Chapter 3

Meeting Iran's Energy Requirements without Nuclear Power

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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/آمار-تفضیلی-صنعت-برق-ایران،-ویژه-مدیریت-راهبردی،-س. 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)*.

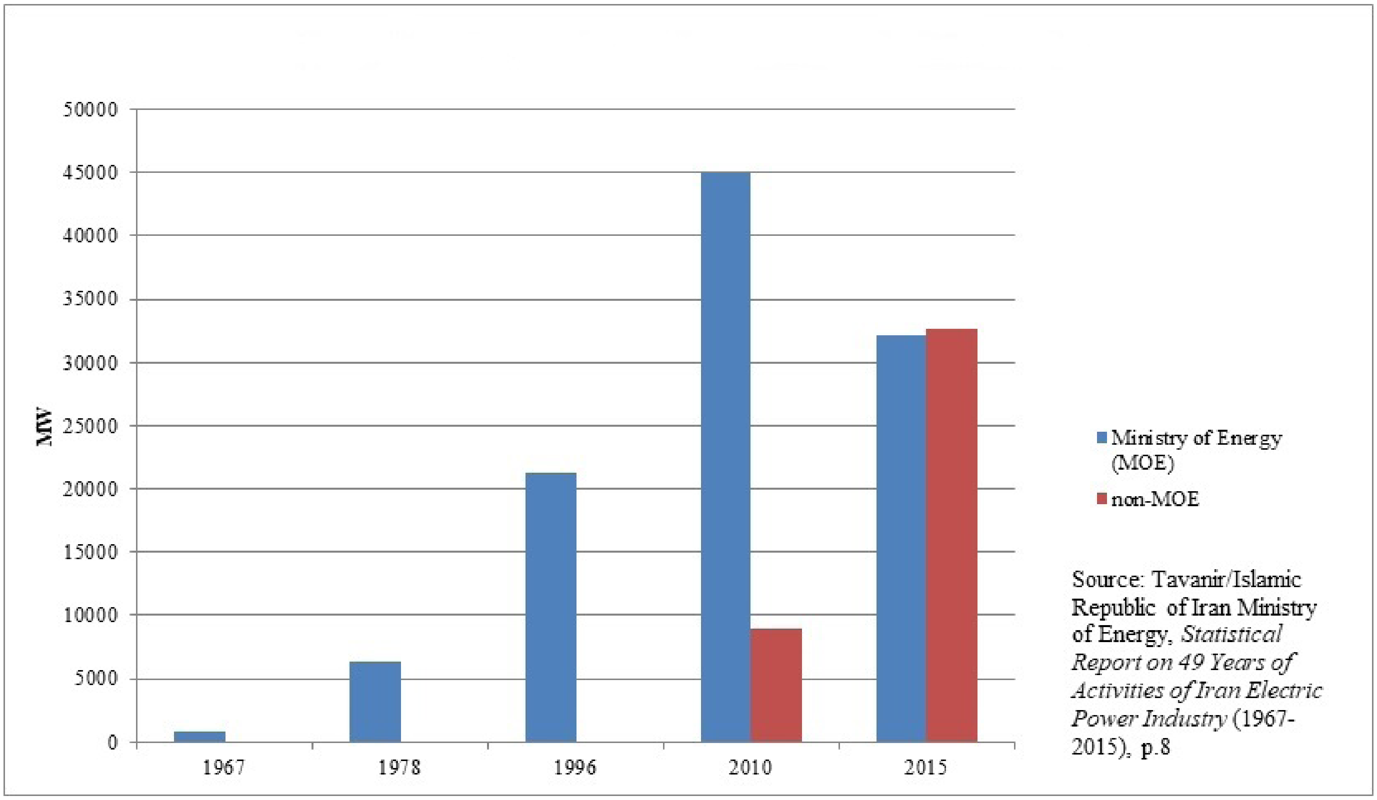

Figure 1: Operational Capacity of Power Plants by Ownership

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), 1967-2015[4]

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

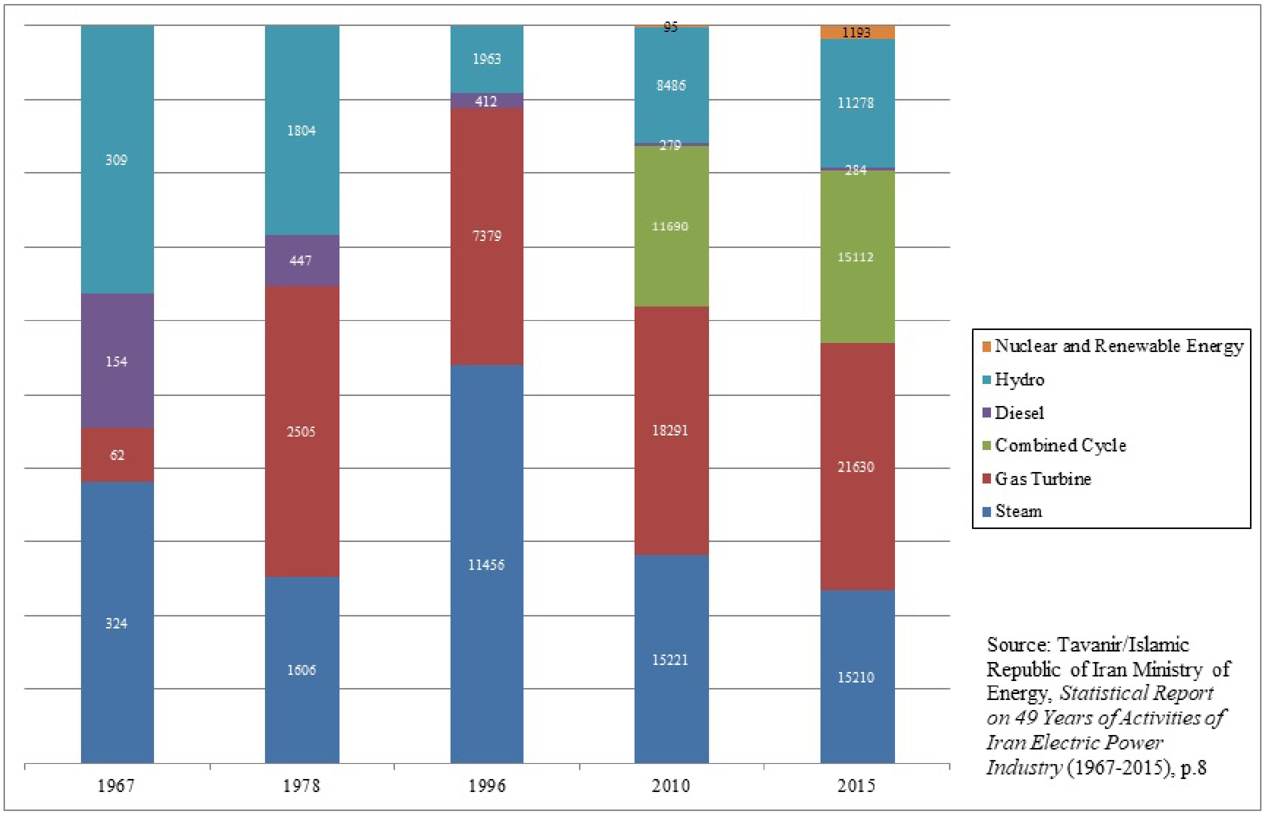

Figure 2: Operational Capacity of Power Plants by Fuel Type

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), 1978-2015[7]

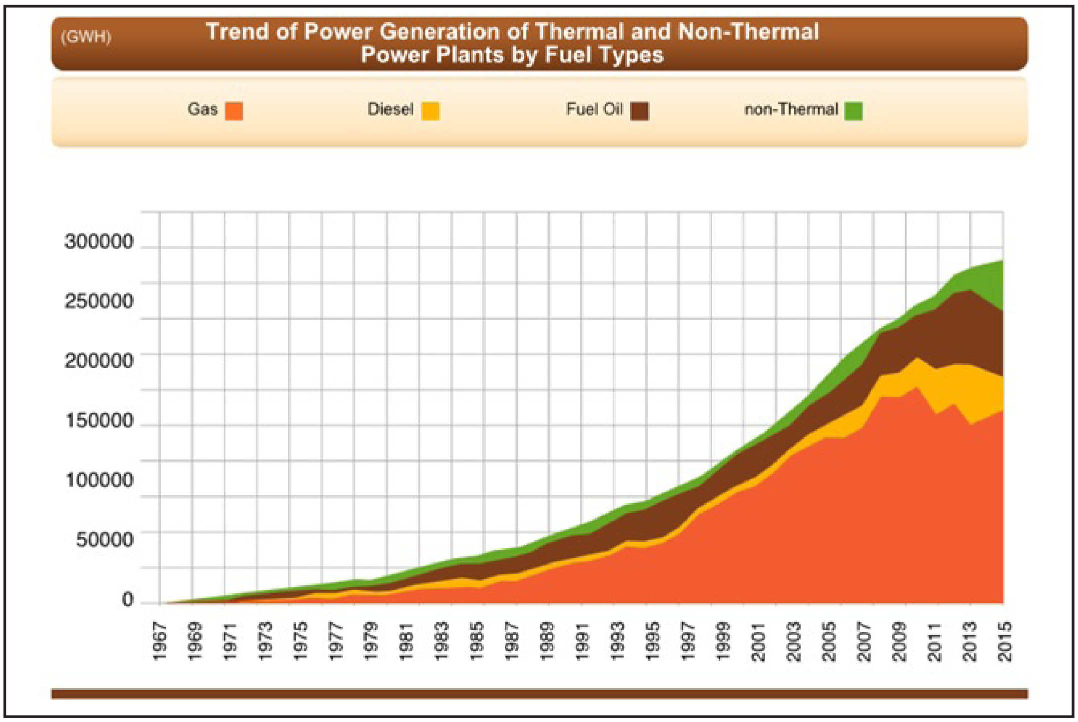

Figure 3: Trend of Power Generation of Thermal and Non-Thermal Power Plants by Fuel Types[8]

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

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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/, خیز-ایران-برای-تولید-2-هزار-مگاوات-برق-هسته-ای-جدید-در-حاشیه-خلیج-فارس.

to mark the formal start of construction on March 14, 2017[19]—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 irms 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.

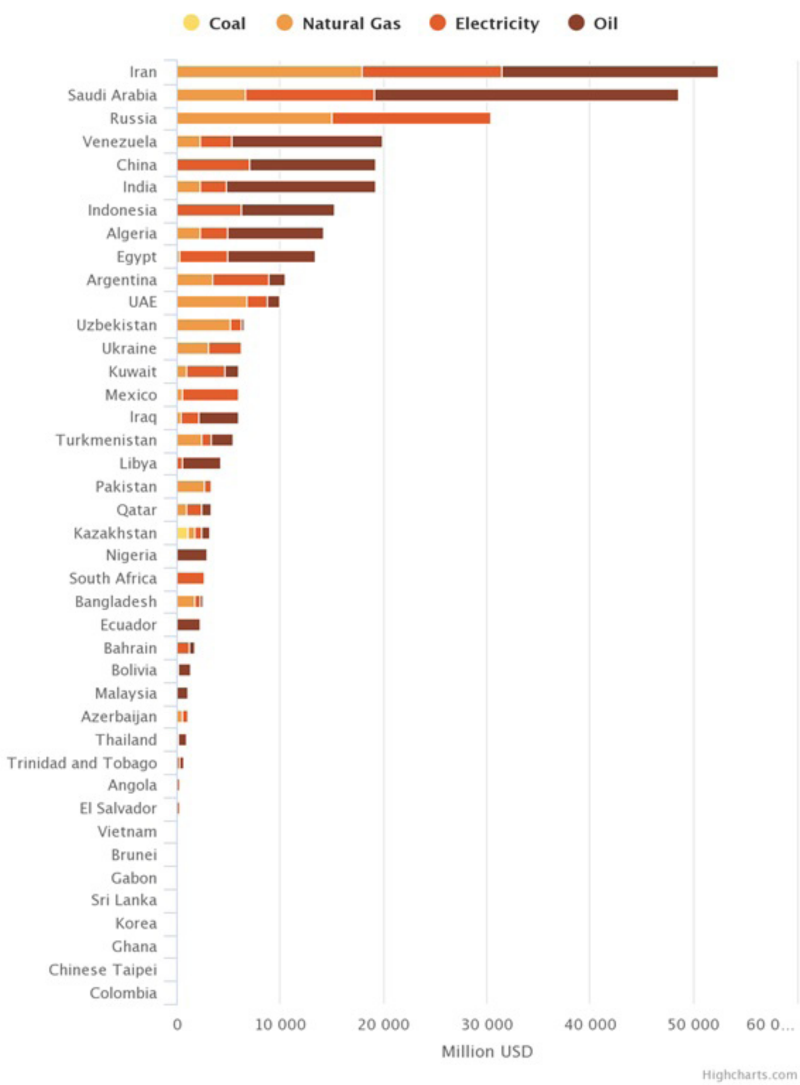

Figure 4: Energy Subsidies by Country 2015[27]

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, availble 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.

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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, S*tatistical 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 in presumably cheap. Fuel oil is not in high demand internationally; indeed, what market does exist for the fuel oil will

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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

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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.

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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 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 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.