reserves/production ratio is 59 years, indicating (simplistically) that production could continue at current rates for 59 years from the existing reserves base. Saudi Arabia has aspirations to raise its total recoverable oil substantially, mostly by increasing recovery from the known fields.

Saudi Arabia is also a major oil consumer, refining 2.5 million bbl/day in 2016 and consuming 3.2 million bbl/day⁵, the fifth largest figure in the world (behind the United States, China, India, and Japan). Of this, a large proportion was crude oil burnt directly in power plants. Figure 1 shows oil consumption by month during 2013-16, and it can be seen that it rises some 700-800 000 barrels per day in summer versus winter, mostly due to an increase in the direct burning of crude oil and to some extent fuel oil.

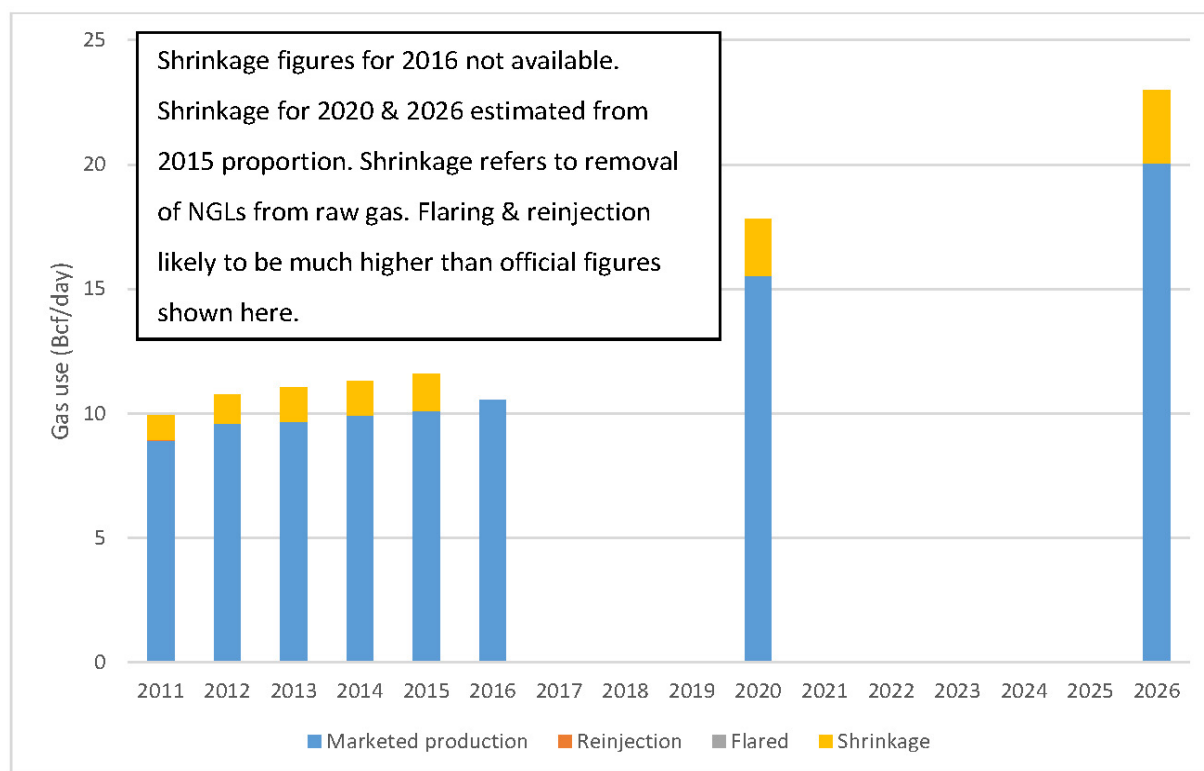


Figure 1: Saudi Arabia Monthly Oil Consumption⁶

All Saudi oil and gas production, apart from that in the Neutral Zone with Kuwait, is operated by Saudi Aramco, the state-owned oil company. Aramco also operates the Kingdom's oil refineries (some in partnership with foreign companies), has a substantial petrochemical and power generation business, and a number of significant international investments in refining and petrochemicals in the United States, China, South Korea, Japan, and elsewhere. Aramco is respected as a relatively efficient and technically proficient

[loads/publications/ASB2017_13062017.pdf](https://www.aramco.com/en/About-us/Investor-Relations/ASB2017_13062017.pdf)

4. Ibid.

5. Ibid.

6. Qamar Energy graph from Joint Organisations Data Initiative (JODI)

operator. There are plans for an Initial Public Offering (IPO) of 5% of Aramco on the Saudi stock exchange (the Tadawul) and a to-be-chosen international exchange, set for 2018.

Natural Gas

Saudi Arabia is also an important producer and consumer of natural gas, though not to the same extent as for oil. Official reserves at the end of 2016 were 297.6 trillion cubic feet (the 6th-largest in the world), and marketed production was 10.6 billion cubic feet per day (the 8th largest in the world). All of this gas was used domestically, making the Saudi domestic gas market the world's 6th largest.

A large part of gas production is associated (a by-product of oil production) and is therefore cheap to collect and use but not flexible. The proportion of associated gas, though, has fallen from 42% in 2005 to about 33% in 2015.⁷ The reserves/production ratio for gas is 77 years, indicating ample reserves to increase production; however, if oil production remains constant, significant increases in gas production would have to come from non-associated fields. The country has developed its first non-associated fields offshore in the Gulf, Karan and (together feeding the Wasit gas plant) the Arabiyah and Hasbah fields.

Saudi Arabia has significant unconventional (tight/shale) gas resources, estimated at 645 trillion cubic feet.⁸ Apart from initial projects in the north-west of the country (Tabuk Basin), shale gas production has consisted only of pilots, with estimates of high production costs (\$9/MMBtu in 2012). However unconventional gas production is targeted to reach 4 Bcf/day by 2026.⁹ Most versions of hydraulic fracturing, required to produce tight gas, use fresh water, which would require desalination. BP has developed tight reservoirs in Oman's Khazzan field, also in a desert setting, using reverse osmosis desalination plants. Alternatively fracturing fluids using saline water, propane or carbon dioxide could be employed though they may be less effective. In either case, this raises the likely initial cost of tight gas production in Saudi Arabia.

Although it borders two of the world's largest gas resource holders, Iran and Qatar, Saudi Arabia by policy does not import or export gas. Difficult political relations with these two countries (and with another gas-rich neighbour, Iraq, although relations here have somewhat improved recently) make direct imports unlikely. Other than Yemen, whose moderate LNG exports are shut down by the continuing war, its other neighbours—Egypt, Jordan, UAE, Oman, Bahrain, and Kuwait—are themselves gas importers or about to become so.¹⁰ If political conditions did change to allow gas imports from a neighbour, its lower cost might undermine high-cost domestic gas production. It is also possible that Saudi Arabia could at some point import liquefied natural gas (LNG).¹¹ In July 2017, Russian energy minister Alexander Novak said

7. "Natural Gas and the Vision 2030," *Jadwa Investment*, October 2016, available from <http://www.jadwa.com/en/download/natural-gas-and-the-vision-2030/gdp-report-16-6-2-1-3-3-2-1-1-1-1-1-1-1-1-1-1>.

8. Baker Hughes quoted in "Work starts on shale production," *Oil and Gas News*, available from http://www.oilandgasnews-worldwide.com/Article/34799/Work_starts_on_shale_production.

9. Mark Thomas, "Saudi Shale Drive Powers Up," *E&P Magazine*, June 22, 2016, available from <https://www.epmag.com/saudi-shale-drive-powers-850356#p=full>.

10. Oman exports LNG but the plant runs below capacity because of a shortage of feedstock; it is negotiating with Iran for gas imports. Egypt may again become a marginal gas exporter with development of its Zohr field, but any excess is likely to be exported through currently mothballed LNG plants on the Mediterranean coast.

11. "Saudi Aramco could import gas to boost use in energy mix: minister," *Reuters*, June 6, 2016, available from <https://www.reuters.com/article/us-saudi-plan-saudi-aramco-gas-int/saudi-aramco-could-import-gas-to-boost-use-in-energy-mix-minister>.

that Aramco had been offered a share in Novatek's Arctic LNG-2 project in the north of west Siberia.¹²

Energy minister Khaled Al Falih has indicated an aspiration to raise gas from 50% of the “energy mix” to 70%, which probably refers to its share of electricity generation (gas's share of total primary energy use is rather lower, at about 32% in 2016). Under the National Transformation Plan, gas production is intended to rise from a (gross) 12 Bcf/day in 2016 to 17.8 Bcf/day in 2020 and 23 Bcf/day by 2026.¹³ Gas production is shown in Figure 2, as well as the projected production in 2020 and 2026, assuming the proportion of shrinkage (removal of natural gas liquids) remains the same (shrinkage figures are not available for 2016). On official figures, flaring and reinjection is minimal although likely to be substantially more in reality. It can be seen that, although marketed gas production has increased by 1.6 Bcf/day from 2011 to 2016, it has to increase by a further 5 Bcf/day by 2020. 2.5 Bcf/day of this will come from the Fadhili processing plant due online in 2019 (which will process 0.5 Bcf/day from the onshore Khursaniyah field and 2 Bcf/day from the second phase of the offshore Hasbah field), and 1.3 Bcf/day from an expansion of the Hawiyah gas plant.¹⁴ 0.075 Bcf/day will be produced from the Midyan field, in a new gas-producing area in the north-west of the country. It is not clear where the remainder of the increase, 1.125 Bcf/day, will come from, although an expansion of the Haradh gas processing plant is also in the works (both Hawiyah and Haradh process gas from the Ghawar field).

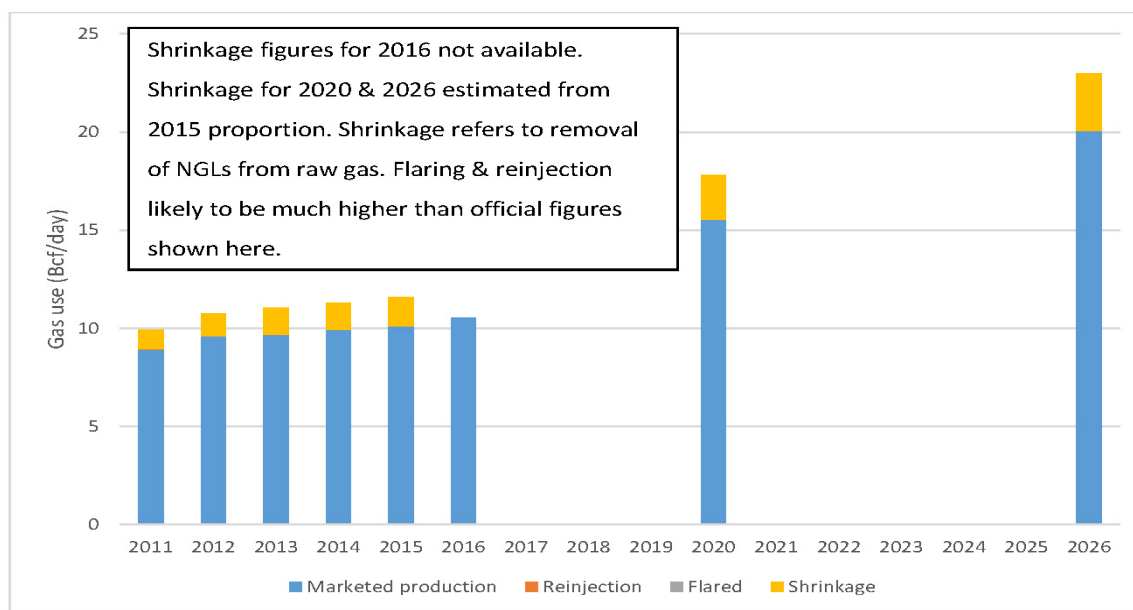


Figure 2: Gas Production¹⁵

[idUSKCN0YS2MS.](#)

12. Vladimir Soldatkin, Oksana Kobzeva, and Katya Golubkova, “Russia offers Saudi Aramco role in Arctic LNG project: Novak,” *Reuters*, July 6, 2017, available from <https://www.reuters.com/article/us-russia-saudi-novak/russia-offers-saudi-aramco-role-in-arctic-lng-project-novak-idUSKBN19R1RF>.

13. Mark Thomas, “Saudi Shale Drive Powers Up.”

14. “Saudi Aramco to boost gas production at Hawiyah, Haradh: sources,” *Reuters*, January 20, 2017, available from <https://www.reuters.com/article/us-aramco-gas/saudi-aramco-to-boost-gas-production-at-hawiyah-haradh-sources-idUSKBN1541PK>.

15. *OPEC Annual Statistical Bulletin 2016*, available from http://www.opec.org/opec_web/static_files_project/media/downloads/publications/ASB2016.pdf and *BP Statistical Review of World Energy 2017*, available from <https://www.bp.com/con->

The International Energy Agency has become progressively more sceptical on Saudi Arabia's gas output targets. In 2014, it forecast production would be approaching 13 Bcf/day by 2019, but in subsequent editions of its Medium Term Gas Outlook, it reduced that down to just over 9 Bcf/day by 2019 and about 10 Bcf/day by 2022.¹⁶

Gas consumption by sector is shown in Figure 3. The power sector is about 56% of total gas consumption. (Note that there is an unexplained discrepancy between the IEA figures, used here, and the OPEC and BP figures for total production which are significantly higher, while Saudi Electricity Company (SEC)'s figures for generation use are significantly *lower* than those of the IEA). 26% of the country's petrochemical feedstock is methane (the main constituent of natural gas) and 46% is ethane (primarily derived from natural gas).¹⁷

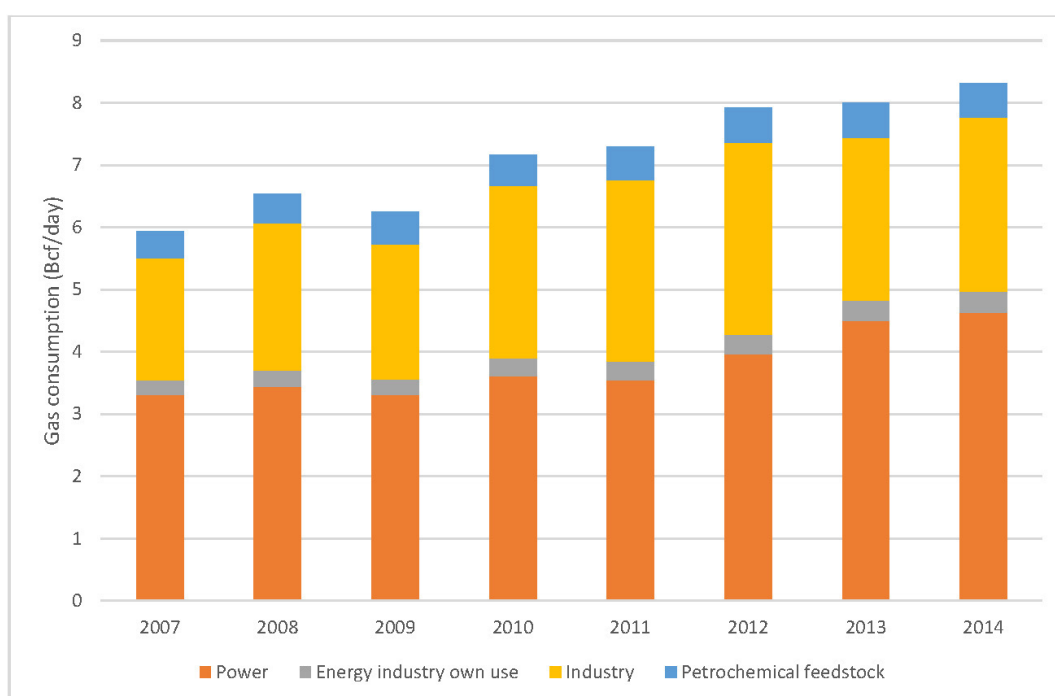


Figure 3: Gas Consumption by Sector¹⁸

Gas prices are regulated by the government and are very low by global standards, being raised in 2016 from \$0.75 to \$1.25/MMBtu, and for ethane (used in petrochemicals) from \$0.75 to \$1.75/MMBtu.¹⁹ These are still well below the price that would be paid for imported LNG, or the cost of developing

[tent/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf](http://www.oxfordbusinessgroup.com/news/saudi-arabia-plans-diversify-power-sources).

16. International Energy Agency, *Medium Term Gas Report 2014, 2015, 2016, 2017 and Middle East Economic Survey* vol. 60, no. 28, July 14, 2017, p. 2.

17. "Natural Gas and the Vision 2030," *Jadwa Investment*.

18. International Energy Agency, "Saudi Arabia: Natural Gas for 2014," available from <http://www.iea.org/statistics/statistics-search/report/?year=2014&country=SAUDIARABI&product=NaturalGas>.

19. Oxford Business Group, "Saudi Arabia plans to diversify power sources," September 9, 2016, available from <https://oxfordbusinessgroup.com/news/saudi-arabia-plans-diversify-power-sources>.

domestic unconventional gas.

Electricity

Electricity demand has been rising rapidly, at an annual average rate of 6.2% in the ten years 2006-16, spurred by the economic boom (up to 2014), rising population and low, subsidised tariffs. However, with an economic slowdown and an increase in tariffs, demand grew by only 0.7% in 2016. It remains to be seen whether this slower growth becomes the norm, but without efficiency measures the government expects demand growth to be 4-5% annually.²⁰

Total generating capacity attached to the national grid was 74.3 GW at the end of 2016 (up from 69.2 GW a year earlier), of which 55 GW was provided by the state-owned Saudi Electricity Company and the rest by industrial companies with their own grid-connected power plants. The highest reported load was 62.26 GW in August 2015 although that may be exceeded this year.²¹ The reserve margin is therefore almost 20% which would be considered adequate (SEC's target is 12%). Power plants receive fuel at prices fixed by the government which are far below world market levels: \$1.25 per MMBtu for natural gas, \$4.4 per barrel for heavy fuel oil, \$11.7 per barrel for diesel, and \$5.94 per barrel for crude oil (these are the prices after a sharp increase ordered in January 2016; they were even lower before).²²

Figure 4 shows Saudi power generation by source. It can be seen that virtually all comes from oil (crude oil and refined products) and natural gas (the breakdown of generation for 2015 and 2016 is not available from IEA). A very small proportion (0.083 TWh out of total generation of 330.46 TWh in 2016, or 0.03%) is provided by solar photovoltaics (PV), with current installed capacity of 85 MW.²³ Saudi Arabia's first wind turbine (2.75 MW) was installed in January 2017²⁴, and it does not currently make use of any other form of renewable electricity production²⁵, nuclear power or coal. Saudi Arabia is constructing three integrated solar combined cycle (ISCC) plants, using small amounts of solar thermal to boost the efficiency of combined-cycle plants: Duba 1 (43 MW solar out of total 605 MW), Waad Al Shamal (50 MW solar out of total 1390 MW) and Taiba (180 MW solar out of total 3600 MW).²⁶

KA CARE's 2013 strategy foresaw total generation capacity by 2032 of 123 GW. This would be met by 60 GW of hydrocarbon power (oil and gas), 18 GW of nuclear, 41 GW of solar (16 GW PV and 25 GW CSP), 3 GW of waste-to-energy, and 1 GW of geothermal. A further 9 GW of wind power would be used for desalination, with the intermittency presumably managed by other generation and/or water storage.

20. Ibid.

21. Saudi Electricity Company.

22. *Middle East Economic Survey* (8th January 2016), vol. 59, no. 1, p. 8 and Walid Matar and Murad Anwer, "Jointly reforming the prices of industrial fuels and residential electricity in Saudi Arabia," *Energy Policy* 109, pp. 747-756.

23. Middle East Solar Industry Association, *Middle East Solar Outlook for 2016*, January 2016, available from <https://www.mesia.com/wp-content/uploads/2017/09/MESIA-Outlook-2016-web.pdf>.

24. Saudi Aramco, "Commissioning of First Wind Turbine in Turaif," January 17, 2017, available from <http://www.saudiaramco.com/en/home/news-media/news/first-wind-turbine.html>.

25. There are some solar hot water systems.

26. Heba Hashem, "Saudi Arabia's first ISCC plant to set record low CSP cost," *New Energy Update*, February 23, 2016, available from <http://tracker.newenergyupdate.com/technology/saudi-arabia's-first-iscc-plant-set-record-low-csp-cost>.

80% of the renewable and 60% of the nuclear expenditure would be in-country (local content). By 2020, 17.35 GW of solar and 6.5 GW of other renewables would have been installed.

However, very little progress was made on this plan, due to bureaucratic infighting and unclear lines of responsibility.²⁷ In 2016, the new National Transformation Plan intends that 3.45 GW of renewable energy should be introduced by 2020 (4% of the energy mix) and that the renewable share would reach 9.5 GW²⁸ by 2023 and 10% by 2030 (instead of almost 50% in the KA CARE plan). In April 2017, companies were shortlisted for a 300 MW solar plant and 400 MW wind farm. The wind power, originally intended to be at Midyan in the north-west Tabuk region, will now be in Al Jouf in the north²⁹, and by July 2017 was already five months behind its original target. By the fourth quarter of 2017, the country intends to tender another 620 MW of solar PV and 400 MW of wind. If all awarded and built, this would amount to 1.7 GW, which, sustained annually, would be a sufficient pace to meet the 2020 and 2023 targets.

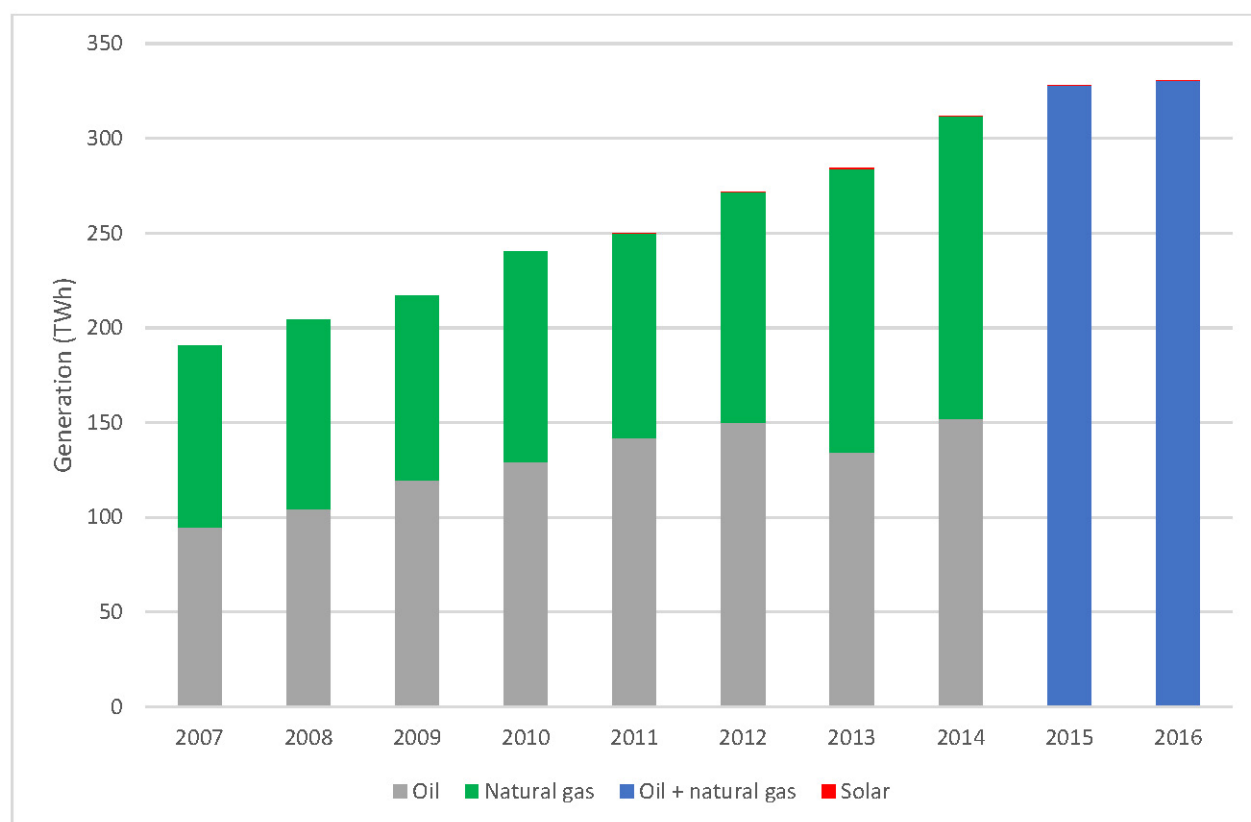


Figure 4: Saudi Arabia Electricity Generation by Source³⁰

27. Moritz Borgmann, "Potentially Game-Changing Saudi Arabian Government Restructuring Bolsters 9.5 GW Renewable Energy Target by 2023," *Apricum*, May 9, 2016, available from <https://www.apricum-group.com/saudi-arabia-announces-9-5-gw-renewable-energy-target-new-king-salman-renewable-energy-initiative/>.

28. Ilias Tsagas, "WFES 2017: Saudi Arabia announces new energy master plan," *PV Magazine*, January 17, 2017, available from <https://www.pv-magazine.com/2017/01/17/wfes-2017-saudi-arabia-announces-new-energy-master-plan/>.

29. LeAnne Graves, "Saudi Arabia looks past oil and pushes ahead with wind energy ambitions," *The National*, available from <https://www.thenational.ae/business/energy/saudi-arabia-looks-past-oil-and-pushes-ahead-with-wind-energy-ambitions-1.609330>.

30. "Solar Consumption – TWh" and "Electricity Generation" in *BP Statistical Review of World Energy 2017* and International Energy Agency statistics available from <http://www.iea.org/statistics/statisticssearch/>.

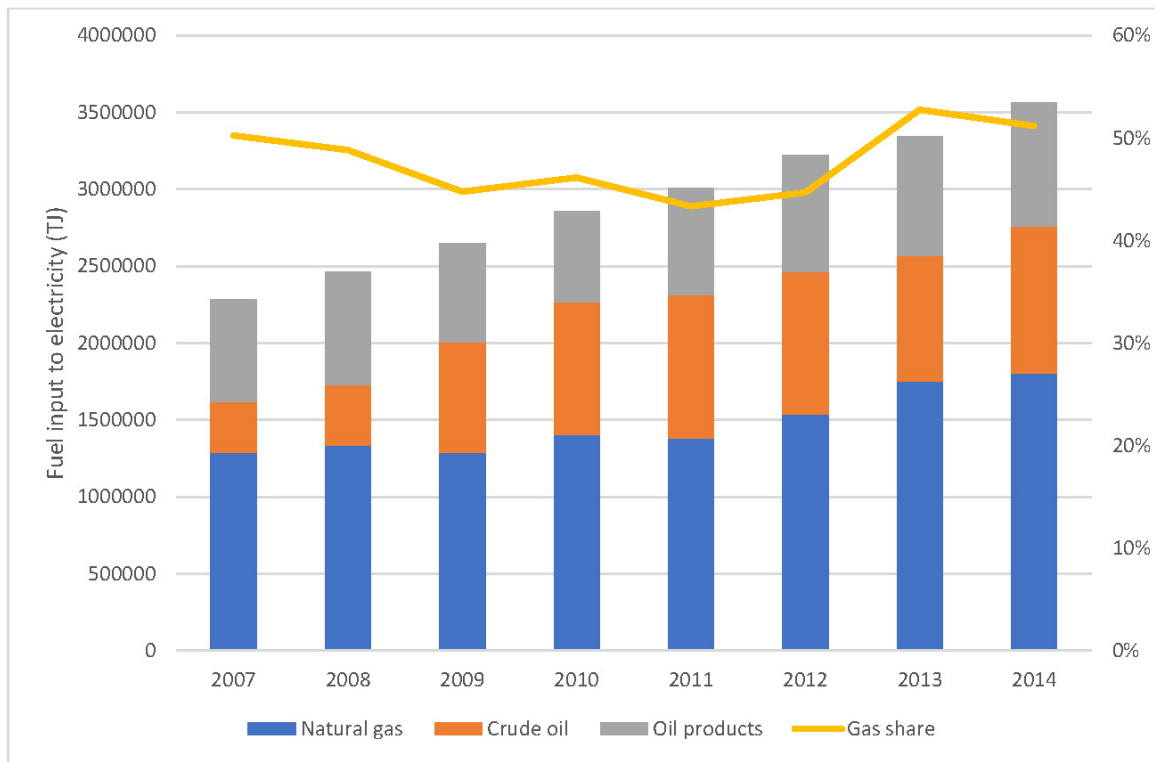


Figure 5: Fuel to Electricity Generation³¹

Figure 5 shows a breakdown of fuel supply to power generation. 1801750 Tj of gas supplied in 2014 is equivalent to about 4.6 Bcf per day. The share of gas in the fuel mix has hovered a little below 50%, rising a little in 2013 and 2014 as new gas supplies became available. Saudi Arabia is almost unique globally for the large-scale direct use of crude oil in power generation, which averaged about 450 kbbbl/day during 2014 and reached 1 million bbl/day at times during the summer months when demand for air-conditioning peaks.

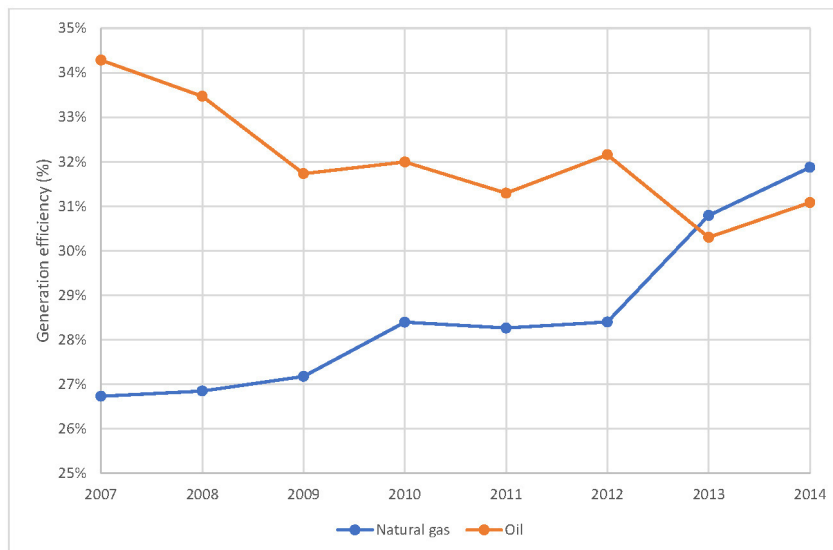


Figure 6: Power Generation Efficiency by Fuel³²

31. Data from International Energy Agency, available from <http://www.iea.org/statistics/statisticssearch/>.

32. Ibid.

Figure 6 shows gross power generation efficiency for oil (crude and products) and natural gas. The efficiency of gas-fired power plants has risen somewhat over time while that for oil-fired power plants has declined. But the overall efficiency of both is low. SEC claims that the efficiency of its plants was 35.6% in 1Q 2017, compared to 34.5% in 1Q 2016³³, although as this period is cooler it would be expected that efficiency would be higher than later in the year. Nevertheless as this figure is higher than the overall efficiencies shown in Figure 6, this implies that the non-SEC power generation has low efficiency.

The hot and (along the Red Sea and Gulf coasts) humid climate, the highly seasonal load profile (peak demand in summer), and, for cogeneration plants, the requirement to co-produce desalinated water, all reduce efficiency from its theoretical maximum. Nevertheless, these efficiency factors are still very low, with over 50% achievable in realistic Gulf operating conditions for a modern combined-cycle plant running on natural gas.

Demand is highly seasonal due to air-conditioning loads (Figure 7), with a peak daytime summer load of about 60 GW, a summer night-time load of about 50 GW, contrasting to about 35 GW daytime and 25 GW night-time in winter.

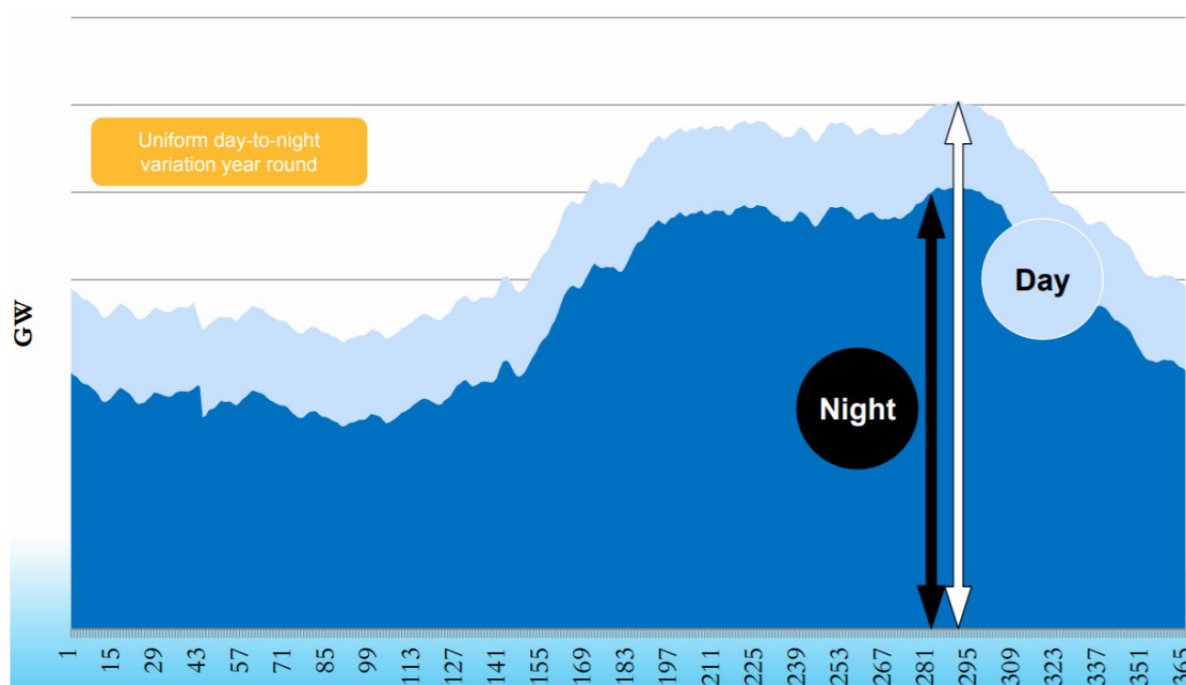


Figure 7: Annual Demand Pattern, Day and Night³⁴

The daily demand pattern is shown in Figure 8. The peak in summer is reached in mid-afternoon, with maximum temperatures and hence air-conditioning load, exacerbated by poor insulation, inappropriate building techniques (e.g. glass-panelled office buildings) and use of inefficient air-conditioning units. There is a second peak around 20-21:00 when temperatures remain high and demand is driven by residential use as people return from work. Even at night consumption does not drop much, as temperatures remain high, falling only by around 6 am.

33. Saudi Electricity Company.

34. Abdulrahman Al Ghabban, "Saudi Arabia's Renewable Energy Strategy and Solar Energy Deployment Roadmap," Presentation, available from <https://www.yumpu.com/en/document/view/42069104/abdulrahman-al-ghabban-presentation>.



Figure 8: Forecast Daily Load Pattern, 2032³⁵

As noted, Saudi electricity prices to consumers are highly subsidised. In 2015, the average countrywide price was 2.09 US¢/kWh, with tariffs tiered by consumption, from the lowest band of 2000 kWh up to amounts in excess of 10,000 kWh. Price rises in 2016 increased the price in the main band by 20%, to 4.3 US¢/kWh.³⁶ However, this remains well below international benchmarks and the cost of generation (if fuel were valued at international prices). These low prices encourage wasteful consumption and make energy efficiency investments or small-scale renewable energy (such as rooftop solar panels) unattractive. SEC is vertically-integrated, and so it is not clear what proportion of its costs relate to transmission and distribution (T&D), or how the end-user subsidy is distributed between generation and T&D. Tariffs do not vary by location, and therefore remote areas are effectively being undercharged for T&D. If all costs were transparently accounted for, local renewable energy may be more cost-competitive for such localities.

Saudi Arabia has an extensive electricity grid that covers essentially the entire country apart from some uninhabited parts of the Rub' Al Khali (Figure 9). Some remote or rural areas are served by unconnected local generation (usually diesel generators) but all of the population has access to electricity. As can be seen from the map, the east-west connections are limited with only two in operation, but more are under construction or planned.

35. King Abdullah Centre for Atomic and Renewable Energy (KA CARE).

36. "Natural Gas and the Vision 2030," *Jadwa Investment*.



Figure 9: Saudi Electricity Grid³⁷

Saudi Arabia is connected to the five other Gulf Cooperation Council (GCC) states via the GCC Interconnection for electricity. This has a capacity of 1200 MW to Kuwait, 1200 MW from Saudi Arabia into the interconnection, 600 MW to Bahrain, 1200 MW to Qatar and 1400 MW to the UAE (with 400 MW to Oman through the UAE).³⁸ Construction of a 3000 MW interconnection with Egypt is also underway with first operations scheduled for 2019 and a connection to Jordan is under discussion.

Nuclear Power in Saudi Arabia

Saudi Arabia's most recent interest in nuclear power dates back to December 2006, when the GCC states (Saudi Arabia, Bahrain, Kuwait, Oman, Qatar, and the United Arab Emirates) announced the commissioning of a study on civil nuclear power. A number of different plans have emerged since then, as described below.³⁹ This

37. Saudi Electricity Company, “Saudi Arabia Electrical Grid,” p. 33, available in Arabic from https://www.se.com.sa/en-us/Lists/NGReports/Attachments/2/NG_2016_AR.pdf.

38. Nasser Al-Shahrani, “GCC Interconnection Supergrid: Launchpad of GCC Energy Power Market,” Presentation given in Slovenia, May 17-20, 2015, available from http://www.epcc-workshop.net/Presentations/EPCC2015-Presentation13_Al-Shahrani-GCCIA.pdf.

39. Material in this list is based primarily on the World Nuclear Associations “Nuclear Power in Saudi Arabia,” page, available

list is not exhaustive and other agreements have also been concluded on research, training, etc. However, Saudi Arabia has not concluded a “123 agreement” which is required for U.S. companies to export nuclear equipment or materials to it.⁴⁰

August 2009 – Government announcement of a national nuclear power programme

2009 – Safeguards agreement in place with the IAEA, but no Additional Protocol

April 2010 – Royal Decree announces the establishment of the King Abdullah Centre for Atomic and Renewable Energy (KA-CARE) to supervise nuclear and renewable programmes.

2011-13 – Various plans and targets announced, including site selection for reactors at Jubail on the Persian Gulf and Jizan and Tabuk on the Red Sea.

June 2011 – Plans for 16 reactors over the following 20 years (likely of ~1 GW each), costing \$80 billion, generating 20% of Saudi Arabia’s electricity, with smaller reactors used for desalination.

April 2013 – KA-CARE proposes 17 GW of nuclear power by 2030, plus renewable energy (see separate section). Construction was to begin in 2016.

September 2013 – GE Hitachi Nuclear Energy signed a contract with Exelon Nuclear Partners to pursue construction of its Advanced Boiling-Water Reactor (ABWR) and (ESBWR), while Toshiba/Westinghouse signed a deal with Exelon to pursue its AP1000 and ABWR reactors with KA-CARE.

January 2015 – Nuclear target date moved to 2040.

March 2015 – Korea Atomic Energy Research Institute (KAERI) signs an agreement with KA-CARE to assess building two or more SMART reactors (up to 100 MW each), including integrated desalination, with a cost for the first unit of up to \$1 billion. Construction was to begin in 2018.

April 2015 – Government adviser Maher Al Odan says the country has a target of 6-7 GW of nuclear power by 2032 and 17 GW by 2040.⁴¹

November 2015 – Announcement at a conference that Saudi Arabia has identified a number of possibly commercial uranium deposits in its territory. These include volcanic, black shale, evaporite and possibly pegmatite deposits.⁴²

from <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/saudi-arabia.aspx>, with other sources noted where used.

40. Nuclear Energy Institute, “Nuclear Cooperation Agreements,” available from <https://www.nei.org/advocacy/compete-globally/nuclear-cooperation-agreements>.

41. Angelina Rascoet and Wael Mahdi, “Saudi Arabia to Select Nuclear Power-Plant Site ‘Very Soon’,” *Bloomberg*, October 20, 2016, available from <https://www.bloomberg.com/news/articles/2016-10-20/saudi-arabia-to-select-nuclear-power-plant-site-very-soon>.

42. Fares M. Howari Fares M. Howari1, Philip Goodell, and Salman Abdulaty, “Uranium Resources in the Middle East,” Presentation, available from https://www-pub.iaea.org/mtcd/meetings/PDFplus/2009/cn175/URAM2009/Session%203/05_88_Howari_USA.pdf.

January 2016 – KA-CARE signs with China Nuclear Engineering Corporation (CNEC) for a high-temperature reactor to be built in Saudi Arabia, based on the HTR-PM being built in China by CNEC.

September 2016 – Russia’s Rosatom announces that it is ready to build 16 nuclear reactors in Saudi Arabia at a cost of \$100 billion.⁴³

October 2016 – Saudi energy minister Khalid Al Falih announces that sites for the first nuclear plant will be chosen within the next 12 months.

January 2017 – Al Falih says that the first two nuclear reactors, totalling 2.8 GW, were in the early stages of feasibility and design studies.⁴⁴

March 2017 – Further agreement signed with CNEC on localisation of the nuclear supply chain in Saudi Arabia. Saudi Arabia announces an investment fund for its neighbour and ally Jordan, which includes uranium mining.⁴⁵

May 2017 – Program framework agreement signed with IAEA; KA CARE holds discussions with China.

July 24, 2017 – National Panel for Atomic Energy established⁴⁶. KA CARE said to be undertaking a technical study for the location of two large and two small reactors, and to explore for uranium for mining and processing its own fuel.⁴⁷

As can be seen from this timeline, Saudi Arabia’s nuclear plans so far have changed frequently and involve numerous outside parties without clear progress, and with unrealistically fast timelines. However, this is not unique to its nuclear sector, as the renewable energy programme championed by KA-CARE has made similarly limited progress. Some recent activity may indicate that the pace of both the nuclear and renewable programmes is finally picking up, but it remains to be seen how effectively the new ‘super-ministry’ of energy and industry, under Khalid Al Falih, will be able to coordinate these complex activities while managing other initiatives such as the IPO of part of Saudi Aramco, the development of the mining sector, and the privatisation of Saudi Electricity Company.

43. “Russia’s Rosatom says ready to build 16 Saudi nuclear power stations,” *Arabian Business*, September 5, 2016, available from <http://www.arabianbusiness.com/russia-s-rosatom-says-ready-build-16-saudi-nuclear-power-stations-644543.html>.

44. “Saudi Arabia Says It’s About to Launch a \$30-\$50 Billion Renewable Energy Program,” *Fortune*, January 16, 2017, available from <http://fortune.com/2017/01/16/saudi-arabia-renewable-energy-program/>.

45. “Saudi Arabia to set up \$3bn joint investment fund for Jordan,” *The National*, March 28, 2017, available from <https://www.thenational.ae/world/saudi-arabia-to-set-up-3bn-joint-investment-fund-for-jordan-1.48544>.

46. “Yamani lauds Cabinet approval for establishment of National Atomic Energy Project,” *Arab News*, July 26, 2017, available from <http://www.arabnews.com/node/1134776/saudi-arabia>.

47. *Middle East Economic Survey* 60, no. 30, p.7

Environment

Saudi Arabia's Intended Nationally Determined Contribution (INDC)⁴⁸ under the 2015 Paris climate agreement seeks to mitigate up to 130 million tonnes of CO₂ equivalent by 2030.⁴⁹ This is to be achieved by economic diversification, energy efficiency (including the conversion of single-cycle power plants to combined cycle), the use of renewable energy, carbon capture and storage, increased use of gas (by implication, to replace oil), reducing flaring, water management, public transport, reduced desertification and other measures.

The submission does not give a figure for estimated business-as-usual emissions by 2030, but estimated CO₂ emissions (excluding other greenhouse gases) from fuel combustion alone were 589.0 million tonnes in 2014 and 621.8 million tonnes in 2016.⁵⁰ The proposed mitigation is therefore about 21% of 2016 emissions. For electricity generation only, CO₂ emissions in 2014⁵¹ were approximately 101 million tonnes from natural gas, 70 million tonnes from crude oil and 61 million tonnes from oil products, totalling 232 million tonnes.⁵² In other words CO₂ emissions from electricity generation were about 40% of the total in 2014.

Energy Outlook

Forecasts

Demand. Total demand was 330.46 TWh in 2016⁵³ and peak load was 60.88 GW (including 2.285 GW from remote, non grid-connected locations).⁵⁴ As noted, peak load is assumed by KA CARE to grow to 123 GW in 2032 plus another 9 GW required for desalination. Including the desalination load, that is an implied growth rate of 5% annually. The growth rate over the past ten years has been 7.4% annually.⁵⁵ However a slower rate of growth in future is reasonable given increases in electricity tariffs, efforts to promote efficiency, and the slowing of economic growth due to lower oil prices.

If the pattern of demand has not changed by 2032, then that implies total required generation would be 716.5 TWh, peak daytime summer load would be 132 GW, night-time summer load would be about 110 GW, daytime winter load would be about 77.8 GW and night-time winter load about 56.1 GW. This ignores the possibility of

48. Saudi Arabia, "The Intended Nationally Determined Contribution of the Kingdom of Saudi Arabia under the UNFCCC," submitted to the United Nations Framework Convention on Climate Change, November 2015, available from <http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Saudi%20Arabia/1/KSA-INDCs%20English.pdf>.

49. Including carbon dioxide, and other gases such as methane and nitrous oxides at their CO₂-equivalent warming potential.

50. "Carbon Dioxide Emissions," in *BP Statistical Review of World Energy 2017*.

51. 2014 is considered since IEA figures are not available for 2015 and 2016, and there is a considerable unexplained discrepancy between EIA and Saudi Electricity Company figures.

52. Author's calculation from IEA consumption figures and emissions factors from IPCC, see Amit Garg and Tinus Pulles, *Draft 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol II, Energy*, available from <https://www.ipcc.ch/meetings/session25/doc4a4b/vol2.pdf>.

53. "Electricity Generation," in *BP Statistical Review of World Energy 2017*.

54. Electricity and Cogeneration Regulatory Authority, Saudi Arabia, "Station Capacities," available from <http://www.ecra.gov.sa/en-us/DataAndStatistics/NationalRecord/StationCapacities/Pages/Home.aspx>.

55. "Electricity Generation," in *BP Statistical Review of World Energy 2017*.

switching the desalination load between different periods.

Generation mix. Estimated generation costs for various generation technologies under Saudi conditions are shown below (Figure 10). These do not include transmission and distribution costs nor the cost of backup for intermittent resources. The fuel price assumed is \$7 per MMBtu and the thermal efficiency assumed is 50% for combined-cycle gas turbines (reasonable for current best-in-class under Gulf conditions), 31% for steam turbines, and 25% for gas turbines. For the purpose of calculating fuel requirements and CO₂ emissions, thermal plants are assumed to burn exclusively natural gas.

The prices for solar CSP (with 8 hours of storage) and solar PV are consistent with bids received in the UAE for recent projects, with Dubai's first CSP project attracting a bid of 9.45 ¢/kWh for 200 MW, lowered to 7.3 ¢/kWh for an expanded 700 MW plant with 11-15 hours of storage. However, since the bid cost of solar CSP at 7.3-9.45 ¢/kWh is well below previous projects (such as Morocco's Noor 3 at 15.67 ¢/kWh, despite excellent site conditions)⁵⁶, it should be regarded with caution—the project in Dubai has not yet been built or even awarded. Assumed capital cost for CSP is \$3.6 million per MW, while the reported cost for the Duba and Waad Al Shamal ISCCs is \$1.6 million per MW, albeit providing only a small amount of the plant's total capacity. The solar PV prices are more reliable given that there have been several bids around that level, as well as other sunny countries in Africa and Latin America.

There is little information on Saudi geothermal resources and costs were therefore taken for a typical U.S. project; the planned capacity is small anyway so makes little difference to the analysis.

The cost for nuclear, at about 9.1 ¢/kWh, is consistent with reported costs for the UAE's nuclear programme, although given likely cost escalation and some delays, it is probably an underestimate. It is also questionable whether Saudi Arabia would be able to plan and execute a nuclear programme as quickly and cost-effectively as the UAE, particularly given its ambitions for local content. The reported capital costs are well below those for U.S. reactors, and may represent a combination of low (or zero) land costs, lower permitting and legal costs, the absence of public opposition, lower costs for land and possibly some materials, low (government-backed) financing costs, aggressive bids from suppliers, and over-optimism.

Advanced nuclear designs may achieve costs significantly below this⁵⁷, with a (wide) range from 3.6-9 ¢/kWh and an average of 6 ¢/kWh. Some designs for small modular reactors, being investigated by Saudi Arabia in cooperation with KAERI as noted above, are included in the study quoted, and also have potential to provide nuclear power at more competitive costs. Cogeneration of desalinated water using waste heat could also improve the overall economics. However, these plants are still in design and commercial demonstration plants are a decade away, at least. The cost estimates are also for nth-of-a-kind (NOAK) plants, i.e. incorporating substantial learning from several prior constructions, and the first-of-a-kind (FOAK) plants would cost more.

The costs do not include any future cost reduction from research and development, and therefore the costs of solar and wind in particular can be anticipated to fall; as noted nuclear costs might fall if advanced designs are developed. Saudi Arabia's initial large PV tender shortlisted two bidders at 2.342 ¢/kWh and 2.66 ¢/kWh, rejecting the lowest bid of 1.79 ¢/kWh for having insufficient local content. This shows that despite the relatively smaller size (300 MW) of its plant and the fact it was its first tender, it can receive bids similar to, even slightly lower than, those achieved in the UAE. These prices are anyway amongst the very lowest offered anywhere

56. LeAnne Graves, "24-hour solar power is possible for Mena," *The National*, June 6, 2017, available from <https://www.thenational.ae/business/24-hour-solar-power-is-possible-for-mena-1.40805>.

57. Energy Options Network, *What Will Advanced Nuclear Power Plants Cost?*, Energy Innovation Reform Project, 2017, available from <http://innovationreform.org/wp-content/uploads/2017/07/Advanced-Nuclear-Reactors-Cost-Study.pdf>.

in the world. If Saudi Arabia seeks to achieve high local content targets, which was a major component of the original KA CARE plan, this would raise costs, although achieving wider development goals. On the other hand, its CSP conditions in the north-west are superior to the UAE's.

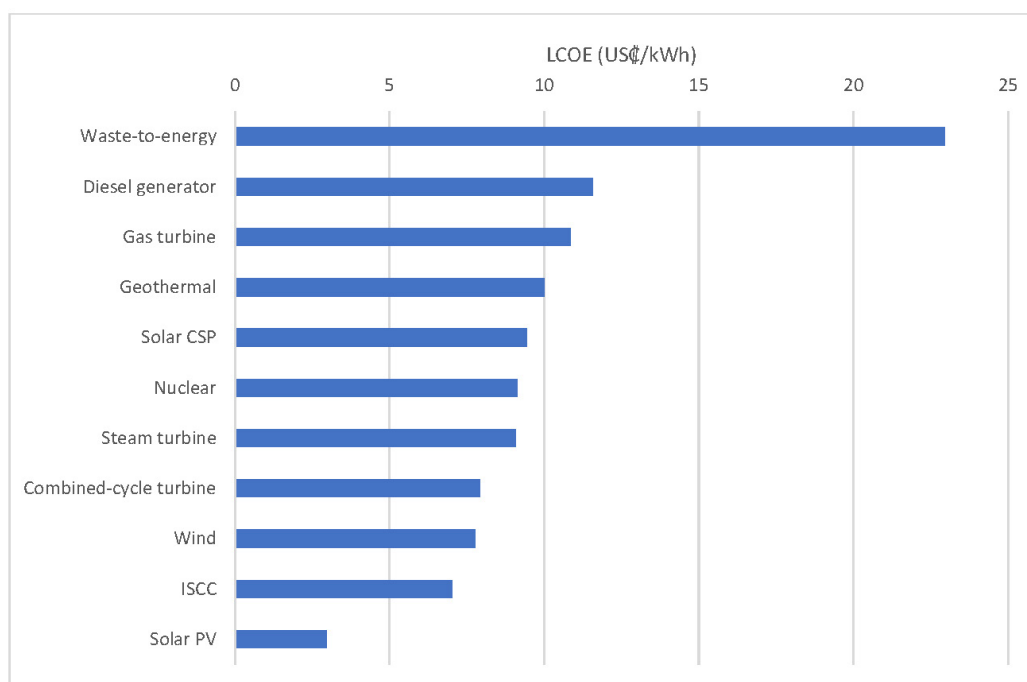


Figure 10: Generation Costs Under Saudi Conditions⁵⁸

These costs cannot be viewed simplistically in isolation, because a realistic generation mix, as discussed below, requires a blend of generation methods. However, it does indicate that, at the relatively high fuel prices assumed (comparable to current LNG prices, and well above current regulated Saudi domestic prices), high-efficiency combined cycle gas turbines are still cheaper than nuclear or solar CSP, which have very similar costs in this view. If the lower CSP prices seen in Dubai could be replicated, or even reduced given the favourable resources in Saudi Arabia, much more CSP could be included, given its capability for night-time storage. The CSP portion of ISCC plants, serving to boost their efficiency, is cheaper than a conventional CCGT and could be considered for inclusion in all suitably-located new CCGTs. Solar PV is extremely cheap, even if considered only as a means of saving fuel.

60% of household water consumption comes from desalination, with the remainder from groundwater, and desalination demand is growing at 14% per year.⁵⁹ This study has not assessed the provision of desalination in detail. One study⁶⁰ has concluded that reverse osmosis plants driven by solar PV or CSP would be slightly cheaper than reverse osmosis driven by nuclear power, and that in any case all the reverse osmosis methods are much cheaper than the multi-effect distillation or multi-stage flash which currently predominates (and which is energy-intensive). It can also be observed that reverse osmosis is more flexible as it can be run when surplus

58. Qamar Energy research and EIA.

59. Said Nachet and Marie-Claire Aoun, *The Saudi electricity sector: pressing issues and challenges*, Institut français des relations internationales, March 30, 2015, available from https://www.ifri.org/sites/default/files/atoms/files/note_arabie_saoudite_vf.pdf.

60. Rami W. Bitar and Ali Ahmad, "Solar vs Nuclear: Which Is Cheaper for Water desalination?" *AUB Policy Institute*, Policy Brief 2, February 2017, available from http://website.aub.edu.lb/ifi/publications/Documents/policy_memos/2016-2017/20170215_solar_nuclear.pdf.

electricity is available and hence function as a kind of energy storage/demand-shifting. Thermal desalination methods can be run using the waste heat from fossil fuelled or nuclear generation, but with some loss of efficiency in electricity generation.

Possible options for the 2032 generation mix are shown below. Some gas turbines have been added to the KA CARE plan to assure that peak summer daytime demand plus that the National Transformation Plan's stated 12% reserve margin can be met. Figures here assume conservatively that no wind power can be counted as firm capacity, that the GCC interconnection is not expanded, that no additional pumped hydro storage nor other storage is added, and that the Egypt interconnector is not usable to meet peak demand.⁶¹ Coal is not considered as an option due to its polluting nature, the lack of domestic or indeed regional resources, and the energy security consequences of importing it (although some studies have been carried out, there are no plans for coal use in the country).

Only CO₂ emissions from fuel combustion are considered, not life-cycle emissions for construction and fuel production. Waste-to-energy is assumed to be carbon-neutral (its contribution in any case is small and it does not vary across the scenarios considered).

The options are constructed so that daytime and night-time summer and winter demand can be met with a minimum 12% margin, and that total generation over the year is sufficient to meet total demand. Assumed maximum annual capacity factors are 90% for all thermal, nuclear, waste-to-energy and geothermal generation; 40% for solar CSP; 20% for solar PV; and 30% for wind. CSP is assumed to have 8 hours of storage so that it can meet the early evening demand peak.

The options considered are as follows:

1. KA CARE plan as described above
2. KA CARE plan but with 18 GW of combined-cycle gas turbines replacing the planned 18 GW of nuclear
3. KA CARE plan but with an additional 21 GW of CSP (taking the total to 46 GW) replacing the planned 18 GW of nuclear
4. KA CARE plan but with no nuclear, more CSP as in option (3) and with solar PV increased from 16 GW to 74 GW
5. KA CARE plan with 18 GW of nuclear and with solar PV increased from 16 GW to 64 GW of solar PV (this saturates winter daytime demand)
6. Current system expanded to meet demand with only combined cycle oil/gas generation and currently-tendered renewables
7. Maximum build-out of nuclear to meet the minimum load (winter night-time) with CCGT meeting the rest

61. This is on the grounds that, as the sun sets in western Saudi Arabia and solar output falls, Egypt would be entering its own peak evening demand period.

Capacity (GW)	Current fleet ⁶²	2032 fleet						
		(1) KA CARE	(2) KA CARE, CCGT replaces nuclear	(3) KA CARE, CSP replaces nuclear	(4) KA CARE, CSP replaces nuclear; more PV	(5) KA CARE; more PV	(6) Current system expanded	(7) High nuclear
Steam turbine	32	0	0	0	0	0	32	0
Gas turbine	38	21.64	21.64	18.64	10.34	13.33	38	23.8
Diesel generator	1	0	0	0	0	0	1	0
Combined-cycle turbine	10	60 ⁶³	78	60	60	60	73.2	68
Solar PV	0.085	16	16	16	74	64	0.3	0.3
Solar CSP	0	25	25	46	46	25	0.111	0.111
Wind	0.00275	9	9	9	9	9	0.4	0.4
Geothermal	0	1	1	1	1	1	0	0
Waste-to-energy	0	3	3	3	3	3	0	0
Pumped hydro	0	2 ⁶⁴	2	2	2	2	2	2
Nuclear	0	18	0	0	0	18	0	52
GCC Interconnection	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

62. Electricity and Cogeneration Regulatory Authority, Saudi Arabia, *Annual Statistical Booklet for Electricity and Seawater Desalination Industries*, 2015, available from http://www.ecra.gov.sa/en-us/MediaCenter/DocLib2/Lists/SubCategory_Library/ecra%20sat_book_15.pdf.

63. Assumed that all thermal generation in KA CARE plan would be combined-cycle burning either gas or diesel.

64. Not explicitly in the KA CARE plan, but under construction today

These scenarios are, of course, simplistic and ignore issues such as the finer scale of demand, seasonal correlations between wind and solar generation, the geographic location of generation and demand, and the time for plants to ramp up and down. They are conservative in ignoring options for storage (other than the planned pumped hydro and CSP), some level of firm wind capacity, new interconnections, or demand response.

The generation mixes are shown graphically in Figure 11, along with the peak summer daytime and night-time demand (plus the desired 12% reserve margin). Demand is shown with a business-as-usual case, and a case with Oliver Wyman's projected 27% decrease in demand through efficiency measures by 2032. It can be seen that the efficiency measures save about 40 GW of peak summer daytime required capacity and 33 GW of peak summer night-time required capacity. The two cases with large amounts of solar PV (4 and 5) have higher overall capacities because of the lower capacity factor of solar and the requirement for back-up generation at night.

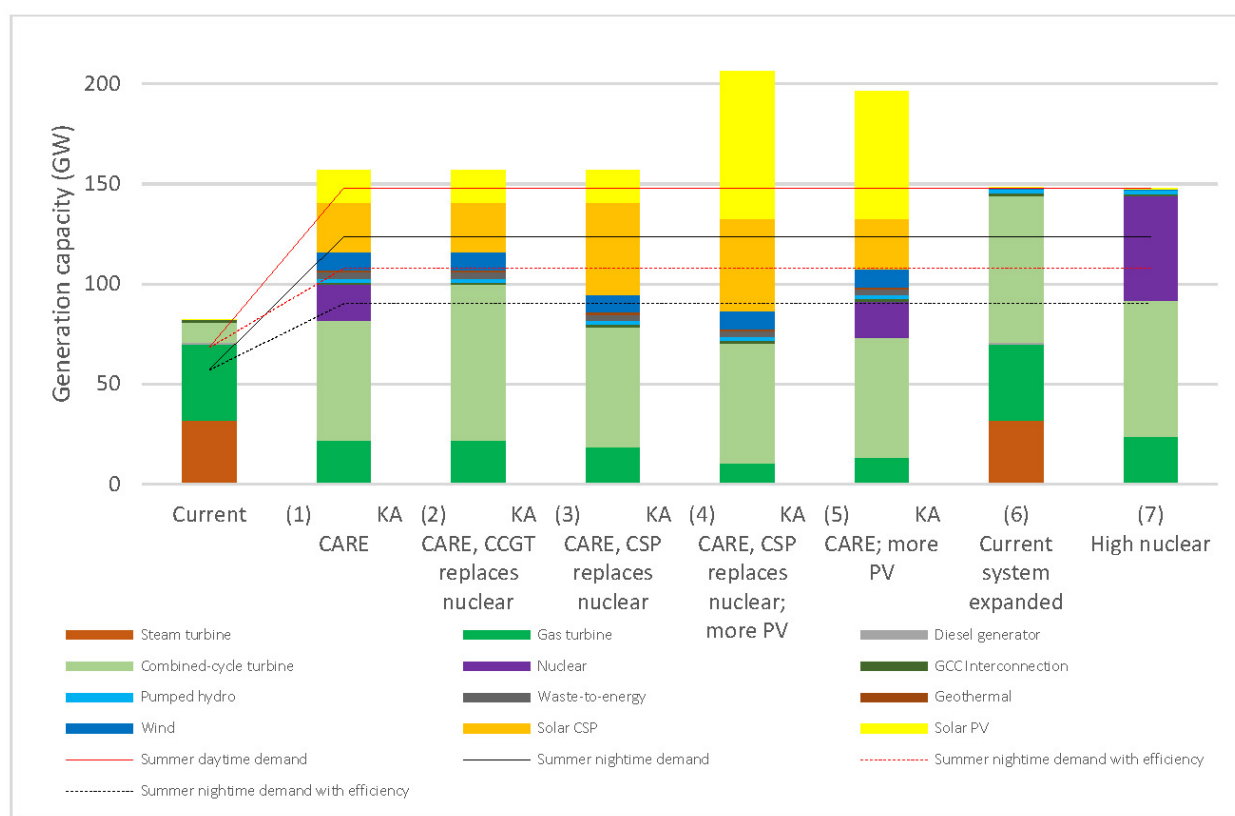


Figure 11: Generation Mixes of Different Options

Average cost per year of the electricity generated (fuel, operating, and capital cost amortisation) is shown below, along with the average gas consumption. Note that costs exclude transmission and distribution. The fuel price assumed is \$7 per MMBtu as a reasonable estimate of long-term LNG import prices or the cost of producing domestic unconventional gas. This assumes the Saudi gas market is reformed so the marginal gas supply sets the price. In this case, industrial gas demand would probably fall (or at least not rise so quickly), making more gas available. Electricity tariffs would have to be increased to avoid incurring a large subsidy burden, and this would also restrain demand. However, these additional effects have been ignored at this stage for the simplicity of comparison.

If instead Aramco's average cost of supply is used, this would be significantly lower given the contribution

of low-cost associated gas as well as large non-associated conventional fields. This would make gas-fired generation appear cheaper, but at the cost of a (hidden) subsidy from Aramco to the power sector.

Scenario	(1) KA CARE	(2) KA CARE, CCGT replaces nuclear	(3) KA CARE, CSP replaces nuclear	(4) KA CARE, CSP replaces nuclear; more PV	(5) KA CARE; more PV	(6) Current system expanded	(7) High nuclear
Average gas consumption (Bcf/day)	7.55	10.2	8.83	6.93	5.98	14.93	5.69
Annual cost (\$ billion)	62.1	60.4	61.5	56.5	58.0	58.3	61.7
Average cost of electricity	8.67	8.43	8.58	7.88	8.09	8.14	8.62
supplied (¢/kWh) ⁶⁵							
Annual CO ₂ emissions (million tonnes)	153.3	207.1	179.2	140.6	121.3	303.9	115.8

65. Excluding transmission & distribution costs.

Gas consumption is higher in all cases than current levels, since oil burning for power is assumed to be completely phased out. However, from all the options 1-5 the highest estimated gas use, in option 2, is equivalent to about 4 million TJ, while total 2014 consumption of natural gas, crude, and oil products for power generation was about 3.6 million TJ. Therefore even the most fossil-fuel intensive option only has a moderate increase in consumption while doubling generation. By contrast, the option 6, relying on the current path of fossil-fuelled generation, has much higher gas (and/or oil) consumption at about 5.75 TJ.

It is not clear what proportion of the planned increase in natural gas production is intended to be devoted to the power sector. 2014 marketed production was 9.9 Bcf/day (on OPEC/BP figures; as noted, the IEA is lower) of which 4.6 Bcf/day goes to power generation, or 47% (as noted, on the IEA's figures, the share is 56%). An increase to 23 Bcf/day gross gas production by 2026, if then held constant to 2032, with an implied 20 Bcf/day of marketed gas, would mean that in the above options 1-5, power generation would consume 30-51% of available gas, while all current oil consumption for power would be freed up for export or other uses. Available gas for industry or other uses would increase from about 5 Bcf/day in 2014 to 10-14 Bcf/day in 2032, which seems sufficient to meet substantial growth. Therefore all these scenarios seem reasonable in terms of gas use, assuming the production targets are met, or domestic production is supplemented with imports. By contrast, option 6 would consume 75% of marketed gas, leaving little for industry.

If gas production only remained constant at current levels, then it could be supplemented with oil for power. Combined-cycle gas turbines would in principle have to run on clean fuels (diesel) which is significantly more expensive. However the total quantities of liquid fuels burnt in options 1-5 would be less than today's quantities except in option (2) where they would be slightly larger and (3) where they would be similar. In the fossil-fuelled current path with gas production at today's levels, oil burning would reach about 1.8 million barrels per day.

It can be seen that the five renewable/nuclear options are all rather similar in cost, since the estimates used here for CCGT (at \$7 per MMBtu gas), CSP, and nuclear are very close. However, adding additional PV does bring down the total cost by saving gas, given its very low costs. Adding more wind, which would also contribute at night, would also reduce gas consumption and total costs. These options are vulnerable to CSP costs, given the uncertainty in its price levels and that it is relied on to contribute to meeting summer evening peak demand. If it turned out to be significantly more expensive, then more gas-fired and/or nuclear generation would be required. Arguably about 6-7 GW of CSP is possible at low cost by hybridisation with combined-cycle gas plants, if suitable land is available near the plants. The fossil-fuelled option (6) is also similar in cost, assuming that the required volumes of fuel are available. The nuclear-heavy option (7) has a somewhat greater cost given the higher (but still probably over-optimistic) cost of nuclear assumed.

All the renewable/nuclear plans represent substantial reductions in CO₂ emissions compared to the estimated 232 million tonnes of electricity-related emissions in 2014, despite much higher total generation. This is achieved by switching entirely to natural gas instead of oil, using more efficient combined-cycle gas turbines almost exclusively, and introducing low/zero-carbon generation. Savings range from 25-112 million tonnes of CO₂ per year versus 2014, while the high nuclear (7) produces slightly less CO₂ than the most aggressive renewables option. The fossil-fuelled option (6) sees a substantial rise in CO₂ emissions, despite the use of high-efficiency CCGTs and the (assumed) replacement of all oil-fuelled generation with gas. If insufficient gas were available, the use of oil would raise emissions further.

Replacing nuclear with CCGT or solar CSP raises CO₂ emissions significantly (since solar CSP has a lower assumed load factor and hence the CCGTs run more). However, the option with much more solar PV is not only cheaper overall but has somewhat lower emissions than the KA CARE case with nuclear. Lowest emissions of all are achieved in the case with both nuclear and increased PV.

All these options would also greatly reduce most other pollutants, notably sulphur oxides from heavy fuel oil, assuming that the primary fuel is gas.

The pace of generation construction in the options presented amounts to 3.6-8.9 GW of renewables per year during 2018-2032, and up to 1.8 GW of nuclear per year (assuming a 2022 start) in the KA CARE case. This would be a significant acceleration on the current tenders for 1.7 GW of renewables. Solar capacity added in Germany per year reached a maximum of about 7 GW between 2010-12.⁶⁶ The UAE began constructing its 1.4 GW reactors in 2012 and the first is due online later in 2017. The high nuclear option (7) would require 52 GW of nuclear to be installed in 10 years (France has 63 GW total installed), a pace comparable to installing almost the UAE's entire nuclear programme (5.6 GW) every year from 2022 to 2032. This appears completely implausible, and therefore the option is shown only for illustration.

Therefore while the renewables and the lower nuclear installation rates appear plausible, they are challenging and would require a quick start with a minimum of bureaucratic delay. More reliance on local content would also slow the programme. However, both renewables and nuclear appear to face similar challenges in terms of installation pace.

All these options assume a quite rapid conversion of current generating plant to combined-cycle operation and/or the construction of new CCGTs. The current fleet of 32 GW of steam turbines, 38 GW of gas turbines and 10 GW of CCGT has to be converted to 60-78 GW of high-efficiency modern CCGT by 2032 plus 10.3-21.6 GW of gas turbines for peaking use. If older plants are retained in service or not converted, the efficiency would be lower and hence more oil/gas fuel would be required. This study has not assessed how much of the existing fleet would be suitable for conversion to CCGT. However, even if all the additional CCGT capacity had to be newly-built, the rate of 3.5 GW per year is still feasible as thermal generation capacity has been rising at about this rate historically.

Efficiency. Energy use in Saudi Arabia is highly inefficient by global standards. At 6.7 tonnes of oil-equivalent per capita in 2013, the 13th-highest in the world, it was slightly behind the United States (7 toe/capita) but well ahead of the EU (3.2 toe/capita) and the world average (1.9 toe/capita). As opposed to most countries, whose energy intensity has been falling, Saudi energy intensity has been rising and reached 137 toe per \$1000 of GDP in 2011, ahead of 95 toe per \$1000 of GDP in the EU.⁶⁷

Saudi Arabia has launched the Saudi Energy Efficiency Center, to develop the Saudi Energy Efficiency Policy, an inter-agency effort. This is focussed on industry, buildings, and transport, primarily by means of benchmarking and standards. Studies have been conducted for a national District Cooling Company and a national Energy Services Company (ESCO). The programme's overall aim is to increase electricity efficiency by 30% by 2030. Building codes have been strengthened, though this will take a long time to have an impact on the existing stock, and monitoring and compliance is likely to be lacking initially.

Areas for gains in efficiency include air-conditioning, in particular, as by far the biggest user of electricity. District cooling use is low in Saudi Arabia, at less than 5%, versus 30% in Dubai.⁶⁸ More efficient air-conditioners, better maintenance, and improved insulation are being targeted (70% of existing build-

66. "Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland," (in German), available from <https://www.bundesverband-bioenergie.de/application/files/6414/9129/3615/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2016.pdf>.

67. Said Nachet and Marie-Claire Aoun, *The Saudi electricity sector: pressing issues and challenges*.

68. Saudi Energy Efficiency Center, "Saudi Energy Efficiency Program," Presentation, September 2016, available from <http://www.swedishepa.se/Documents/konferensdok/hfc2016/04-saad-saudi-presentation-updc-focus-areas-r.pdf>.

ings are not insulated).⁶⁹ Other promising areas include public transport such as the Riyadh Metro, under construction; appliance and vehicle efficiency standards; more efficient lighting; solar water heating; and heat pumps which could drive absorption chillers as well as providing space- and water heating.

One KAPSARC study suggests that a building retrofit programme could save 3.7-22.9 GW of peak electricity capacity, depending on the level of retrofit, with reasonably attractive payback periods, depending on the electricity price⁷⁰, though the payback periods are rather long for the higher levels of ambition.

An Oliver Wyman study⁷¹ concluded that efficiency could cut 27% of electricity demand from the 2030 baseline (with technical feasibility up to 56%), at an assumed electricity price of 10 ¢/kWh (comparable to the numbers calculated above, particularly when transmission and distribution costs are added). If the drop in peak demand by 2032 is proportionate, then it would be reduced from 132 GW to 96 GW; i.e. the annual growth rate would fall from 5% to 2.5%.

Such efficiency gains would substantially improve the feasibility of meeting Saudi Arabia's electricity demand without nuclear power, as they would reduce the required pace of renewable and/or CCGT construction, and save on fuel demand and CO₂ emissions. Achieving efficiency gains is, though, very dependent on continuing to reform and reduce subsidies, as the low electricity and water prices do not encourage energy-saving behaviour or the use of efficient construction and equipment, and replacing them with a more targeted form of social support.

Solar

Saudi Arabia has among the best conditions for solar power in the world. Global horizontal irradiance (relevant for photovoltaic power) in Riyadh is 2242 kWh/m² per year (Figure 12), while direct normal irradiance (relevant for concentrating solar thermal power, CSP) is 2116 kWh/m² per year (Figure 13). For comparison, San Diego has 1964 kWh/m² and 2242 kWh/m² respectively. The western parts of Saudi Arabia are superior for CSP as the climate along the Gulf can be hazy and dusty.

69. International Energy Agency, "Energy Efficiency Standards and Mandates, Saudi Arabia," available from <https://www.iea.org/policiesandmeasures/pams/saudiarabia/name-147402-en.php>.

70. Kankana Dubey, Nicholas Howarth, and Moncef Krarti, *Evaluating Building Energy Efficiency Investments Options for Saudi Arabia*, The King Abdullah Petroleum Studies and Research Center, 2016, available from https://www.kapsarc.org/wp-content/uploads/2016/10/KS-1655-DP049A-Evaluating-Building-Energy-Efficiency-Investment-Options-for-SA_web.pdf.

71. Marc Hormann, Joern Carlos Kuntze, and Jad Dib, "Delivering on the Energy Efficiency Promise in the Middle East," *Oliver Wyman*, 2013, available from http://www.oliverwyman.com/content/dam/oliver-wyman/global/en/files/archive/2013/Energy_Efficiency_inMiddleEastFINAL.pdf.

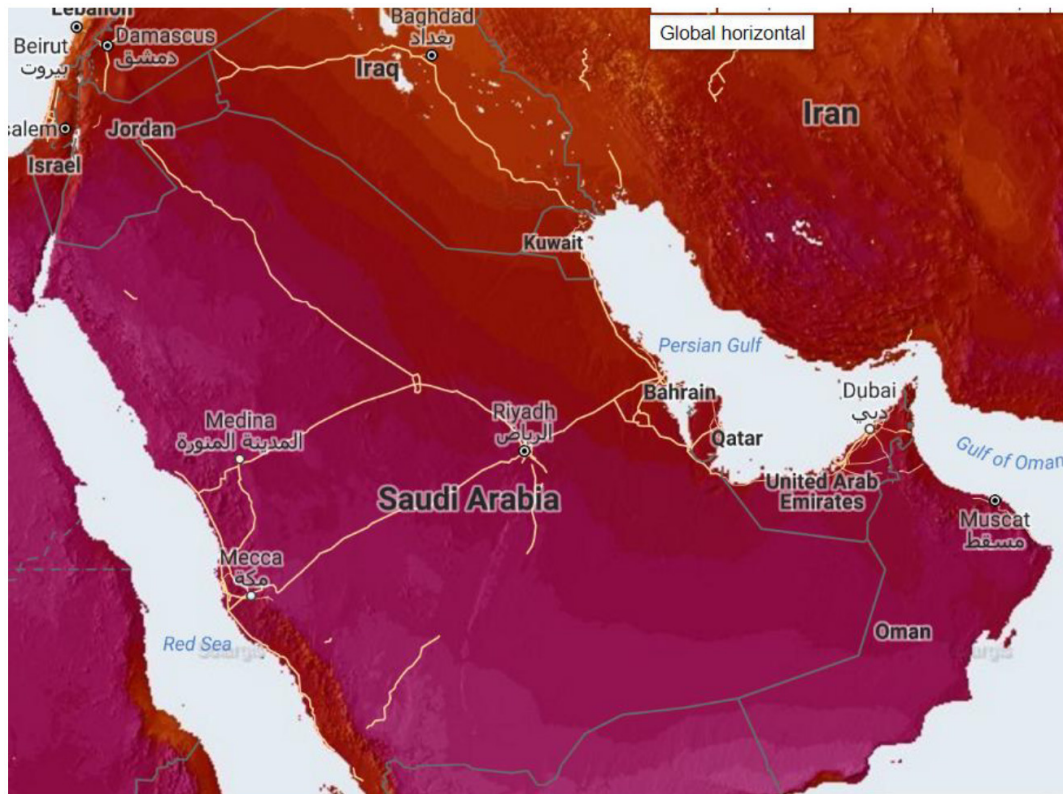


Figure 12: Global Horizontal Irradiation⁷²

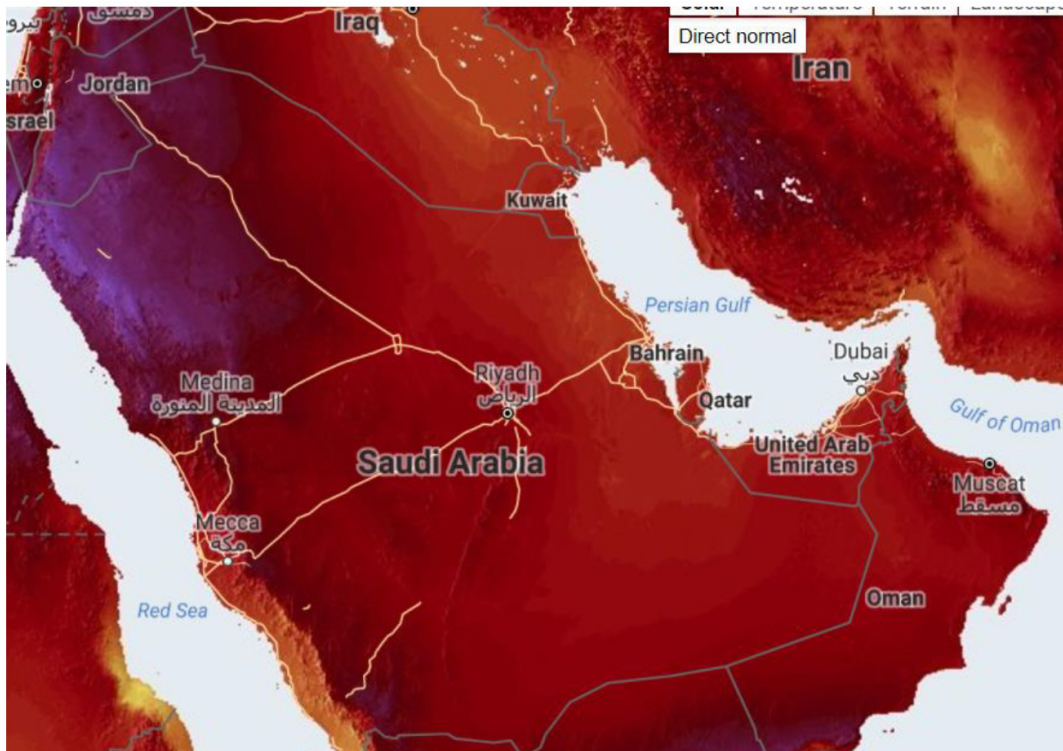


Figure 13: Direct Normal Irradiation⁷³

72. Solargis map available from <https://solargis.info/imaps/#c=25.918526,41.813962&z=5>.

73. Solargis map available from https://solargis.info/imaps/#tl=GeoModel:dni_yr_avg&c=24.806682,42.604978&z=5.

As can be seen from the maps, conditions for solar PV in Saudi Arabia are at least as good as in the UAE which has launched several very successful and cost-competitive solar projects to date. Conditions in the west of the country actually appear to be superior. Conditions for CSP are similar to those in the UAE, except in the north-west where they are superior.

Concerns are often raised about the impact of dust and blown sand on the effectiveness of solar PV in the Gulf. Experience in the UAE suggests that these issues are manageable with a careful cleaning schedule and do not add significantly to operating costs.⁷⁴ Given low population densities in much of the country, and large tracts of arid land with little alternative use, finding suitable cheap land for large solar installations should not be problematic although some transmission costs may have to be incurred.

The Saudi population is concentrated on the east coast (around the oil and industrial centres of Dammam, Dhahran and Jubail), the centrally-located capital Riyadh, and the west coast with the holy cities of Makkah and Madina, the port of Jiddah and industrial city of Yanbu' (Figure 14 – this is for the year 2000 so the population has grown substantially but the overall pattern remains similar). Current demand is roughly evenly split between east, centre and west (~16 GW peak demand each) with a remaining ~10 GW in the south and Yanbu' Industrial City.⁷⁵

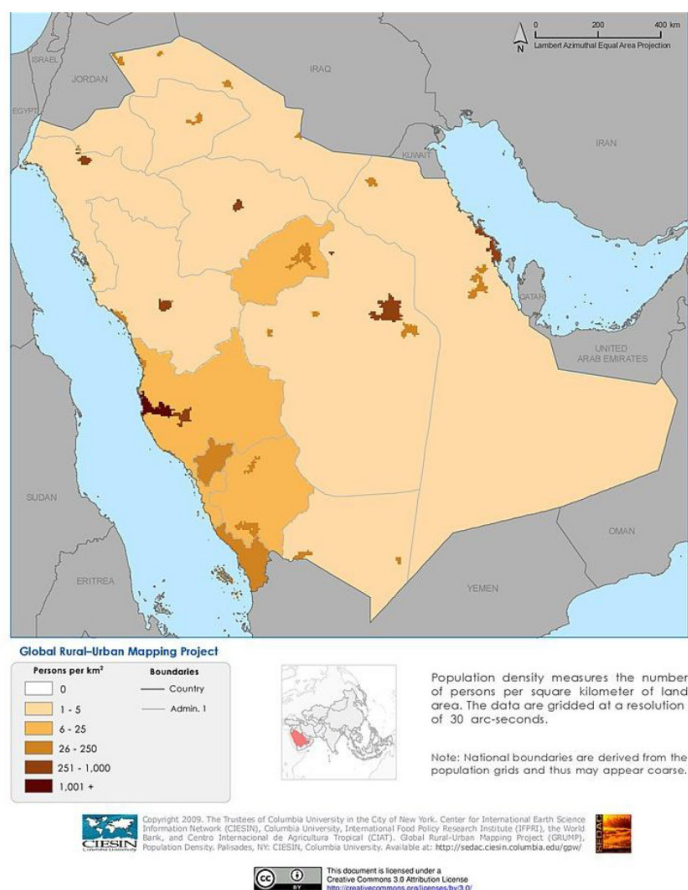


Figure 14: Saudi Arabia Population Density⁷⁶

74. First Solar and Masdar personnel, personal communication.

75. Abdulrahman Al Ghabban, "Saudi Arabia's Renewable Energy Strategy and Solar Energy Deployment Roadmap."

76. Socioeconomic Data and Applications Center, NASA, "Population Density Grid," available from <http://sedac.ciesin.columbia.edu/data/set/grump-v1-population-density/maps/6>.

The difference in sunset times between Dammam on the east coast and the industrial city of Yanbu' on the west coast is about 40 minutes in summer. There is thus some scope for solar generation in the west to serve the east's early-evening peak demand. The large concentration of population in the west would, however, require another solution. This could be via the new interconnector to Egypt, if surplus capacity is available there at the right time.

Wind and Other Renewables

The best Saudi wind resource is located on the west (Red Sea) coast, especially in the north-west around Tabuk (Figure 15). In most sites investigated, wind speed does not show much monthly variation.⁷⁷

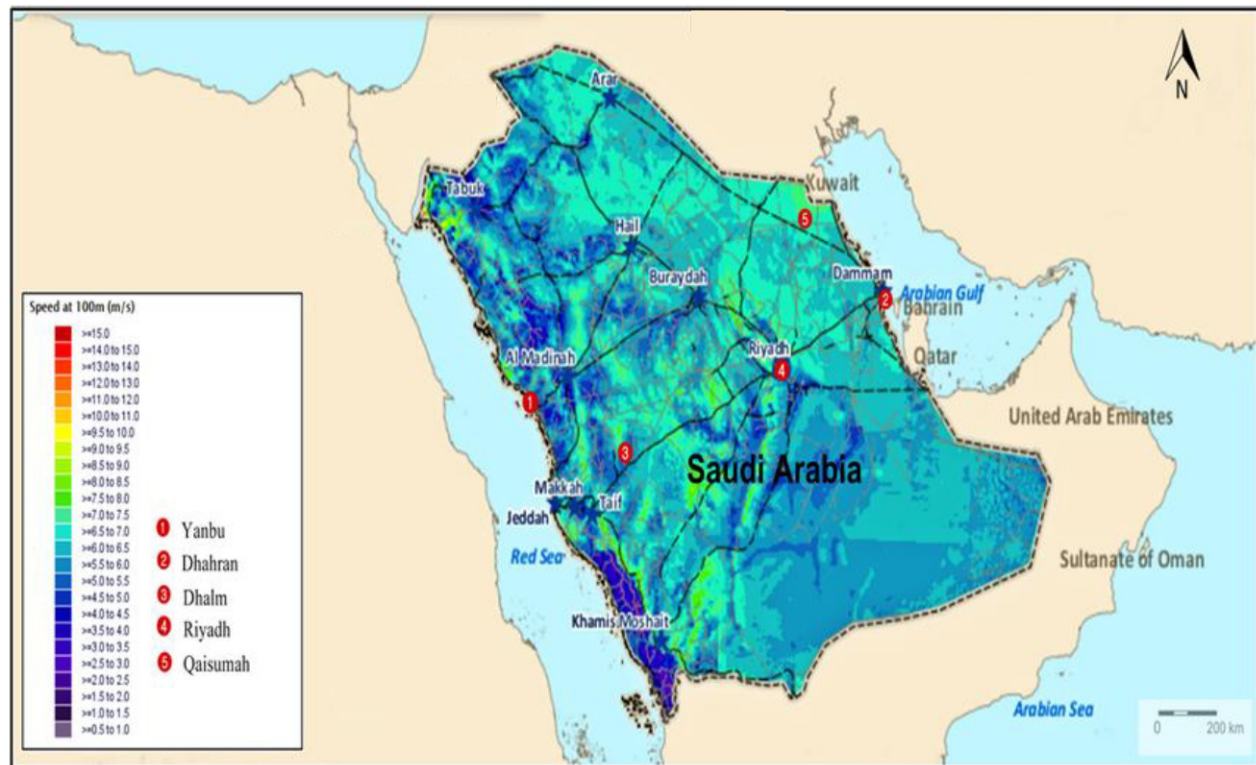


Figure 15: Map of Saudi Wind Resource⁷⁸

It is assumed here that the 9 GW target given by KA CARE is feasible in terms of total capacity of suitably windy sites. No information was identified as to the ultimate wind power potential in Saudi Arabia. With relatively low wind speeds over most of the country, larger amounts of wind power may be possible but with higher costs.

77. Lekshmi Vijayan Krishna and Fatema Abdulla Al Thalhi, "Solar and Wind Energy Potential in the Tabuk Region, Saudi Arabia," *International Journal of Applied Science and Technology* 5, no. 3, June 2015, available from http://www.ijastnet.com/journals/Vol_5_No_3_June_2015/2.pdf.

78. Mohamed, Mohamed & Eltamaly, Ali & Alolah, Abdulrahman, "PSO-Based Smart Grid Application for Sizing and Optimization of Hybrid Renewable Energy Systems," *PLOS ONE* 11, 2016, available from https://www.researchgate.net/figure/Wind-speed-in-Saudi-Arabia-at-the-height-of-100-m_fig17_306068825.

Geothermal potential is present around Jizan in the south-west where there are hot springs⁷⁹, and in various granites in the west of the country with high heat-flow.⁸⁰ Lower-temperature resources may be useful for thermally-driven cooling or desalination. Estimated potential generation is 3-5 GW and hence it is assumed here that the KA CARE target of 1 GW by 2032 is feasible.

Different studies estimate waste-to-energy potential by 2032 of 1.447-2.074 GW.⁸¹ However a recycling policy would substantially reduce this potential (though it would be better for life-cycle emissions). The KA CARE target of 3 GW may therefore be somewhat ambitious and up to 1-3 GW of other generation may be required instead. However the KA CARE target has been used here as the impact is relatively small and it does not vary between scenarios.

Energy Storage

Saudi Arabia is currently constructing two 1000 MW pumped storage facilities on the west (Red Sea) coast, one using seawater and the other desalinated water⁸², with storage of 8 hours (implying 8000 MWh). Additional sites have been identified and so more storage could probably be installed if required.⁸³

As noted, integrated thermal storage was also assumed for the CSP plants included in the generation mix above.

Other storage options, such as batteries, have not been evaluated here, but could be useful in balancing demand and renewable output. Particularly appropriate to the Saudi climate is thermal storage, mainly for air-conditioning given its large share of load, which would be more effective if building insulation is improved. Thermal storage can include pre-cooling buildings before the hottest part of the day; or making ice in low-demand periods (typically at night) to provide cooling during the day. Thermal storage can be integrated with district cooling plants, which are anyway inherently more efficient than individual cooling units. Another option is to use reverse osmosis plants for desalination in low-demand periods, and store the water, as noted above.

79. Alexander Richter, "Saudi Arabia eyeing geothermal energy for future energy mix," *Think Geoenergy*, January 23, 2017, available from <http://www.thinkgeoenergy.com/saudi-arabia-eyeing-geothermal-energy-for-future-energy-mix/>.

80. Aref Lashin, et al., "Geothermal Energy Resources of Saudi Arabia: Country Update," Presented at World Geothermal Congress 2015, Melbourne, Australia, April 19-25, 2015, available from http://www.bu.edu.eg/portal/uploads/Science/Geology/3501/publications/Aref%20Adel%20Ahmed%20Elaraby%20Lashin_01014.pdf.

81. O.K.M. Ouda, et al., "Waste to energy potential: A case study of Saudi Arabia," *Renewable and Sustainable Energy Reviews* 61, 2016, pp. 328-340, available from <https://www.sciencedirect.com/science/article/pii/S1364032116300223> and Ouda, O.K.M. 'Assessment of Waste-to-Energy Potential in Saudi Arabia as Electricity Source & Environmental Protection Measure' Prince Mohamed Bin Fahd University.

82. "AF is awarded a new contract for consulting services for Pumped Storage Hydro Power Plant in Saudi Arabia," October 9, 2015, available from <http://www.afconsult.com/en/newsroom/press-releases/all/2015/af-is-awarded-a-new-contract-for-consulting-services-for-pumped-storage-hydro-power-plant-in-saudi-arabia/>.

83. Willy Kotiuga, et al., "Pre-Feasibility Study of a 1000 MW Pumped Storage Plant in Saudi Arabia," available from <https://www.slideshare.net/SNC-Lavalin/130715-hydrovision-paper-v3>.

Security

Despite some terrorist incidents, the physical security of Saudi Arabia's oil installations has been assured by extensive defensive measures. There is therefore no unusual security risk to relying on domestic oil and gas output for energy, except in case of a total breakdown in national security (which would also badly affect demand). Large, dispersed renewable energy sites do not present a single point of failure and hence would also not be particularly vulnerable to security threats, although long-distance transmission lines could be threatened.

Any strategy depending on imports of natural gas, LNG (or coal) could be vulnerable to various supply disruptions such as boycotts, sanctions, unrest in exporting countries, or threats to maritime supply routes through the Gulf and Red Sea.

Nuclear power plants would, like the oil facilities, likely be highly fortified and built to withstand some level of plausible attacks or natural disasters. Of the sites proposed so far, Jizan is near Yemen and may be problematic given the continuing war there and some cross-border incursions and reported missile attacks. Jubail is in the Eastern Province, with a large Shi'ite Muslim population which has often complained of discrimination and where unrest is frequent. It is also relatively close to Iran with whom Saudi Arabia has poor relations at present. The third site, at Tabuk in the north-west, is relatively close to Israel, which presumably would be expected to agree tacitly to a Saudi civil nuclear endeavour, but otherwise does not present any obvious security concerns.

Conclusions

Saudi Arabia's fast-growing energy demand and heavy reliance on oil and gas for power generation have led to investigations of nuclear power as one component of its future energy mix. Nuclear power has been under consideration for a long period, with frequent changes of plan. Both nuclear and renewable energy have made little headway, but several tenders for solar and wind projects have recently been launched.

This study has assessed options for meeting Saudi Arabia's future energy mix, primarily considering electricity. Based on the original KA CARE plan, a number of plans with varying mixes of renewables, nuclear and fossil fuels are considered. These scenarios suggest that the 2032 demand can be met with a mix of gas-fired (highly efficient CCGT) and renewable energy at a cost comparable to, indeed slightly lower than, options including nuclear. Proposed renewable build-out rates are ambitious but should be achievable. The proposed renewable mix is primarily solar (CSP and PV), for which Saudi Arabia has excellent resources. Both the renewable and nuclear mixes deliver substantial declines in CO₂ emissions, with most oil eliminated from the power sector, and moderate increases in gas demand that should be achievable within Aramco's gas production targets.

These options do not assume significant gains in energy efficiency, which would further reduce costs, CO₂ emissions and required construction pace, nor do they optimise energy storage, or allow for continuing cost reductions in renewable (or nuclear) energy.

Nuclear power may have other strategic, technological or development-related attractions for Saudi Arabia. However, overall, it appears that it would be economically, practically, environmentally and organisationally feasible for it to meet its energy needs without resort to nuclear power.

Section III: Should the United States Be “Flexible” in Allowing Riyadh to Reprocess and Enrich?

Chapter 6

Don't Give Saudi Arabia an Easy Path to Nukes¹

Victor Gilinsky and Henry D. Sokolski

U.S. Secretary of Energy Rick Perry and Saudi Energy Minister Khalid al-Falih are about to meet in London to discuss a nuclear agreement that would allow Riyadh to enrich uranium and extract plutonium in return for American companies getting a chance to build nuclear reactors in Saudi Arabia. Inevitably, comparisons will be made with the 2015 Iran nuclear agreement, which permitted limited uranium enrichment.

But the current debate over this deal is missing the most important point: The issue isn't whether it's fair to constrain the Saudis more than the Iranians, or whether there is an opportunity to revive U.S. nuclear manufacturing, or to thwart Russian and Chinese influence in the Middle East. It's that giving Riyadh a pass on tight nuclear nonproliferation rules would be playing with fire.

Despite its denials, Saudi Arabia's resistance to restrictions on uranium enrichment and plutonium extraction amounts to a public declaration that the kingdom wants to keep a nuclear weapons option open.

This is certainly the way Iran's program has been viewed. It's also why Riyadh wants this option; it is engaged in a struggle with Iran for regional dominance. But the U.S. government shouldn't condone it. Any nuclear agreement worth striking with Saudi Arabia must be at least as tight as the one Washington has with its neighbor the United Arab Emirates, which prohibits enrichment and reprocessing.

The Saudi regime's past behavior provides ample reason to insist on strict rules for nonproliferation. It was Riyadh, remember, that funded the development of Pakistan's nuclear arsenal.² The United States should demand nothing less than what is seen as the nonproliferation gold standard for such agreements: no uranium enrichment and no extraction of plutonium.

The Saudis also possess the missiles needed to deliver nuclear weapons, should they ever acquire them. In the 1980s, they bought long-range DF-3 "East Wind" missiles from China—missiles that are designed to carry nuclear weapons—without informing the United States.³ Then, 10 years ago, they bought newer nuclear-capable Chinese missiles. They designated the Royal Saudi Strategic Missile Force as one of the five branches of the Royal Saudi Arabian Armed Forces, responsible for commissioning long-range mis-

1. This piece originally appeared as Victor Gilinsky and Henry Sokolski, "Don't Give Saudi Arabia An Easy Path to Nukes," *Foreign Policy*, March 1, 2018, available from <http://foreignpolicy.com/2018/03/01/dont-give-saudi-arabia-an-easy-path-to-nukes/>.

2. Julian Borger, "Pakistan's Bomb and Saudi Arabia," *The Guardian*, May 11, 2010, available from <https://www.theguardian.com/world/julian-borger-global-security-blog/2010/may/11/pakistan-saudi-arabia>.

3. Jeffrey Lewis, "Why Did Saudi Arabia Buy Chinese Missiles?," *Foreign Policy*, January 30, 2014, available from <http://foreignpolicy.com/2014/01/30/why-did-saudi-arabia-buy-chinese-missiles/>.

siles. What is often left unsaid is that these missiles only make sense if armed with nuclear weapons.

Saudi Arabia is neither a stable state nor a benign actor in the Middle East that deserves U.S. coddling.

The U.S. government portrays Saudi Arabia as a partner in the fight against Islamic extremism, but the truth is that the Saudis have been the main purveyors of the fundamentalist religious doctrines that have spread the seeds of terrorism throughout the Arab world. Indeed, the Saudi-supported brand of Islam, Wahhabism, has served as inspiration for many of the world's most violent terrorists.⁴

But the most important reason for caution about any nuclear deal with Saudi Arabia is that it is unlikely to survive for long in its current form, because Saudi Arabia's ruling family is remarkably unstable. An absolutist monarchy that represses minorities, chops off heads of political opponents, and lacks a codified system of law is out of step with 21st-century reality. It rests on a shaky foundation. It is unclear whether a future regime that replaces the current monarchy would be friendly to U.S. interests. What is clear is that any new regime would inherit whatever nuclear technology and materials the current government acquires. It is worth recalling that the Shah of Iran was considered a good friend and a modernizer before being deposed in the 1979 revolution—and that the United States once supported a nascent nuclear program during his rule.

The United States shouldn't get carried away by Saudi Crown Prince Mohammed bin Salman's reported efforts to modernize the country, in particular the highly advertised decision to let women drive. More significant is his extremely poor judgment in getting involved in a war in Yemen, and his zeal for confronting Iran. His method of shaking money out of Saudi billionaires, meanwhile, should raise concerns about the kingdom's financial situation.

A nuclear cooperation agreement pursuant to the U.S. Atomic Energy Act—which is different from the political understanding reached with Iran—would last for decades, and any enriched uranium and plutonium explosives produced under it would last indefinitely.

If the United States cuts a deal with Riyadh on nuclear power, it must restrict Saudi nuclear activity strictly to generating electricity.

The Saudis don't need uranium enrichment for this. The United States doesn't even have a U.S.-owned uranium enricher, and there is no country today operating nuclear power plants that needs to separate plutonium. Any interest in doing so raises obvious questions about ulterior military motives.

The existing U.S. deal with the United Arab Emirates, which is just completing construction of four nuclear power reactors, should serve as a model for the type of tight restrictions that should be placed on Saudi Arabia's nuclear energy program. It meets the exigencies of international security while imposing no economic penalties.

4. "What is Wahhabism? The reactionary branch of Islam from Saudi Arabia said to be 'the main source of global terrorism,'" *The Telegraph*, May 19, 2017, available from <https://www.telegraph.co.uk/news/2016/03/29/what-is-wahhabism-the-reactionary-branch-of-islam-said-to-be-the/>.

Chapter 7

Want Nuclear Controls on Riyadh? Start with Seoul¹

Victor Gilinsky and Henry D. Sokolski

The Trump administration is on the verge of signing a nuclear agreement with Saudi Arabia that is reportedly “flexible” on Saudi acquisition of centrifuge technology to enrich uranium—the technology that can provide material for nuclear weapons and that was the central concern in regard to Iran’s nuclear program. This flexibility is necessary, the administration argues, to ensure the Saudis choose Westinghouse as their nuclear power reactor supplier. But Westinghouse, which performed abysmally on its last two U.S. projects and is in bankruptcy as a result, is far less likely to win the bid than the South Korean construction firm whose work force is coming off successful completion of a large nuclear project nearby in the United Arab Emirates. This increases the importance of striking a tight U.S.-Saudi agreement to ensure the Saudis don’t get to enrich under their nuclear cooperative agreement with Seoul.

The administration’s pitch that Congress should go along with “flexibility” pulls out all the usual bogey-men. Energy Secretary Rick Perry told the Senate Armed Services Committee on March 22 that, “Either Russia or China is going to be a partner in building civil nuclear capability in the Kingdom of Saudi Arabia, or the United States.”² The Saudis, guided by several Washington lobbying firms, have been pushing this line, which much of the Washington establishment has swallowed, adding that allowing Moscow to gain a nuclear foothold in Saudi Arabia would deal a serious blow to U.S. regional influence and prestige.

But the Saudis are not so foolish as to choose Russia or China. Moscow is nuclear supplier to Saudi Arabia’s foe, Iran, and Beijing has yet to bring a power reactor online outside of China. The Saudis already have a significant history of nuclear involvement with South Korea. They signed an agreement for “cooperation in the peaceful uses of nuclear energy” in 2011 and a memorandum of understanding in 2015, with a view to buying two smaller, so-called small modular (SMART) Korean reactors.³ Dozens of Saudis have gone to South Korea for nuclear training.⁴

1. This piece originally appeared as Victor Gilinsky and Henry Sokolski, “Facing reality in the US-Saudi nuclear agreement: South Korea,” *Bulletin of the Atomic Scientists*, April 10, 2018, available from <https://thebulletin.org/facing-reality-us-saudi-nuclear-agreement-south-korea11683>.

2. Ari Natter, “U.S.’s Pass on Saudi Reactors Benefits China, Russia, Perry Says,” *Bloomberg*, March 22, 2018, available from <https://www.bloomberg.com/news/articles/2018-03-22/u-s-pass-on-saudi-reactors-benefits-china-russia-perry-says>.

3. Andrew Roscoe, “Exclusive: Saudi Arabia Shortlists Two Sites for First Nuclear Power Project,” *Middle East Business Intelligence*, January 22, 2018, available from <https://www.meed.com/exclusive-saudi-arabia-shortlists-two-sites-first-nuclear-power-project/>.

4. Ghazanfar Ali Khan, “Kingdom makes significant progress in nuclear reactors: Envoy,” *Arab News*, March 17, 2017, available from <http://www.arabnews.com/node/1069531/saudi-arabia>.

In these circumstances, the enrichment provision in the 2011 Saudi-South Korean agreement is of vital concern.⁵ It reads as follows: “Uranium transferred pursuant to this Agreement or used in any equipment so transferred shall not be enriched to 20 percent or more in the isotope U-235 unless the Parties otherwise agree.” In other words, the 2011 agreement permits installation of Saudi enrichment facilities generally, and in particular the enrichment to 20 percent of uranium supplied under the agreement. A reason this is worrying—and was worrying in the case of Iran—is that, although it may seem counter intuitive, to further enrich the 20 percent product to a bomb explosive level takes only an additional one-tenth of the work it took to get to 20 percent. It becomes especially worrying when coupled with the Saudi Crown Prince’s hair-trigger promise (see this 60 Minutes interview)⁶ that if Iran got a bomb, the Kingdom would, too, “as soon as possible.”

This means that if we intend to bar Saudi Arabia’s path to nuclear weapons, and we absolutely should, we have to insist on a provision in our agreement with Saudi Arabia like that included in the agreement with its UAE neighbor: That the country will not engage in its territory in activities related to enrichment or reprocessing (extracting plutonium from spent nuclear fuel—the other path to a bomb). And we need to make sure South Korea agrees to hold off on moving forward on Saudi reactors until such a provision is in place.

Why would Saudi Arabia agree to such a restrictive provision? And why would South Korea agree to cooperate in ensuring it is in place. The short answer is that both countries depend on our protection. If we can pressure countries on trade terms—something the administrations brags about—surely, we can do so in the interest of security. As U.S. Sen. Jack Reed, ranking member of the Armed Services Committee, said in response to Perry’s testimony, “The proliferation dangers are so great that we should be able to wield all of the influence we have, which goes way beyond just this one transaction, to insist [on the] same standards we applied to the Emirates.” And as President Gerald Ford said many years ago, “nonproliferation objectives must take precedence over economic and energy benefits if a choice must be made.”

This of course assumes the administration adheres to the traditional U.S. policy objective of preventing the spread of nuclear weapons, even among friends. An especially worrying aspect of this entire affair is that there seems to be a sense, born of hostility to Iran, that a Saudi nuclear weapon option might not be such a bad thing—in fact that it might even be useful to frighten Iran. All that can be said about such thinking is: This way lies chaos. We should move in the opposite direction, starting with barring Saudi Arabia from getting nuclear weapons.

5. “Agreement between the Government of the Republic of Korea and the Government of the Kingdom of Saudi Arabia for Cooperation in the Peaceful Uses of Nuclear Energy,” available from http://npolicy.org/files/123_Agreement_ROK_Saudi.pdf.

6. “The Saudi Crown Prince Talks to 60 Minutes,” *CBS News*, March 18, 2018, available from https://www.cbs.com/shows/60_minutes/video/QBSli_U_PPAJyYuZgvJIEI44rZxYTE23/the-saudi-crown-prince-talks-to-60-minutes/.

Chapter 8

Why Nuclear Cooperation Agreements Need “Gold Standard” Protection

Victor Gilinsky

It has always been clear that if we are going to spread nuclear power plant technology worldwide, we have to make sure it won't lead to bombmaking. With time we learned that this was harder to do than we at first thought. We've had to upgrade requirements that countries had to meet to provide reasonable assurance that their nuclear activities were strictly peaceful. The upgrades didn't come easy, as enthusiasts for nuclear energy export both in and out of government tried to preserve the status quo. The question of how much protection is needed is now coming to a head again, this time over a proposed U.S.-Saudi nuclear cooperation agreement: The issue is whether the agreement should contain a ban on nuclear fuel technologies whose possession would put the Saudis within easy reach of a bomb.

A confluence of U.S. industry figures and Middle East and nuclear “experts” in government and academic think tanks, some with ties to Saudi Arabia, are vigorously campaigning against inclusion of such a ban (the so-called “Gold Standard” of nonproliferation protection). They argue it would offend the “proud” Saudis to our commercial disadvantage and loss of political influence, and that the old form of nuclear agreement is good enough.¹ The outcome of this dispute will set the course for future nuclear agreements and will profoundly affect worldwide protection against proliferation.

A bit of nonproliferation history helps understand why experience dictates the need for the Gold Standard. When we started nuclear exports under President Eisenhower's Atoms for Peace program, we relied mainly on customers' pledges to avoid military applications. We needed to back them up with inspection. Upon the creation of the International Atomic Energy Agency in 1957, we required in our agreements for cooperation that Agency inspections apply to all our nuclear exports.

The 1970 Nonproliferation Treaty required members to accept “comprehensive” IAEA inspection on all their domestic nuclear facilities. But, so long as the individual exports were covered by IAEA inspections, it did not bar exports to non-members who have uninspected nuclear facilities. It was not until Congress passed the 1978 Nuclear Nonproliferation Act, over the strong objections of the export lobby, that U.S. agreements for cooperation incorporated the requirement that customers submit to IAEA inspection on *all* their nuclear activities.

But even intensive comprehensive IAEA inspection could not guarantee exclusively “peaceful” use of stockpiles of fuels that were also nuclear explosives—highly enriched uranium and plutonium. They could be put

1. For example, see, “Letter to Congress from Nonproliferation Experts Supports Nuclear Energy Cooperation with Saudi Arabia,” April 25, 2018, available from <https://www.nuclearinnovationalliance.org/single-post/2018/04/25/Letter-to-Congress-from-Nonproliferation-Experts-Supports-Nuclear-Energy-Cooperation-with-Saudi-Arabia>.

to weapon use almost immediately. Clearly, nonproliferation protection required restriction on uranium enrichment (think centrifuges) and reprocessing of irradiated fuel to extract plutonium. The opponents of such restrictions, including the current defenders of the Saudis, point to NPT language that gives members “the inalienable right” to use nuclear energy for peaceful purposes “without discrimination.” But this language is immediately followed by “in conformity with Articles I and II of this Treaty.” These are the basic prohibitions on the spread of the bomb, and in a nonproliferation treaty have to override the permissive language.

The NPT makes no sense if all countries have the right to come within arm’s length of a bomb. U.S. Supreme Court Justice Robert Jackson once wrote in defense of public safety that the Constitution is not a suicide pact. Well, neither can we allow the NPT to become one.

The Saudi case is particularly sensitive as the Crown Prince recently stated that if Iran got a bomb, Saudi Arabia would definitely do so, too.² The Saudis seem particularly attracted to centrifuge enrichment. They have no commercial need for this, as there is a thriving enrichment market and lots of excess world capacity. Our agreements for cooperation generally require that a country obtain U.S. permission to further enrich U.S.-supplied uranium fuel, and we and other major suppliers don’t sell enrichment technology. But there are illicit sources. To keep a country from acquiring and operating a centrifuge plant, it is necessary, at a minimum, to obtain a clear promise that it will not do so—ergo, the gold standard. This standard was accepted by the Saudis’ neighbor, the United Arab Emirates. If the Saudis balk at it, then we know what they are up to.

The Saudi partisans blow smoke in other ways. It’s unfair, they say, for the Saudi agreement to ban enrichment when the international deal with their arch-enemy, Iran, has not completely shut down its enrichment program. But these are completely different compacts dealing with different circumstances. We don’t have any agreement for cooperation with Iran. The focus should now be on backing Iran off further, not expanding the circle of countries with easy access to nuclear weapons.

Then there is the scare talk that the Saudis may buy power reactors from Russia and China and thereby undermine American influence in the region. But neither Russia nor China are going to get the Saudi contracts. The irony is that neither will Westinghouse, the firm backed by the Trump administration (which apparently doesn’t know Westinghouse is no longer an American-owned company). The Saudi contracts will almost certainly go to South Korea.³

It has to be added that Congress, which can reject the administration proposal, should insist on the gold standard not only to provide needed defense against countries being tempted to toy with weapons options, but also to protect against the well-documented tendency of our own government to weaken nonproliferation standards for putative transitory commercial and political gains. The State Department is especially adept at rationalizing that doing so will still maintain the “functional equivalent” of the original provision. It never does. We need the gold standard.

2 See, Norah O’Donnel, “Saudi Arabia’s Heir to the Throne Talks to 60 Minutes,” *CBS*, March 19, 2018, available from <https://www.cbsnews.com/news/saudi-crown-prince-talks-to-60-minutes/>.

3. See, Victor Gilinsky and Henry Sokolski, “Facing reality in the US-Saudi nuclear agreement: South Korea,” *Bulletin of the Atomic Scientists*, April 10, 2018, available from <https://thebulletin.org/facing-reality-us-saudi-nuclear-agreement-south-korea11683>.

Section IV: Is Pushing Nuclear Power in the Middle East a Mistake?

Chapter 9

A Cautionary Tale for Dealing with Riyadh¹

Henry D. Sokolski

As Washington mulls granting Saudi Arabia a permissive civilian nuclear cooperative agreement in the name of peace and prosperity, it should understand we've been here before. Presidents Carter, Clinton, Bush, and Obama also loosened the reins on "atoms for peace" in the name of stability. Their efforts, however, were less than optimal.

Jimmy Carter was willing to finalize a nuclear cooperative agreement with Iran to demonstrate America's support of the Shah's regime. Bill Clinton suspended routine international nuclear inspections of North Korea to secure a unique nuclear Agreed Framework with Pyongyang. George W. Bush went further. He skirted the Nuclear Nonproliferation Treaty to cement a civil nuclear agreement with India, a nonmember. Finally, Barack Obama led the charge to negotiate a special nuclear political understanding with the mullahs.

Each believed they could ensure a more certain peace by allowing these states access to modern, dual-use nuclear technology under some form of inspections. Rather than abate these countries' nuclear weapons ambitions, though, each nuclear deal, to varying degrees, fueled them.

In the case of Iran, President Carter saw the Shah much as we now view Saudi Crown Prince Mohammed bin Salman—as the guarantor of American interests in the Persian Gulf. Carter championed the Shah's nuclear power aspirations and reopened U.S. negotiations to assist the program. Shortly thereafter, the Shah died and the Mullahs inherited the program. Soon, they began a uranium enrichment program followed by suspicious nuclear weapons-related activities.

Bill Clinton hoped by offering nuclear power assistance to North Korea, he could buy time to wean Pyongyang away from producing weapons plutonium. Pyongyang, however, broke its no enrichment pledge under Clinton's Agreed Framework, built and tested its first bomb in 2006, and soon may use American light water reactor technology America transferred under the Framework to make more nuclear weapons materials.²

After 9/11, George W. Bush was keen to make a friend in India. He hoped that by allowing New Delhi access to otherwise prohibited civilian nuclear know-how and commodities, he could end India's inter-

1. This piece originally appeared as Henry Sokolski, "A cautionary tale for dealing with Riyadh," *The Hill*, March 14, 2018, available from <http://thehill.com/opinion/international/378458-a-cautionary-tale-for-dealing-with-riyadh>.

2. David Albright, Sarah Burkhard, and Allison Lach, "On-Going Monitoring of Activities at the Yongbyon Nuclear Site," *Institute for Science and International Security*, February 13, 2018, available from http://isis-online.org/uploads/isis-reports/documents/Monitoring_Yongbyon_13Feb2018_Final.pdf.

national nuclear isolation and “bring India into the nuclear nonproliferation mainstream.”³ Instead, the deal allowed India to import otherwise banned uranium that, in turn, freed up nearly all India’s domestic uranium resources, which could legally be enriched for military purposes.⁴ With this importation in full swing⁵ India currently is engaged in a massive military fissile production build up.⁶

As for the Iran deal, critics fear Tehran is using previously frozen financial assets that the understanding released to help build out a fleet of nuclear-capable missiles, which Iran might arm with nuclear warheads just as soon as restrictions on it enriching uranium are relaxed. Among these critics is President Trump.

None of this history makes for pleasant reading. All of it, though, is directly relevant to any U.S. effort to strike a civil nuclear agreement with Saudi Arabia. The deal most often discussed is one that would allow the Saudis (now or in due course) to enrich uranium and reprocess spent fuel—two activities that can bring the Kingdom to the brink of making nuclear weapons. The premise behind cutting such a permissive deal is that if we want to restrain an aspiring nuclear weapons state, we must first demonstrate our trust that it will not go nuclear by sharing dual-use technology essential for both civil and military use. The hope here is that the economic lure of this technology’s peaceful uses and our influence in making the sale would temper these states’ desires to ever use the technology to build bombs.

As already noted, history has not been kind to this proposition. Nor does it help that in the Saudi case, the economics of nuclear power are now negative compared to cheaper natural gas, wind, and photo voltaic and solar thermal storage systems that can provide electricity 24/7.⁷ These are the technologies and fuels we should be helping the Saudis with, which, in turn, could help to focus the world (and Iran) on what Tehran should be pursuing instead of nuclear power.

Proponents of a cutting a permissive deal with Riyadh, however, insist that none of this matters; that if the United States does not make accommodations and the sale, Russia and China (or France) will; and that if they do, they will undermine the “nonproliferation” influence that America otherwise would enjoy. This narrative, although popular, is specious. First, it ignores how improbable a reactor sale in the Kingdom is unless it is South Korean (a nuclear vendor the Washington has considerable leverage over).⁸

Second, if we buy its basic logic, we are immediately reduced to caving to anything the Saudis might

3. Gregory L. Schulte, “The India Safeguards Agreement: Moving India Towards the Nonproliferation Mainstream,” *U.S. Department of State*, July 24, 2008, available from <https://2001-2009.state.gov/p/sca/rls/rm/2008/109025.htm>.

4. Zia Mian, Abdul Hameed Nayyar, R. Rajaraman, and M.V. Ramana, “Plutonium Production in India and the U.S.-India Nuclear deal,” available from https://www.researchgate.net/publication/265228293_CHAPTER_4_PLUTONIUM_PRODUCTION_IN_INDIA_AND_THE_US-INDIA_NUCLEAR_DEAL.

5. “India continues to import fuel for nuclear power reactors in large quantities,” *Newsroom 24x7*, January 5, 2018, available from <https://newsroom24x7.com/2018/01/05/india-continues-to-import-fuel-for-nuclear-power-reactors-in-large-quantities/>.

6. Adrian Levy, “India is Building a Top-Secret Nuclear City to Produce Thermonuclear Weapons, Experts Say,” *Foreign Policy*, December 16, 2015, available from http://foreignpolicy.com/2015/12/16/india_nuclear_city_top_secret_china_pakistan_barcl/.

7. Ali Ahmad, “Economic Considerations of Nuclear Power Deployments in Saudi Arabia,” *Nonproliferation Policy Education Center*, November 2017, available from http://npolicy.org/Articles/Ahmad_Saudi_Arabia.pdf and Peter Fairley, “The United Arab Emirates’ Nuclear Power Gambit,” *IEEE Spectrum*, January 4, 2018, available from <https://spectrum.ieee.org/energy/nuclear/the-united-arab-emirates-nuclear-power-gambit>.

8. Henry Sokolski, “5 Myths About Saudi Arabia’s Nuclear Program,” *The National Interest*, March 6, 2018, available from <http://nationalinterest.org/feature/5-myths-about-saudi-arabias-nuclear-program-24771>.

demand. It's also at war with itself. On the one hand, we are told we should downplay nonproliferation concerns when dealing with a close friend (e.g., an India, Saudi Arabia, or an Iran under the Shah) because they can and should be trusted. On the other hand, we are warned, if we don't, they will betray our trust and go elsewhere.

Here, it is worth noting that our closest ally in the Middle East, Israel, is wary of a nuclear Saudi Arabia. Prime Minister Netanyahu recently urged Washington to reject cutting any nuclear deal with Riyadh unless the Kingdom legally forswore enrichment and reprocessing.⁹ The Israelis, of course, live in the Middle East; have bombed or threatened to bomb reactors in Iraq, Syria and Iran; and fear being bombed themselves. Their history also is instructive.

9. Herb Keinon, "Elections Take Back Seat to Nuclearized Middle East at Cabinet Meeting," *The Jerusalem Post*, March 11, 2018, available from <http://www.jpost.com/Israel-News/Elections-take-back-seat-to-nuclearized-Middle-East-at-cabinet-meeting-544774>.

Chapter 10

Washington and Moscow Should Focus on Keeping Nuclear Energy Out of the Middle East¹

Alexander Savelyev and Henry D Sokolski

Although there are an ever increasing number of disputes between Washington and Moscow, one thing President Trump and Vladimir Putin ought to agree on is how reckless it would be to lose money creating additional nuclear security threats in the Middle East. You'd think this, yet both are now pushing construction of large nuclear power plants in Saudi Arabia. It is uncertain if either will win the Saudi bid (a South Korean reactor seems most likely).² But what's clear is that if Washington and Moscow are intent on selling large energy projects in the Middle East, they would do well by all parties if they reconsidered and began competing selling nonnuclear alternatives instead.

Why?

First and foremost, building a large reactor in the Middle East accomplishes little more than building a proven military target. History has validated this. Iran, Israel and, later, the United States all bombed Iraq's Osirak reactor. The Iraqis bombed Bushehr. During Desert Storm, Saddam fired a Scud toward Israel reactor at Dimona. Later in 2007, Israel bombed Syria's reactor near Deirdre al Zour. More recently, the Houthis claimed they aimed their long-range missiles against the United Arab Emirates nuclear reactors at Barakah.

One has also to worry about possible terrorist attacks. The Shia Muslim minority in Saudi Arabia account for 10 to 15 percent of the population. Just last summer, armed resistance by one Shia enclave was brutally put down by Saudi security forces.³ The government blamed "terrorists." Human Rights Watch has documented persuasive Saudi discrimination against this group. And there also have been armed "terrorist" attacks against large Saudi energy facilities, including Saudi Arabia's giant oil cracking plant at Abqaiq.⁴

Protecting against such military and terrorist attacks won't be cheap. Riyadh just bought a \$15 billion U.S.

1. This piece originally appeared as Alexander Savelyev and Henry Sokolski, "Washington and Moscow should focus on keeping nuclear energy out of the Middle East," *The Hill*, April 20, 2018, available from <http://thehill.com/opinion/national-security/384172-washington-and-moscow-should-focus-on-keeping-nuclear-energy-out-of>.

2. See Chapter 7 of this volume.

3. Adam Coogle, "Saudi Arabia's 'War on Terror' is Now Targeting Saudi Shiites," *Foreign Policy*, August 23, 2017, available from <http://foreignpolicy.com/2017/08/23/saudi-arabias-war-on-terror-is-now-targeting-saudi-shia>.

4. "Saudis 'foil oil facility attack,'" *BBC News*, February 24, 2006, available from http://news.bbc.co.uk/2/hi/middle_east/4747488.stm.

Terminal High Altitude Area Defense system and is reportedly in talks with Moscow to buy an equally large S-400 missile defense system.⁵ Some of these defenses, undoubtedly, would be deployed to defend whatever nuclear power plants Riyadh might build. Of course, none of these defense costs are included in the price of any reactor. They should be.

This brings us to the second count against nuclear power in the Middle East: It's now become expensive, uneconomical and obsolete. Reactors are technically complex but having been first developed more than a half century ago, they are no longer cutting edge. Worse, they can no longer compete economically against natural gas and, now, are failing behind renewables, such as wind and solar, particularly in the Middle East.⁶ Putting aside the significant external costs of defending these plants against attacks, the costs of developing sufficient electrical distribution systems to support such large generators (which can easily equal or exceed the cost of the reactors), and the costs of nuclear waste management and decommissioning, nuclear power plants themselves cannot compete against their alternatives.

No, we are not talking about burning cheap Middle Eastern oil or imported coal, but exploiting proven conventional natural gas in Saudi Arabia and throughout the Middle East. Gas-fired electrical plants cost less than 6 cents per installed kilowatt hour, nearly half the cost of nuclear. Then, there is solar. Photovoltaics are now being bid in the Middle East below 2 cents per installed kilowatt hour. Concentrated solar power, which heats up sodium during the day and operates all night, is coming in well below 8 cents. Nuclear, in contrast, is now pegged to cost roughly 11 cents. It is no wonder, then, that the United Arab Emirates recently announced that it would not build any more nuclear power plants.⁷

Why, then, would anyone in the Middle East bother to build a large reactor? Increasingly, the unspoken rationale is to gear up to develop a nuclear weapons option. Israel used its nuclear plants to make bombs. Syria, Iraq and Iran have all been suspected of having planned to do likewise. Crown Prince Mohammed Bin Salman recently announced that the Kingdom would get nuclear weapons “as soon as possible” if Iran does.⁸ Certainly, working with large reactors and their related fuel systems gives states a leg up to do so.

What, then, should Russia and the United States do? Two things. First, it would be nice if Washington and Moscow could coordinate their energy policies in the Middle East. For the moment, however, this is unlikely. What is totally feasible, however, is that the two states could refocus their current energy competitions in the region to secure nonnuclear contracts rather than nuclear ones. Competing in this sector would not only be safer for the region, it would help push both the American and Russian energy sectors focus on promising energy technologies for themselves.

Second, it would be useful for the two countries to compete limiting the most dangerous of nuclear activities—enrichment and reprocessing, which can bring states within weeks of acquiring nuclear explosives.

5. “U.S. approves possible \$15 billion sale of THAAD missiles to Saudi Arabia,” *Reuters*, October 6, 2017, available from <https://www.reuters.com/article/us-usa-saudi-missiles/u-s-approves-possible-15-billion-sale-of-thaad-missiles-to-saudi-arabia-idUSKBN1CB2IN> and “Saudi ambassador to Moscow: S-400 missile deal with Saudi Arabia in final stages,” *Al Arabiya English*, February 20, 2018, available from <https://english.alarabiya.net/en/News/gulf/2018/02/20/Saudi-ambassador-to-Moscow-S-400-missile-deal-with-Saudi-Arabia-in-final-stages.html>.

6. Ali Ahmad, “Economic Considerations of Nuclear Power Deployment in Saudi Arabia,” *Nonproliferation Policy Education Center*, November 2017, available from http://npolicy.org/Articles/March%202018%20Drafts/Ahmad_SaudiArabia_Nov17.pdf.

7. Peter Fairly, “The United Arab Emirates’ Nuclear Power Gambit,” *IEEE Spectrum*, January 4, 2018, available from <https://spectrum.ieee.org/energy/nuclear/the-united-arab-emirates-nuclear-power-gambit>.

8. “Saudi crown prince: If Iran develops a nuclear bomb, so will we,” *CBS News*, March 15, 2018, available from <https://www.cbsnews.com/news/saudi-crown-prince-mohammed-bin-salman-iran-nuclear-bomb-saudi-arabia/>.

Russia already takes back spent fuel after several years on the understanding that the client state has no need to recycle spent fuel. The United States leads in once-through nuclear technologies, including dry cask spent fuel storage, which makes reprocessing unnecessary and less economical. So, there is a bit of healthy competition already. Both countries, however, could be more firm in requiring all Middle Eastern non-weapons states under the Nuclear Nonproliferation Treaty not to reprocess or enrich.

Appendix¹

Avoiding A Nuclear Wild, Wild West in the Middle East

Henry Sokolski
Executive Director
Nonproliferation Policy Education Center
www.npolicy.org

© Nonproliferation Policy Education Center

1

Three Questions

- I. Do the Saudis need nuclear power or to enrich or reprocess?
- II. Can the US strike a formal nuclear cooperative 123 agreement with Riyadh that fails to prohibit enriching uranium or recycling plutonium without undermining nuclear nonproliferation both regionally & globally?
- III. Doesn't the US lack leverage since the Saudis can always buy a French, Russian or Chinese reactor if they don't buy American?

2

1. These PowerPoint Slides are taken from a presentation given on March 17, 2018 at the Middlebury Institute of International Studies at Monterey's James Martin Center for Nonproliferation Studies. The talk, "How Likely is Atoms for Peace in the Middle East, Starting with Saudi Arabia," focused on the dangers of a lax civil nuclear cooperative agreement between the US and Saudi Arabia. A video of the event is available here <http://npolicy.org/article.php?aid=1384&rid=4>.

One Answer

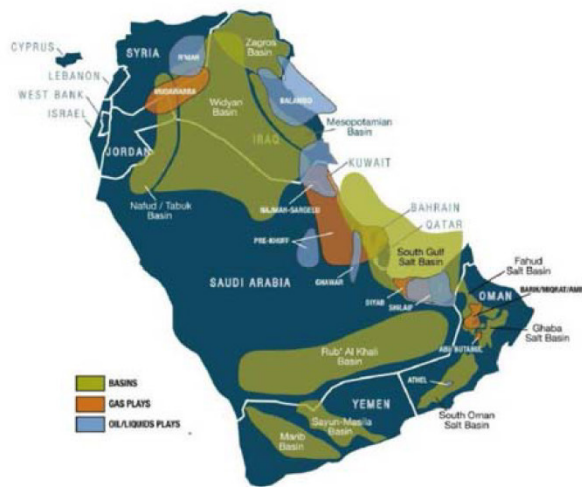
- **No**

3

I. Does A Saudi Nuclear Program Make Economic Sense Compared to Nonnuclear Alternatives?

4

Saudi Arabia New & Proven Gas Options

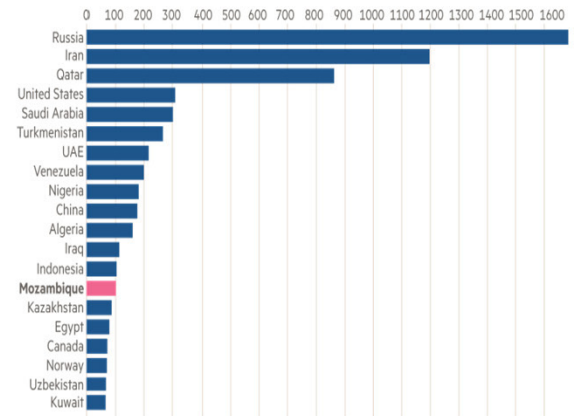


Source: PacWest; Qamar research

World's top natural gas reserves

Proved reserves of natural gas, 2016

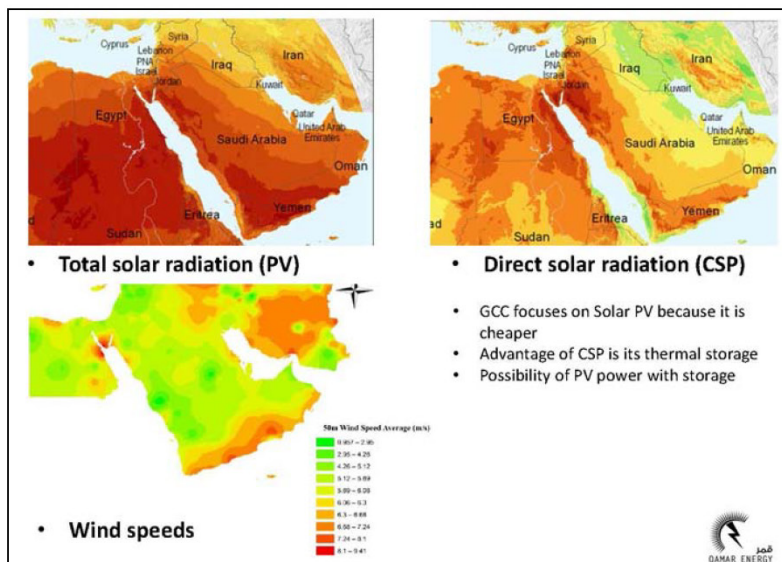
Cubic feet (tr)



Source: U.S. Energy Information Administration
© FT

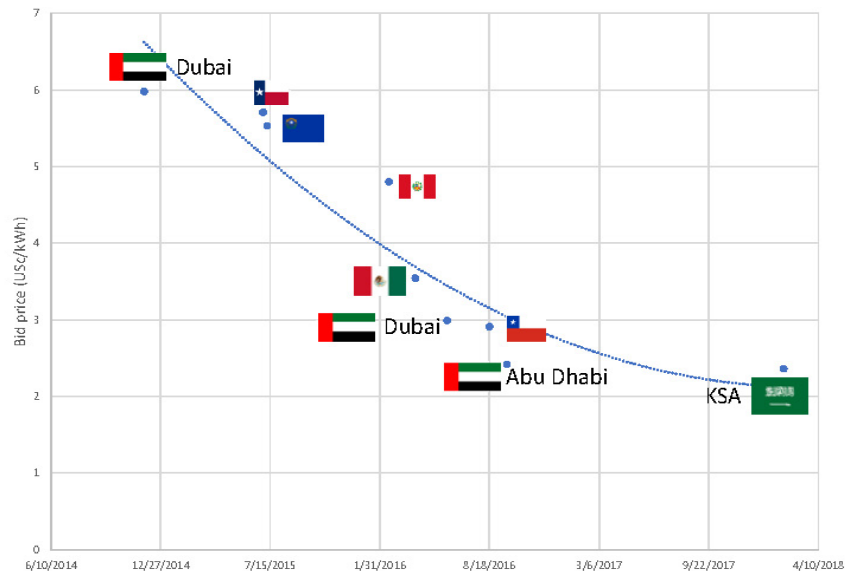
5

Saudi Arabia: Rich in Renewable Energy Potential



6

Dramatic Falls in Solar PV Power Bids



Source: Qamar research

Concentrated Solar Power Costs: Now Well Below Nuclear

Falling Prices for CSP Plants with Molten Salt

The prices for electricity from concentrated solar power (CSP) plants with molten salt energy storage have dropped by more than half since SolarReserve started developing its Crescent Dunes plant in 2009. Some recent bids to build new plants show the price trajectory.

CSP MOLTEN SALT TOWER PROJECTS

PROJECT/LOCATION	DEVELOPER(S)	CAPACITY/STATUS	POWER PRICE	DATE PRICED
Crescent Dunes Tonopah, Nevada	SolarReserve	110 MW (operating)	13.5¢/kWh	2009
Noor III Ouarzazate, Morocco	ACWA Power, Sener	150 MW (under construction)	15¢/kWh	2014
Redstone Postmasburg, South Africa	SolarReserve, ACWA Power	100 MW (preferred bidder)	12.4¢/kWh	2015
MBR Solar Park Phase 4 Dubai, UAE	ACWA Power, Shanghai Electric	100 MW* (construction to begin 2018)	7.3¢/kWh	2017
Aurora Port Augusta, South Australia	SolarReserve	150 MW (construction to begin 2018)	6¢/kWh	2017
Copiapo Copiapo, Chile	SolarReserve	260 MW (pending bid)	<5¢/kWh	2017

Power price is based on the power purchase agreement (PPA) signed by the developer for power from the project; it may not reflect other sources of project income such as the sale of environmental credits or excess power.
*PPA for this project covers a mix of trough and CSP tower facilities.

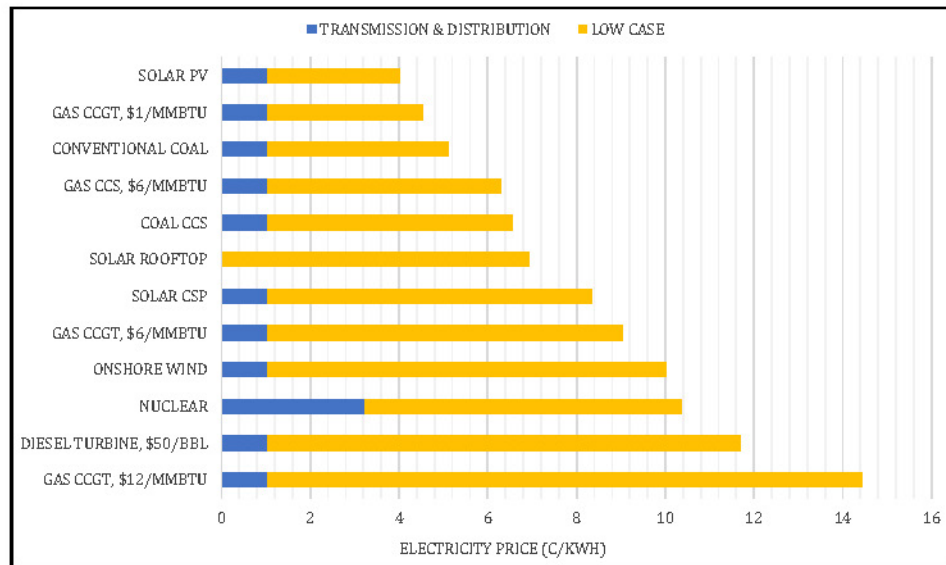
SOURCES: SolarReserve; National Renewable Energy Laboratory

PAUL HORN / InsideClimate News



8

Saudi Arabia's Best Bet Is Not Nuclear



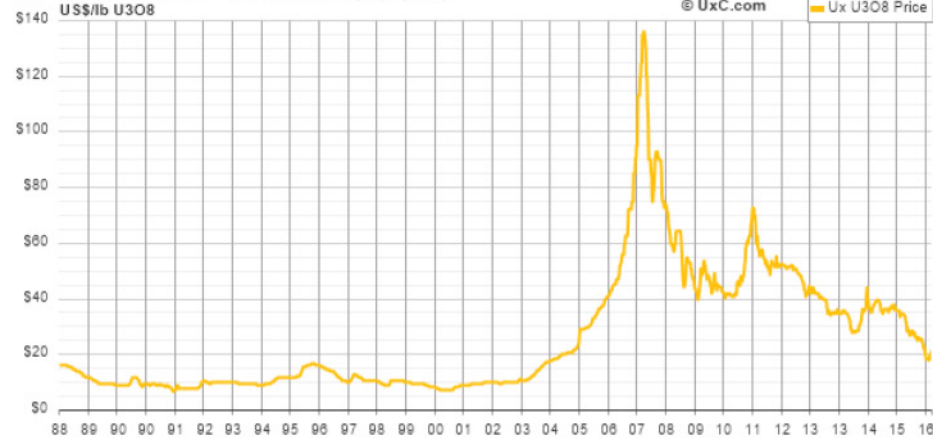
Source: Qamar research

9

Uranium: Plentiful and Cheap

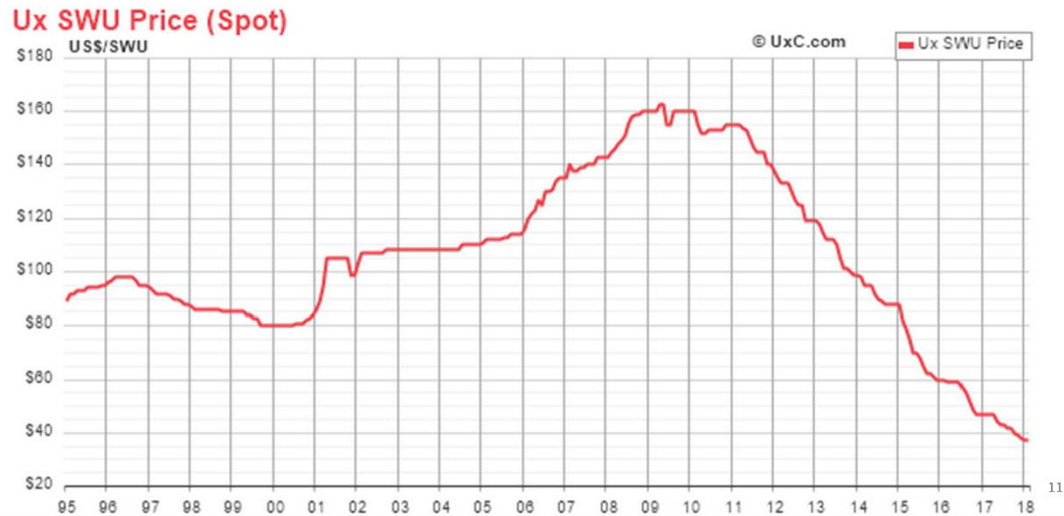
Ux U3O8 Price - Full History

Ux U3O8 Price® - Full History (Spot)



10

Enrichment Services: Also Abundant & Cheap



II. Proliferation Impacts of a Saudi-US 123 Without the Gold Standard

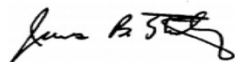
12

The US-UAE Deal Calls for Terms “No Less Favorable”

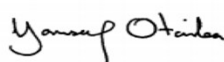
Equal Terms and Condition for Cooperation

The Government of the United States of America confirms that the fields of cooperation, terms and conditions accorded by the United States of America to the United Arab Emirates for cooperation in the peaceful uses of nuclear energy shall be no less favorable in scope and effect than those which may be accorded, from time to time, to any other non-nuclear weapon State in the Middle East in a peaceful nuclear cooperation agreement. If this is, at any time, not the case, at the request of the Government of the United Arab Emirates the Government of the United States of America will provide full details of the improved terms agreed with another non-nuclear-weapon State in the Middle East, to the extent consistent with its national legislation and regulations and any relevant agreements with such other non-nuclear weapon State, and if requested by the Government of the United Arab Emirates, will consult with the Government of the United Arab Emirates regarding the possibility of amending this Agreement so that the position described above is restored.

FOR THE GOVERNMENT OF
THE UNITED STATES OF
AMERICA:



FOR THE GOVERNMENT OF
THE UNITED ARAB
EMIRATES:



13

The Same Is True of the Egyptian Deal

EQUAL TERMS AND CONDITIONS FOR COOPERATION

The Government of the United States confirms that fields of cooperation, terms and conditions accorded by the United States to the Arab Republic of Egypt for cooperation in the peaceful uses of nuclear energy shall be no less favorable in scope and effect than those which may be accorded by the United States to any other non-nuclear weapon state in the Middle East in a peaceful nuclear cooperation agreement. In this connection it is understood that the safeguards required by this agreement shall be no more restrictive than those which may be required in any peaceful nuclear cooperation agreement between the United States and any other state in the region. By entering into this agreement the United States confirms its recognition of the importance of the Arab Republic of Egypt's adherence to the NPT, and its longstanding support of international non-proliferation measures, including establishment of a nuclear weapon free zone in the Middle East. If any situation arises which could increase the risk of proliferation of nuclear weapons, the United States and the Arab Republic of Egypt, at the request of either, shall enter into consultations with respect thereto with a view to maintaining the objectives of the NPT.

14

Middle Eastern 123 Agreements

- Egypt, expires 2021
- Morocco, expires 2021
- Turkey, expires 2023
- Jordan?

15

What About Israel?

The last time the United States made an exception from its nonproliferation policies and legal requirements not to promise to transfer controlled nuclear commodities to another close friend, India, Israel quietly petitioned for equal treatment.

See, Glen Kessler, "Israel Submits Nuclear Trade Plan," *The Washington Post*, September 30, 2007, available from <http://www.washingtonpost.com/wp-dyn/content/article/2007/09/29/AR2007092901530.html>

16



“Despite my strong inclination, I have not yet withdrawn the United States from the Iran nuclear deal,” Trump said in a statement. “Instead, I have outlined two possible paths forward: either fix the deal’s disastrous flaws, or the United States will withdraw.” January 11, 2018

17

We Have Been Here Before



"Saudi Arabia does not want to acquire any nuclear bomb, but without a doubt if Iran developed a nuclear bomb, we will follow suit as soon as possible," Prince Mohammed bin Salman, Saudi Arabia

GUESS WHO'S BUILDING NUCLEAR POWER PLANTS.



The Shah knows that nuclear energy is not only economical, it has enjoyed a remarkable 30-year safety record. A record that was good enough for the citizens of Plymouth, Massachusetts, too. They've approved their second nuclear plant by a vote of almost 4 to 1. Which shows you don't have to go as far as Iran for an endorsement of nuclear power.

NUCLEAR ENERGY. TODAY'S ANSWER.

18

The Mathematics of Nuclear Deterrence in the Middle East

1 Iranian nuclear weapons option or nuclear weapon + 1 Saudi nuclear weapons option or nuclear weapon

= 0?

= 2?

OR

= >2?

19

And Then There's the RoK and E. Asia

- Even “anti-nuclear South Korean President Moon wants a nuclear submarine program — i.e., likely to enrich US-origin materials
- How might Washington resist Seoul's request if it allows Riyadh to enrich and recycle?
- How might South Korea's neighbors “react” to Washington green lighting ROK enrichment?

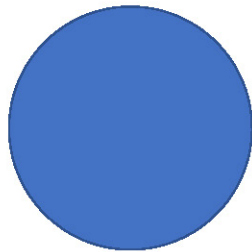


20

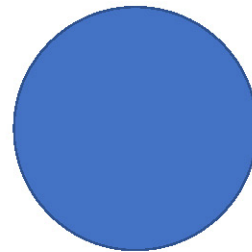
III. American Nuclear Leverage Over the Saudi Program

21

Westinghouse: American in Name Only



Today: 100% **Japanese** Owned

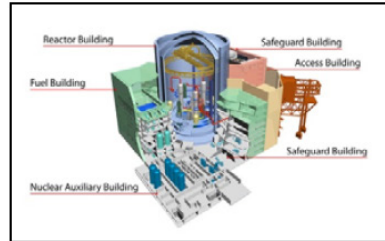


Later this year: 100%
Canadian Owned

Westinghouse no longer builds reactors abroad and makes no major components in US; it designs reactors and makes smaller components

22

CAP 1400, HPR 1000: Not Quite Ready



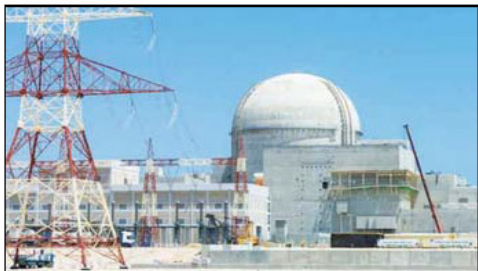
23

VVER 1200: 1st Safety Test Late 2016, Bounced Reactor off the Grid



24

KEPCO APR 1200, Tried, Roughly on Schedule and Budget, Construction Crew in Region



25

Korean SMART Reactor: A Sleeper that Doesn't Require a 123 Agreement

SMART (System-integrated Modular Advanced Reactor). Saudi Arabia's King Abdullah City for Atomic & Renewable Energy (KA-Care) signed a memorandum of understanding (MoU) with ROK in November 2016 to develop the technology in the kingdom.

According to a source at KA-Care, *Saudi Arabia owns a percentage of the intellectual property (IP) rights for the technology, and is already moving ahead with plans to begin to develop the first two SMART reactors, which will have a capacity of about 100MW each, within the next four years.*

Source: Middle East Business Intelligence, January 22, 2018
<https://www.meed.com/exclusive-saudi-arabia-shortlists-two-sites-first-nuclear-power-project/>



27

South Korea – Saudi Arabia 2011 Nuclear Cooperative Agreement Allows Enrichment

ARTICLE 8 Enrichment and Reprocessing

2. Equipment or technology transferred pursuant to this Agreement and equipment based on such technology ***shall not be used for the production of uranium enriched to twenty (20) percent or more in the isotope U-235, unless the Parties otherwise agree.***

28

Kingdom's SMART Option Suggests How Important the Gold Standard Is to Secure

- If the Kingdom wants a bomb, the SMART reactor is large enough to
 - Serve as a procurement cover for a covert enrichment program
 - Serve as a justification for an overt enrichment program
 - Server as a plutonium production plant for either abrupt or incremental military diversions
- The best diplomatic way to head this off is to push for the Gold Standard whether the Kingdom buys American or not

29

Leverage: We Have It

- Seoul may or may not need a 123 for the APR 1400 or for SMART. Either case, Washington has their number
- Senator Jack Reed (D. Ranking SASC) got things right when he noted March 22, 2018 that

“ I think the proliferation dangers are so great that we should be able to wield all the influence we have, which goes way beyond this one transaction, to insist upon the same standards that we applied to the Emirates”



About the Contributors

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Victor Gilinsky is an independent consultant primarily on matters related to nuclear energy. He was a two-term commissioner of the U.S. Nuclear Regulatory Commission from 1975-1984, and before that Head of the Rand Corporation Physical Sciences Department. He holds a Bachelors of Engineering Physics degree from Cornell University and a Ph.D. in Physics from the California Institute of Technology, which gave him its Distinguished Alumni Award. He is a member of the American Physical Society and the Institute of Electrical and Electronics Engineers.

Robin Mills is the CEO of Qamar Energy (Dubai) and an expert on Middle East energy strategy and economics. He is the author of two books, *The Myth of the Oil Crisis* and *Capturing Carbon*, columnist on energy and environmental issues at *The National*, and comments widely on energy issues in the media, including the Financial Times, Foreign Policy, Atlantic, CNN, BBC, Bloomberg, Sky News and others. He worked for a decade for Shell, concentrating on new business development in the Middle East, followed by six years with Dubai Holding and the Emirates National Oil Company, and spent two years as Non-Resident Fellow for Energy at the Brookings Doha Center. He holds a first-class degree in Geology from the University of Cambridge, and speaks five languages including Farsi and Arabic.

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Henry D. Sokolski is the executive director of the Nonproliferation Policy Education Center (NPEC) and teaches at the Institute of World Politics in Washington, DC. He has served in the Pentagon as deputy for Nonproliferation Policy, as a full-time consultant to the Secretary of Defense's Office of Net Assessment, as a consultant to the National Intelligence Council, a member of the Central Intelligence Agency's Senior Advisory Group, and as a Senate legislative aide on nuclear energy and military affairs. He was appointed to the Commission on the Prevention of Weapons of Mass Destruction Proliferation and Terrorism and the Deutch WMD Proliferation Commission and has authored and edited numerous volumes on strategic weapons proliferation issues, including *Underestimated: Our Not So Peaceful Nuclear Future* and *Best of Intentions: America's Campaign against Strategic Weapons Proliferation*.

Geoffrey Styles is Managing Director of GSW Strategy Group, LLC, an energy and environmental strategy consulting firm. Since 2002, he has served as a consultant and advisor to organizations and executives, particularly through the application of scenario planning. His industry experience includes 22 years at Texaco, Inc., culminating in a senior position on Texaco's leadership team for strategy development, focused on the global refining, marketing, transportation and alternative energy businesses, and issues such as climate change and sustainable development. Previously he held senior positions in alliance management, planning, commodity trading, supply and distribution, and risk management. Mr. Styles also served on NASA's Senior Management Oversight Committee for Space Solar Power. He earned an M.B.A. from Berkeley's Haas School of Business and a B.S. in Chemical Engineering from University of California, Davis. His "Energy Outlook" blog has been quoted by *The Wall Street Journal* and other media and was named one of the "Top 50 Eco Blogs" by the *Times of London*.



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