Combined Heat and Power (CHP) Policy Review for the Kingdom of Saudi Arabia

Volume I: Final Report

PREPARED FOR

The Electricity and Co-generation Regulatory Authority

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This report was prepared for the Electricity and Co-Generation Regulatory Authority. All results and any errors are the responsibility of the authors and do not represent the opinion of The Brattle Group, Inc. or its clients.

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I. Executive Summary

Background

The Brattle Group and its partners, Navigant Consulting, EcoSolutions and Pierce Atwood LLP, were retained by the Electricity Cogeneration and Regulatory Authority (ECRA) to assess the technical and economic potential for combined heat and power (CHP) applications in the Kingdom of Saudi Arabia (KSA) between now and 2040. We were also asked to assess what barriers exist to enhanced deployment of CHP in the KSA and what policy solutions might be pursued to overcome these barriers.

This report summarizes our findings. It is based on the application of a number of approaches including desk research, numerous meetings in the KSA with ECRA, the National Team responsible for the development of a uniform long-term energy plan for the KSA ("National Team"), and multiple stakeholders, in-person interviews and surveys of potential CHP clients as well as stakeholders, and the application of economic-engineering models.[1]

CHP is widely recognized as a means of increasing the overall efficiency of an energy system by taking advantage of waste heat/steam from power generation to provide inputs to other processes such as the provision of process steam, which, absent CHP, would have to be procured using fuel and dedicated boilers (topping cycle), or to use the waste steam from industrial processes to generate electricity (bottoming cycle).

The value of increasing energy efficiency increases with the cost of producing usable energy such as electricity or process steam, where the cost can be understood as either the private or societal cost. Private (or participant) costs may differ from societal costs because prices charged for energy to participants may not reflect the full costs to society and/or because societal costs don't fully reflect all relevant costs, in particular those associated with potential externalities such as greenhouse gases.

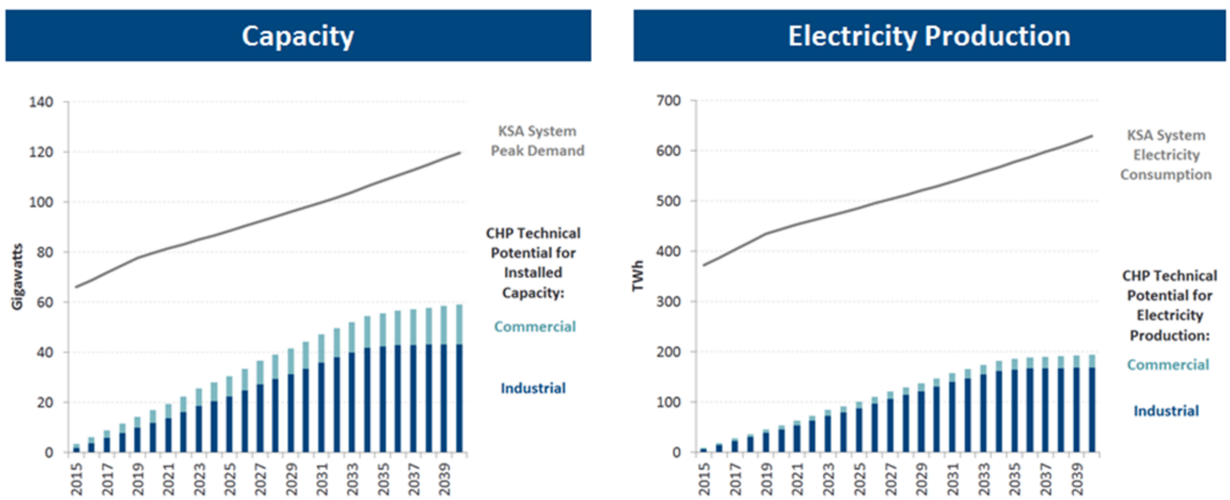
Consequently, efforts to increase the use of CHP are particularly prominent in countries with significant steam demand, relatively high energy production costs and/or ambitious greenhouse gas reduction targets such as Northwestern Europe (Denmark, Germany), the United States, Canada, and Kazakhstan, where waste heat from power generation is used for district heating. Given the KSA's climate, there is not much demand for district heating but a case could potentially be made for the use of CHP for district cooling.

1 The full National Team includes ECRA, the Ministry of Petroleum, Saudi Aramco, the Saline Water Conversion Company (SWCC), the National Water Company (NWC), the Saudi Electricity Corporation (SEC) and the Ministry of Finance

A Review of the Technical Opportunities

Given the current and likely future mix of industries in the KSA, the technical potential for CHP applications is large, as shown in Figure ES-1. Petroleum refining with an already installed CHP capacity of 1,050 MW and additional planned CHP capacity of a similar amount, petrochemical industries, cement production as well as aluminum manufacturing represent important economic activities, all of which lend themselves to CHP applications (because they either require large amounts of process heat or generate large amounts of waste heat or waste steam). It is important to note, however, that this estimate of technical potential does not account for the cost-effectiveness of CHP and should therefore be used only to put more realistic estimates of CHP potential in context.

Figure ES-1: Technical Potential for CHP



With assistance from the National Team we developed a projection of the likely future demand (and supply) of process heat/steam in the KSA for 92 industry and size segments. We were not asked to assess the CHP potential in the refining sector since the National Team is already intimately familiar with CHP developments in this sector. Also, after an initial analysis we decided not to assess the CHP potential in the seawater desalination sector. It was found that cogeneration in the sense of using the waste heat from power generation to drive a thermal desalination process is already standard practice and mandated by law.[2]

A significant early deliverable of our project was the development of a technical assessment mapping industrial applications by size class (small, medium and large) to feasible CHP technologies. This effort resulted in a Technical Assessment summarized in this report and attached as Appendix B. By and large, a number of technological solutions exist to deploy CHP technology across many of the KSA's important industrial sectors. CHP technology also exists

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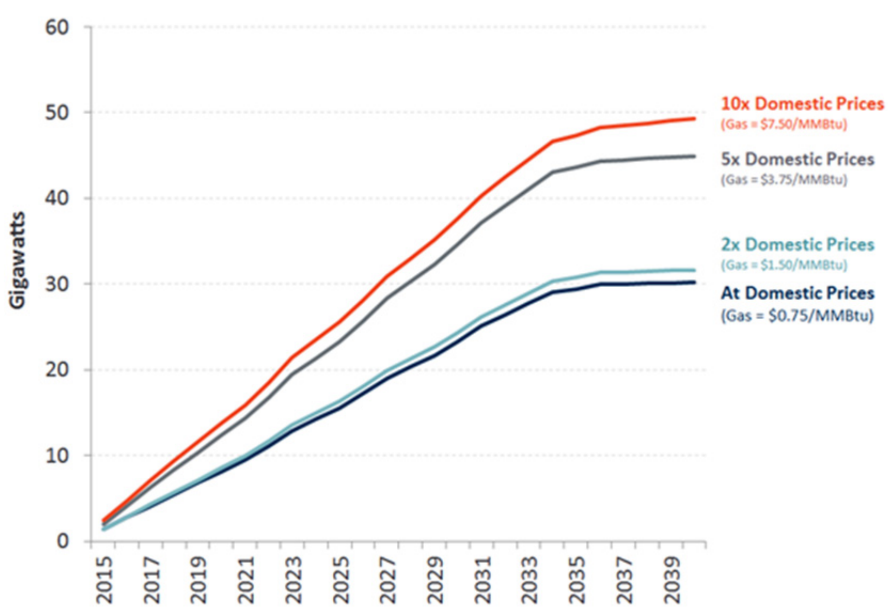
2 According to the Electricity Law (Amended Article 5-3), "The use of Cogeneration is mandatory for power and water desalination projects on the coastal areas."

that could be used to apply CHP in the commercial sector, most notably to use waste heat to generate air conditioning in large buildings or in district cooling applications. The main conclusion of the technical assessment was that it is possible to apply CHP applications for a large portion of industrial and commercial activities.

Market Potential and the Economics of CHP

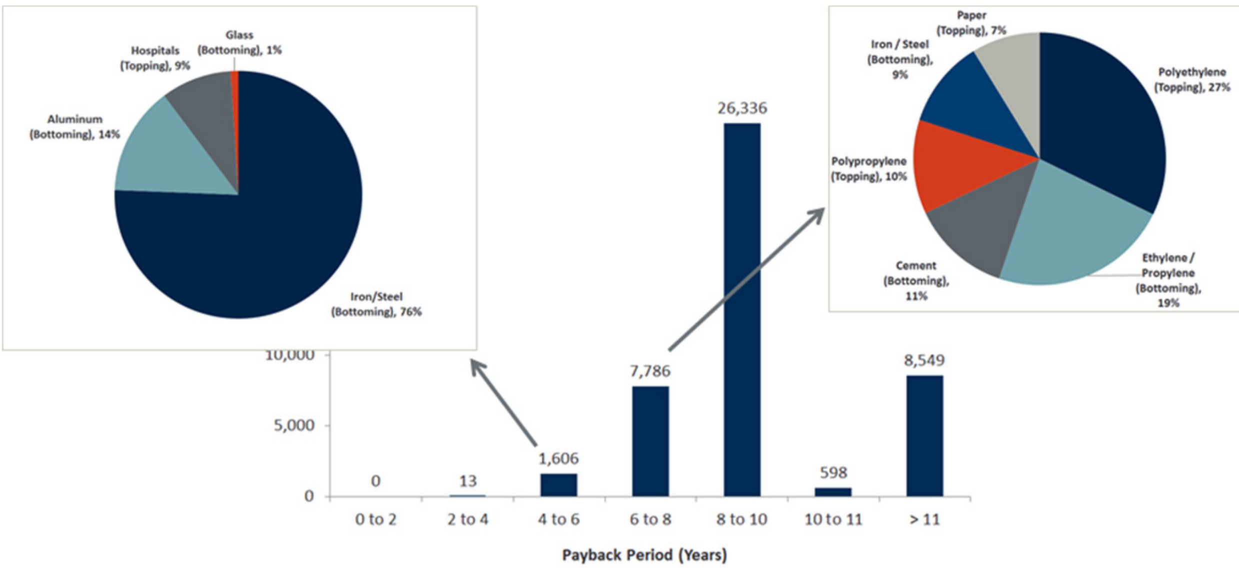
A second deliverable, and the core of the assignment, was to estimate the economic and market potential for CHP applications in the KSA. Using a number of inputs including the technical assessment report (with associated steam demand by industry and commercial sector as well as the characteristics of potential CHP technologies, CHP costs), macro inputs such as growth in output across multiple industrial and commercial sectors, fuel prices and retail electric rates, we developed estimates of the optimal CHP technology and the resulting economic and market CHP potential under a number of scenarios. Figure ES-2 below shows our estimates of the economic potential for CHP between 2015 and 2040 for various multiples of current domestic fuel prices.

Figure ES-2: Economic Potential for CHP Capacity



Economic potential is defined as the amount of CHP that would be beneficial to the KSA as a whole rather than to individual customers or CHP participants. Because payback periods are an important determinant of market adoption, Figure ES-3 shows the distribution of payback periods of the economic potential for CHP assuming a value of fuels equal to five times current domestic prices.

Figure ES-3: Economic Potential at 5x Domestic Prices in Sectors with the Shortest Payback Periods (2040)



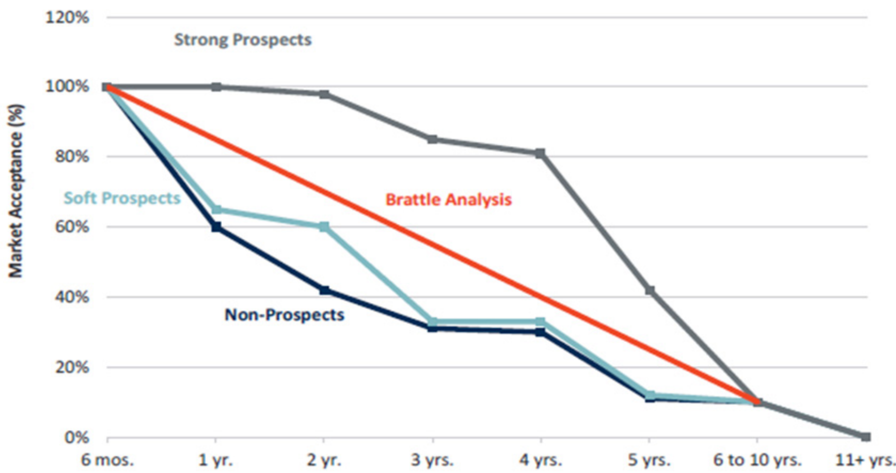
The economic benefit of CHP may differ between society at large and individual participants when the prices/costs of important inputs for CHP (fuel, capital costs, etc.) faced by participants differ from the values of those same inputs from society's perspective. In the KSA, the major differences between societal and participant costs relate to the cost/value of fuels (oil, gas), which are currently offered to domestic customers at prices potentially below their national values.[3] Also, retail electricity rates in the KSA do not reflect underlying production costs (even assuming that fuel used for power generation is priced at national values).

Another important factor driving differences between economic (societal) and market CHP potential is related to the observation that private adoption of CHP (and many other) technologies requires relatively short pay-back periods, i.e., that a project that would seem to be in society's interest (in the sense of societal benefits exceeding societal costs) may not be adopted by private parties having to allocate scarce capital resources and facing alternative investment opportunities that have quicker payback periods/higher returns. To reflect this difference, we used a customer adoption rate curve shown below in Figure ES-4, which was derived from a study on customer adoption rates for certain types of distributed energy technologies (such as CHP) and broadly consistent with empirical observations and estimates of customer adoption rates that investments with pay-back periods greater than five years are quite low. As can be seen, market adoption rates are typically high for projects with very short payback periods, in the order of less than a year to 2 to 3 years. Adoption rates fall quickly and are around 10% to

[3] The national fuel value is the value of fuel if it were sold in the global market. Due to the complexities associated with determining national fuel values we present our results in a range of multiples of current domestic fuel prices.

40% (depending on assumptions about the propensity of a particular customer to adopt a given technology) for payback periods of 5 years and are very low for projects with payback periods of 6 years or longer.

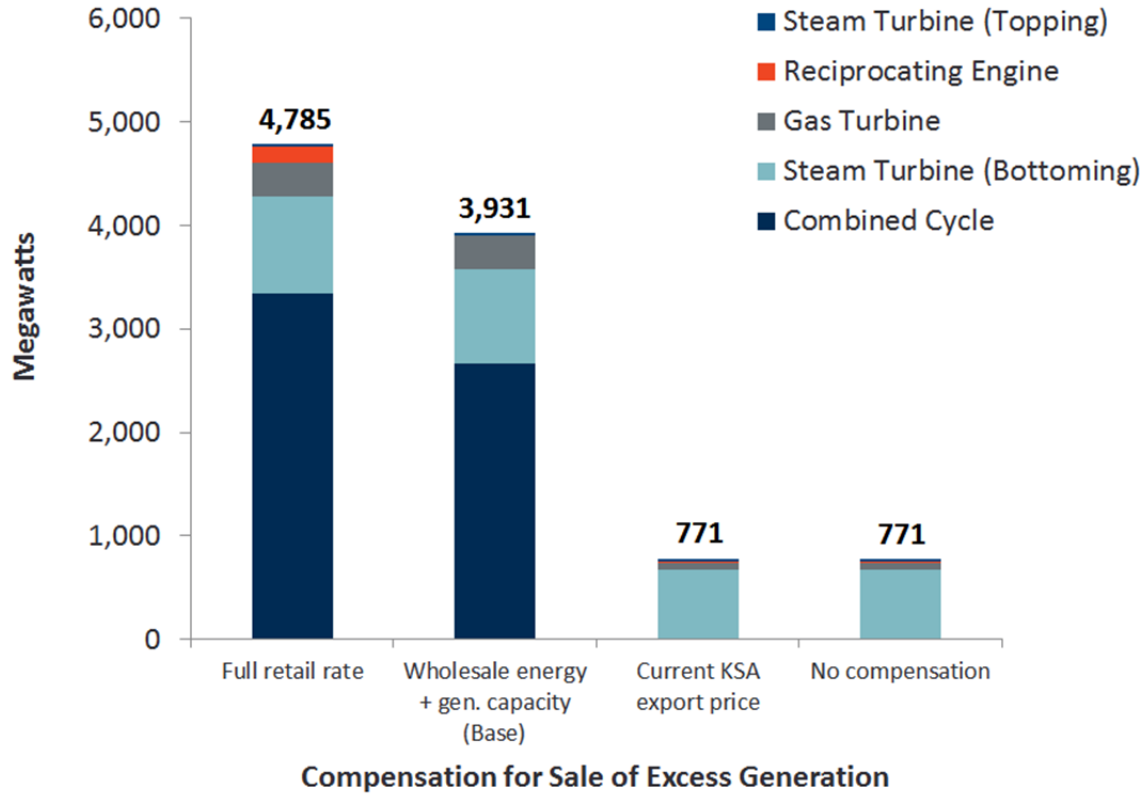
Figure ES-4: Market Adoption as a Function of Payback Period



Sources and notes:
Reproduced from Figure A-2 on Page A-8, Combined Heat and Power: Policy Analysis and Market Assessment: 2011-2030, ICF, with the addition of Brattle Analysis
As noted in the ICF's report,the original source is Primen's 2003 Distributed Energy Market Survey

Using an average adoption rate curve ("Brattle Analysis), we estimate the commercial CHP potential under current domestic prices to be very low. Even assuming that national fuel values of five times domestic fuel prices are used to estimate commercial adoption, the resulting commercial CHP potential would be relatively small and concentrated in a small number of sectors, as shown in Figure ES-5. As the figure shows, in 2040 the market size of CHP ranges between 4-5 GW. This assumes that CHP plants are compensated either at the full retail rate or at prevailing wholesale prices for energy and capacity – essentially receiving the full avoided cost for their power production. Under current rules for the export of surplus energy, only a very small amount of CHP would likely be adopted by the market.

Figure ES-5: Market Potential at Various Export Prices and Price Multiple of 5x (2040)



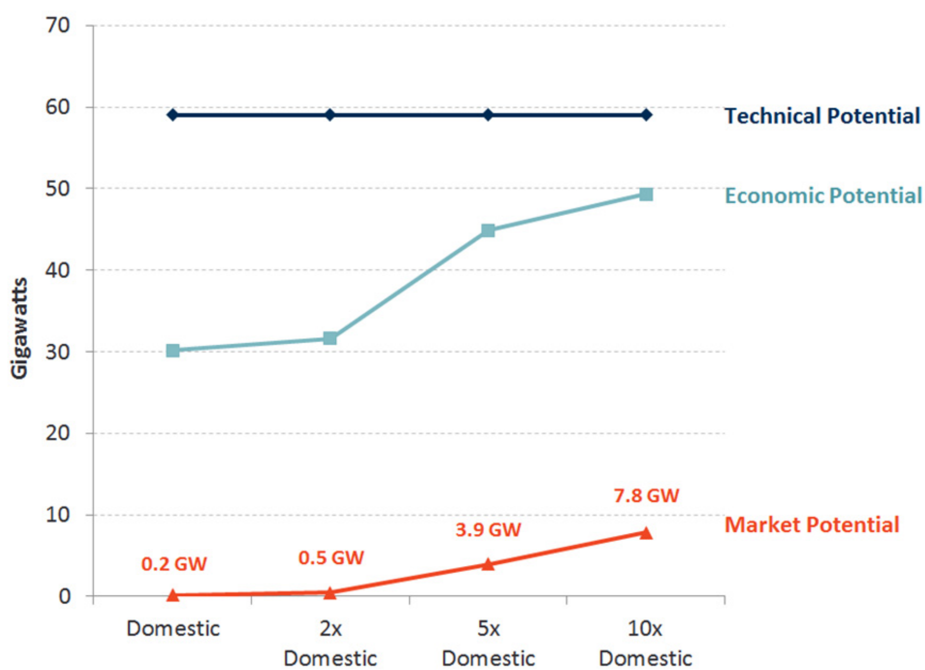
As these figures suggest, for the market potential for CHP to be substantial when compared to overall installed electric capacity in the KSA, several important conditions must likely be met. First, domestic fuel prices likely have to move significantly closer to national fuel values, or at least CHP hosts have to face incentives similar to what they would face in such an environment. While we have not made any assumptions about what those values might be, the fact that CHP potential – economic or market – only becomes significant at approximately five times current prices suggests that unless domestic prices increase significantly or potential CHP customers receive financial incentives that reflect such higher values little CHP deployment should be expected.

Second and somewhat related, since a significant amount of the economic CHP potential in the KSA is for topping cycle applications (where power produced in a plant results in waste heat/steam then used in an industrial or commercial application), and since the most cost-effective CHP in such applications tends to result in significant excess power production relative to local power needs at the CHP site, the terms for selling excess power to the grid are critical. Under current conditions for selling excess power, we would expect little additional CHP to be deployed by the market, as shown above.

Third, as shown in Figure ES-3, the economic potential for CHP in the KSA is limited to a relatively small set of large customers in a narrow set of industrial sectors. They are mostly in the petrochemical sector (our study excludes the refining industry, since CHP is already being deployed there through Saudi Aramco) and several bottoming cycle applications in the iron/steel, aluminum and cement industry.

Finally, also as shown in Figure ES-3, the economic potential for CHP in the KSA, even at valuations of fuel five times current levels of domestic fuel prices, is concentrated among projects with payback periods of five years or longer, with the bulk of projects with "positive" benefit-cost ratios (i.e., ratios greater than unity, where benefits exceed costs) at those higher national fuel values having payback periods of 6 to 8 years. Intuitively, this result is the consequence of the fact that at present the assumed fuel for future baseload power generation will be natural gas and that CHP units are also assumed to use natural gas. As a consequence, there is relatively little economic savings to be derived by switching from more to less expensive fuels (as a matter of fact, on a BTU basis, natural gas would be more expensive than fuel oil, the default fuel for stand-alone boiler applications). Rather, the primary source of savings from CHP is the avoidance of fuel, capital and O&M expenses from stand-alone boiler applications to produce steam/heat. On the other hand, at least in some cases CHP units would not be as efficient as their alternative, namely the construction of natural-gas fired combined cycle plants for the sole purpose of power generation. This is because in some cases the most efficient CHP application calls for a less efficient power generation source, such as a steam turbine or a combustion turbine. For commercial sector applications, any savings we estimated are in fact the result of capital cost savings rather than fuel savings. As a matter of fact, fuel consumption in commercial sector CHP applications tends to be higher than it would be assuming air conditioning is provided with the help of electric chillers alone. This is because, using today's technology, electric chillers operate at very high levels of efficiency. Figure ES-6 summarizes our analysis.

Figure 1: CHP Capacity Potential (2040)



Together, this assessment of the economic and market potential for CHP in the KSA leads us to conclude that a relatively targeted support of CHP efforts in key industrial sectors and size segments is likely to be more promising and economically beneficial for the KSA than broad support strategies for CHP. To the extent broad CHP policies are being pursued in other countries, they tend to be driven by factors such as lowering greenhouse gas emissions..

The Path Forward: Barriers and Solutions

After a careful review of international experience with both barriers and policy solutions, we identified several important barriers that likely prevent the most promising CHP applications in the KSA from being implemented and developed several relatively narrow policy proposals for the KSA.

As stated earlier, domestic fuel prices are relatively low in the KSA. These yield fuel cost savings to be low relative to the incremental capital investment for CHP, creating long payback periods. The situation is exacerbated by the fact that CHP customers will receive low electric prices when they sell excess power to the grid. These two factors, low fuel prices and low electricity prices, represent the most important barriers to deployment of cost-effective CHP in the KSA. Our estimates of economic and market potential for CHP highlighted above show in detail how the attractiveness of CHP increases as domestic fuel prices and prices for the sale of excess power increase.

Many of the more general barriers identified internationally also apply in the KSA context. Among them are the general lack of awareness and knowledge about CHP, lack of skill in operating CHP for a potential industrial host, and the fact that private parties seem to use higher discount rates (or require quicker pay-back periods) for CHP projects than a social perspective suggests should be used.

Based on these barriers, we suggest that a mix of policies aiming at generally improving the economic conditions for CHP through a mix of broad electric sector reforms improving the economic incentives for all energy related investment decisions and some broad policies to help CHP should both be implemented. However, we suggest that the emphasis in the KSA would likely best be placed on developing a relatively targeted set of initiatives to encourage/support the deployment of CHP in the relatively small sectors we identify as promising for CHP. In particular, we propose to use the fuel allocation mechanism already in place and well understood by all local consumers of allocated fuel to create incentives for CHP. Fuel allocation decisions could be made conditional on certain industrial customers demonstrating that they have evaluated the potential for CHP.

We also suggest that unless or until domestic fuel prices are brought more closely in line with national values it will be necessary to bridge the gap between domestic prices and national values for potential CHP hosts. This could be accomplished in a number of ways including the provision of capital grants, soft loans or some form of heat credit, all of which would need to be financed by an entity realizing the national value of fuel savings resulting from CHP. The former two options reduce the upfront capital cost of a CHP project and thus reduce the payback period. A heat credit would likely take the form of a production payment tied to the total electric output (or the heat output) of a CHP facility. It would lower the variable cost (or increase the income stream) for a CHP project and thus also reduce the resulting payback period. The size of either of these should be tied to the difference between prevailing local fuel prices and domestic fuel values.

We also suggest aligning infrastructure and CHP in the sense of promoting the development of CHP specifically in areas with existing gas pipeline infrastructure. Since the KSA is a rapidly developing country, new industrial developments are quite common. Locally, these developments often take the form of new "industrial cities", where common infrastructure is shared by multiple commercial/industrial customers. While it seems tempting to develop CHP in this context to supply process heat/steam and electricity to a range of customers in new industrial cities thus potentially avoiding the necessity of an electric grid connection in remote areas, the pros and cons of this approach should be carefully evaluated since CHP applications for multiple steam hosts are relatively rare. This is likely at least in part a consequence of CHP applications typically being quite host-specific and in part due to complex potential liability issues when steam generation falls short of steam demand, for example during (partial) CHP outages.

To overcome the perceived or actual lack of skill in operating CHP facilities by potential CHP hosts, we also suggest that the KSA should encourage third party ownership and operation of CHP facilities. This is quite normal in many countries and we believe there likely already exists significant expertise amongst existing power generation operators to form a solid basis for safely and reliably operating CHP facilities.

Finally, to increase awareness and technical competence around CHP, we suggest that a mix of technical assistance programs and CHP pilots should be developed.

II. Introduction

Combined heat and power (CHP), also known as cogeneration or in some cases trigeneration, is the simultaneous production of electricity and heat from a single fuel source, such as natural gas, oil, biomass, biogas, coal, or waste heat. CHP is often viewed not as a single technology, but as an integrated energy system that can be modified depending upon the needs of the energy end user. Given the large loads for process heating and cooling in the Kingdom of Saudi Arabia (KSA), there has been growing interest in whether it would be feasible to adopt policies and programmatic frameworks that would lead to wider adoption of CHP technology resources in the country.

ECRA retained a team of consultants ("the team") led by The Brattle Group and assisted by Navigant Consulting, EcoSolutions, and Pierce Atwood, to develop a national roadmap for combined heat and power in the Kingdom of Saudi Arabia ("KSA"). Since April 2014 we have worked closely with ECRA and the National Team tasked with developing the Long Term Plan ("LTP") for energy in the Kingdom to conduct primary and secondary research, analyses and prepare reports in accordance with the scope of work for this project.

The purpose of our study was to assess the variety of available CHP options and then draw on the team's expertise to assess the applicability of those options in the KSA. The analysis considers the cost-effectiveness of the CHP technologies, the existence of various barriers and the identification of policies to overcome those barriers, the market potential for CHP adoption, and regulatory infrastructures that would be needed in order to more firmly establish the resource.

This Final Report summarizes the main elements of our work. It is structured to be consistent with the various tasks under the SOW and includes the following topics:

- Technical Assessment
- Economic and Market Assessment
- Barriers Assessment
- Policy Recommendations

For each of these topics this report contains a summary review, complemented by appendices with further work product for each of the four topic areas.

III. The Technical Assessment

The purpose of the Technical Assessment was to specify the operational characteristics of a wide range of CHP technologies that could feasibly be adopted in the KSA. For example, such characteristics include fixed and variable operations and maintenance costs, up-front capital costs, incremental heat rate, capacity factor, and other characteristics that are needed to assess the economics of each CHP facility. This database of CHP technologies, when combined with an estimate of total demand for steam or waste heat in each industry segment, forms the basis for our assessment of CHP potential. The deliverable for the Technical Assessment included a Microsoft Excel database describing CHP technology characteristics (which we refer to as the "CHP Performance Database"). The CHP Performance Database is provided in Appendix A. An accompanying report describing the database in more detail is provided in Appendix B.

To develop the KSA-specific inputs for the database, the team conducted primary and secondary research. The primary research was conducted by Eco Engineering & Energy Solutions (EcoSolutions), a KSA-based firm with a background in energy efficiency and with numerous business contacts in the KSA. The secondary research was conducted by Navigant Consulting. Primary research consisted of visiting and interviewing local industrial and commercial facilities. The secondary research focused on literature review of internationally recognized CHP sources and drew on Navigant's engineering team's expertise. We incorporated the findings from both research activities to develop technical, operational, and financial characteristics of CHP technologies.

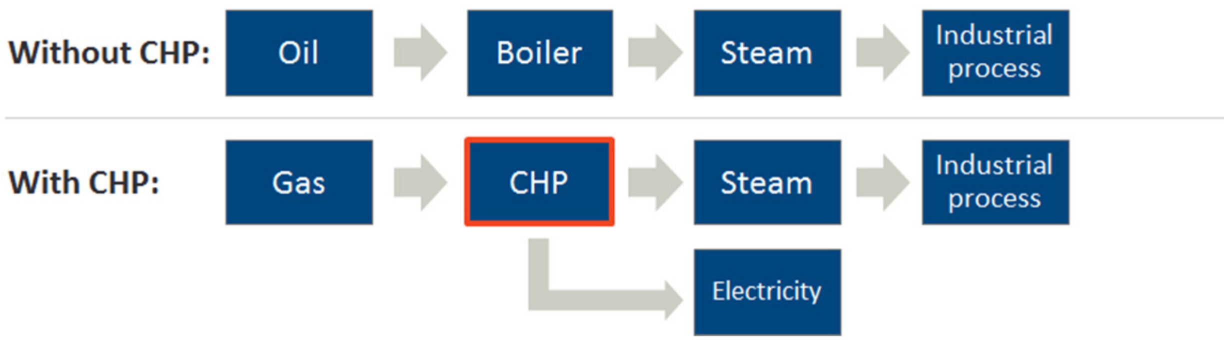
CHP is best applied at facilities that have significant and concurrent electric and thermal demands. Two different types of CHP markets were included in this evaluation of technical potential: 1) industrial and 2) commercial. In the context of the KSA's industrial sector, CHP thermal output is in the form of heat used for industrial processes. For commercial and institutional users, thermal output is used primarily for providing space cooling with absorption chillers. Both of these markets were further disaggregated based on industrial processes and commercial building types, resulting in the analysis of multiple industrial and commercial distinct market segments. We picked industrial market segments with significant production capacities. These are determined by analyzing the KSA industrial production data that was provided to us by the National Team. Internationally cooling with absorption chillers and CHP is only feasible at facilities with large cooling loads. We therefore limited our analysis to commercial market sectors that would require at least 1,000 tons of cooling capacity.

The Technical Assessment and the related CHP Performance Database do not address CHP potential for electric utilities, such as those owned by Saudi Electric Company, desalination plants in the KSA, or facilities owned by Saudi Aramco. These plants were outside of the scope of this study and it is our understanding that the Saudi Aramco and desalination plants are already using or planning to use CHP in the future. However, it should be noted that the CHP potential in these sectors is quite large and should continue to be explored.

A. CHP OVERVIEW

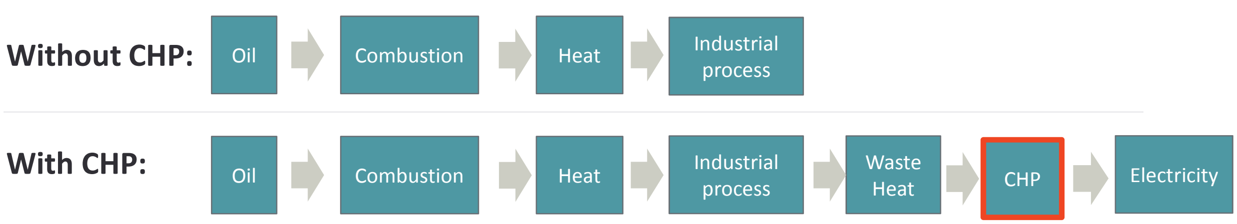
CHP can be characterized as either "topping cycle" or "bottoming cycle" generation. This is an important distinction, in part because it determines the fuel requirements of the CHP system. In a topping cycle application, the CHP plant is used to generate electricity, and the steam that is the byproduct of this activity is captured as thermal energy to drive the applicable industrial processes. The CHP plant acts as a substitute for the boiler that would otherwise be used by the industrial facility to generate steam. This is illustrated in Figure 2.

Figure 2: Illustration of Topping-Cycle CHP for Industrial Customers



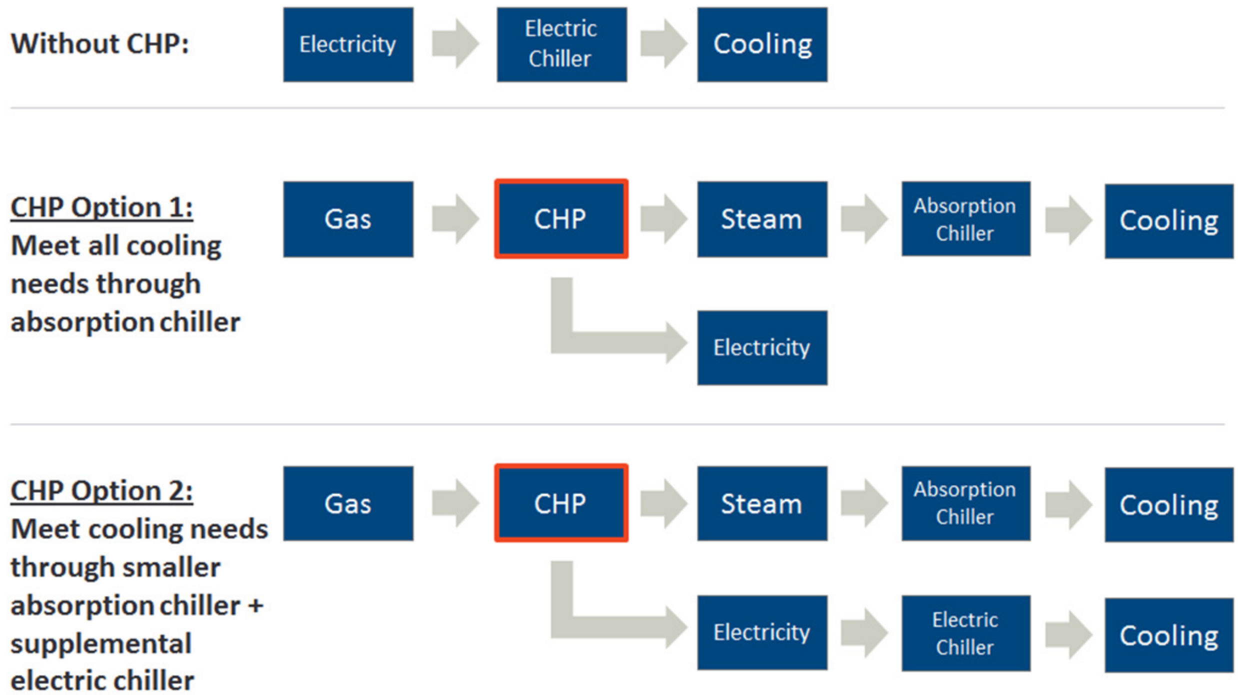
In a bottoming cycle application, waste heat from an existing industrial process is recovered by the CHP plant and used to generate electricity. In this application, there is no difference in fuel consumption with or without CHP. The CHP plant simply utilizes as input the heat that would otherwise be wasted. This is illustrated in Figure 3.

Figure 3: Illustration of Bottoming Cycle CHP for Industrial Customers



In our analysis, industrial CHP applications can be either topping or bottoming cycles depending on the industry and technology. For the commercial sector, all applications are topping cycles and CHP is used specifically to serve the building's cooling needs. We considered two common sizing options for commercial customers. In the first option, the CHP plant is sized to meet all cooling needs through an absorption chiller. The electricity that is produced by the CHP plant is used to serve other non-cooling electricity needs on-site or sold to the grid. In the second option, we assume a smaller sized CHP plant. The plant would meet a portion of the building's cooling needs through the absorption chiller, and would utilize the electrical output of the CHP plant to serve the rest of the cooling needs through a supplemental electric chiller. In this second option there is no excess electricity available for non-cooling loads or for sale back to the grid. The commercial CHP sizing options are illustrated in Figure 4.

Figure 4: Illustration of CHP for Commercial Customers



B. PRIMARY RESEARCH

Primary research for the Technical Assessment consisted of on-site visits to a variety of industrial and commercial potential end users of CHP in the KSA. Common practices were studied, but the nature of this field study was to provide in-depth insight at a few key facilities rather than provide a statistical analysis of the entire country. The on-site visit included interviews with staff able to provide technical details on their industrial process or commercial operation. We used these data to supplement and verify secondary research data, to calibrate assumptions used in the model, and to calibrate energy intensity values as needed. Likewise, some of these primary data were used to directly develop values for inputs in the model where secondary data was missing or not available. We developed surveys to aid the on-site visits and provide a level of consistency in questions asked. Our local partners, EcoSolutions, sent these surveys to several industrial and commercial customers.

Relying on the surveys, we developed KSA-specific operational characteristics of CHP systems. We leveraged survey results to develop inputs for the performance of CHP technologies when employed at industrial and commercial sites. In general, sites that have significant and relatively constant heating and/or cooling loads were visited, as they typically are the best candidates for CHP.

1. Industrial Sector Primary Research

In the KSA, the petrochemical, steel, and cement industries jointly account for 85 percent of industrial electricity consumption.[4] Furthermore, the petrochemical, steel, paper, and cement industries jointly account for 90 percent of industrial steam demand and waste heat. As such, we made sure that the primary research covered these subsectors to a reasonable extent.

Overall, the industrial survey was sent to more than 50 contacts and 14 companies were successfully interviewed. Table 1 shows the details of our survey sample. The sample represents approximately 25 percent of the total tons of material production in the KSA with more than 1.5 gigawatts (GW) of electricity demand. From the 14 companies interviewed, six of them have on-site generators and two of them have CHP units, totaling 600 MW of electricity generation capacity. The study benefited from the diversity and substantial size of the participants.

Table 1: Summary of Industrial Sample

Industry Type	Total Inter-viewed	With On-Site Generation	With CHP	Total Production Capacity (tons)	% of KSA Production [a]	Total MW Demand	Total On-Site Generation MW Capacity
Petrochemical	4	0	1	17,500,000	25%	750 MW [b]	250 MW
Cement	3	3	0	8,500,000	15%	181 MW	259 MW
Iron & Steel	3	1	0	12,000,000	38%	615 MW	16 MW
Paper	1	0	1	200,000	28%	35 MW	12.5 MW
Food Processing	1	1	0	20,000	N/A	20 MW	41.6 MW
Chemical	1	1	0	1,000,000	N/A	6.5 MW	6.5 MW
Glass	1	0	0	7,200 [c]	2%	N/A	N/A
Total	**14**	**6**	**2**	**40,000,000**	**25%**	**1.6 GW**	**0.6 GW**

[a] The percentage of KSA production was calculated as the ratio between the sum of all the reported annual material production amounts and Saudi ARAMCO's annual material production estimates.

[b] Navigant estimated demand for two of the facilities due to missing information.

[c] A glass density of 20 kg/m² is used as a conversion factor.

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4 Saudi Energy Efficiency Center. "Industrial." http://www.seec.gov.sa/2013/03/27/%D8%B5%D9%86%D8%A7%D8%B9%D9%8A/?lang=en

2. Commercial Sector Primary Research

Commercial and government buildings account for over one third of electricity usage in the KSA, with half of this usage going to cooling.[5] Additionally the national team provided insights on the new developments, such as stadiums, social compounds, and multifamily complexes. Based on our understanding of the role of CHP (tri-generation) in this sector, we focused primary data collection efforts on buildings and complexes which have high CHP potential and applicability.

Overall, the commercial survey was sent to more than 100 contacts and 14 companies were successfully interviewed. Table 2 shows the details of our survey sample. The sample represents approximately 650,000 square meters (m^2) of commercial buildings with more than 64,000 tons of cooling capacity. This sample covers all the targeted building types except military base buildings. We were not able to conduct interviews with military buildings due to difficulties in getting permission to fill out the survey. Of the 14 customers interviewed, two have district cooling systems, nine have chillers with some support by packaged unitary or split systems, and two large malls have only packaged unitary or split systems. As with the industrial visits, the study benefited from the diversity and substantial size of the participants.

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[5] Based on data collected during the development of a 2011 study of demand-side management potential in the KSA: The Brattle Group, Global Energy Partners, and PacWest Consulting Partners, "Bringing Demand Side Management to The Kingdom of Saudi Arabia," prepared for ECRA, May 2011.

Table 2: Summary of Commercial Sample

Building Type	Customer	Total Conditioned Area (m²)	Cooling Load (Tons)	Primary Equipment Used To Cool	On-site Generator/CHP
Large Retail/Mall	Jamjoom Commercial Center	N/A	5,100	Chiller	N/A
	Sahara Mall	70,000	5,100	Packaged Unitary/Split	Stand by Diesel Generator
	Panorama Mall	95,000	6,700	Packaged Unitary/Split	N/A
Large Hotel	Sheraton Hotel	13,000	2,400	Chiller	Stand by Diesel Generator
	Riyadh Palace Hotel	20,000	1,100	Chiller	Stand by Diesel Generator
Large Office	Kind Road Tower	N/A	N/A	District Cooling	CHP
	SABIC Headquarters	140,000	3,500	Chiller	N/A
Large Hospital	King Abdul-Aziz University Hospital	54,000	2,575	Chiller	Stand by Diesel Generator
	King Faisal Specialist Hospital	N/A	N/A	Chiller, District Cooling, Packaged Unitary/Split	Diesel Generator
Airport	General Authority of Civil Aviation (KKIA)	100,000	22,500	Chiller	Stand by Diesel Generator
Government Buildings	Ministry of Petroleum & Minerals Resources	24,000	1,500	Chiller, Packaged split/unitary	Stand by Diesel Generator
University	Princess Noura University	N/A	13,000	District Cooling	Stand by Diesel Generator
Stadium	King Fahad Stadium	150,000	1,000	Chiller, Packaged split/unitary	Stand by Diesel Generator
Multifamily Complex and Social Compound	Al Hamra and Cordoba Compound	N/A	N/A	N/A	N/A

C. The CHP Performance Database

The Project Team developed the CHP Performance Database with multiple functions in mind. First, the database provides a comprehensive overview of the applicable technologies for use in the KSA, as well as their technical, operational, and financial characteristics. Second, the database feeds critical inputs into the benefit-cost analysis. Accordingly, we structured the database such that it provides information on operating characteristics and results for a baseline scenario and a CHP scenario. In the following discussion, a "facility" is an industrial or commercial end user that has electricity needs and either thermal power needs or large cooling loads.

The results of the Technical Assessment, which include the technical, operational, and financial characteristics of the technologies that would apply in each scenario, are captured within the CHP Technology Database. The Project Team has classified the results into the categories of fuel consumption, energy production, and financial costs.

In developing the CHP Technology Database, the primary research provided information on KSA specific utilization, load factors, and peak coincidence factors. In addition, we were provided data regarding fuel consumption at the facility level and industrial production at the country level. For the industrial sector, we used fuel consumption as a proxy for either waste heat or fuel requirements. We analyzed this data to segment each industry into large, medium, and small facilities, statistically, and to determine the thermal demand for an average facility in each size segment. After doing so, we used engineering judgment to determine the appropriate CHP technology for each combination of industry and size segment.

For the commercial sector, we first estimated building area by square meters using the commercial survey results and general market knowledge as indicators. We then obtained energy intensity data for commercial building types from the U.S. Commercial Building Energy Consumption Survey (CBECS) as well as the U.S. Department of Energy commercial prototype building models and adjusted this data to better represent the KSA's climate conditions. After converting this energy intensity data (in kilowatt-hours per square feet [kWh/ft^2]) into power intensity data (tons of refrigeration/m^2), we multiplied that data by building area to obtain cooling demand estimates (in tons of refrigeration) for different building types and size segments within the KSA.

The Project Team also conducted secondary research, collected from internationally published studies, articles, and reports, to determine the critical technical, operational, and financial characteristics of each technology. These technologies can be bucketed into four categories: topping cycle CHP units, bottoming cycle CHP units, boilers, and chillers.

We developed a set of five appropriate CHP prime driver technologies for industrial and commercial applications in the KSA. These five technologies are:

- Gas turbines
- Combined cycle turbines
- Reciprocating engines
- Steam turbines (topping cycle)
- Steam turbines (bottoming cycle)

While other CHP technologies, like micro turbines, fuel cells, and solar were considered, they are currently not mature enough to allow a full assessment of their technical potential in the context of the KSA compared to traditional prime movers that drive large facilities. Additionally, micro turbines and fuel cells have limited capacity ranges much smaller than other technologies discussed, while the KSA's primary opportunities for CHP consist of large systems in heavy industry or large cooling loads.

The sources include a number of reports from organizations such as the International Energy Agency (IEA), the Danish Energy Agency, the Indian Renewable Energy Development Agency, the European Union, the World Bank Group, the EPA, the U.S. Energy Information Agency (EIA), the U.S. Department of Energy (DOE), and numerous other sources. In addition, we utilized internal reports from The Brattle Group and Navigant, alongside internal engineering expertise, to develop relationships between CHP unit size and the previously listed characteristics. Documentation within the CHP Performance Database provides a full list of the numerous sources used in this analysis.

All CHP units in the database, in both commercial and industrial sectors, are sized based on projected thermal demand or recoverable waste heat. In the industrial scenarios, CHP units will replace boilers and recover the waste heat. In the commercial scenario, there are two sub-scenarios – the electric chillers will be replaced either by CHP units, electric chillers, and absorption chillers or by CHP units and absorption chillers, as described previously.

D. Findings of Technical Assessment

CHP has significant technical application options beyond the current CHP technologies deployed by Saudi Aramco and the desalination sector. Of primary interest is the petrochemical industrial sector which has many heat intensive and electrical loads that can be simultaneously met by CHP more efficiently than convention means. Other heavy industries, which are abundant in the KSA, are also good technical applications of CHP. Industrial applications can be divided in to topping and bottoming CHP cycles. Topping cycles are best suited to processes where low quality heat is required and is provided by the exhaust coming out of a steam turbine, a gas turbine or a reciprocating engine. Bottoming cycles are employed where the industrial process requires high heat and there are opportunities to recover waste heat for electricity production.

Should the KSA desire to further explore CHP development, the commercial and institutional sectors have considerable technical opportunities. In these cases the heat is primarily used to power absorption chillers that provide chilled water for cooling or refrigeration. Additionally, the heat produced can also be used for any heat or hot water needs; this configuration is sometimes referred to as tri-generation due to the simultaneous production of heat, chilled water and electricity. The complexity of using CHP to provide cooling requires a large cooling load to make the system technically and economically attractive.

The result of the technical study is the CHP Performance Database which pairs technically viable CHP prime mover technologies with KSA-specific applications. The Microsoft Excel-based tool combines data from 28 industrial and commercial KSA sites visited for the primary research as well as 32 referenced sources of secondary data. There are eight tabs detailing the characteristics of CHP prime drivers, boilers, and chillers. Characteristics include capital costs, operation and maintenance costs, heat rates and power to heat ratios, lifetimes, and availabilities all adjusted to capacity sizes. Three calculation tabs are provided that detail how baseline capacities are matched to CHP capacities as well as how the bottoming cycle thermal demand is calculated. The results are concluded in two outputs tabs for the industrial section and the commercial sector. The industrial tab has 127 rows of output matching industrial applications to viable CHP prime driver technologies, summarizing CHP and baseline characteristics including international costs[6] and technology performance. Similarly the commercial tab has 126 rows of output matching commercial applications to viable CHP prime driver technologies.

6 The economic study translates international costs to KSA specific costs.

IV. Economic and Market Assessment

Based on the technical assessment, and using inputs from the National Team related to general data on economic and energy market parameters in the KSA, the team prepared an economic and market assessment for CHP in the KSA. This task involved three discrete steps. First, the technical assessment was combined with data on the current or future composition of various industrial and commercial sectors in the KSA economy to derive an estimate of the maximum amount of CHP that might be deployed in the KSA between 2015 and 2040, assuming that all industrial steam load and waste heat and all commercial cooling loads would be met with CHP applications with the largest possible power to heat ratios (i.e., the technology which, for a given amount of steam production, produces the largest amount of electricity). We refer to this as **technical potential**.[7]

In a second step, using assumptions about CHP costs gathered by Navigant Consulting and KSA-specific costs provided by the National Team, the team developed an estimate of the economic potential for CHP in the KSA between 2015 and 2040. For this purpose, the team developed an economic model, provided to ECRA as a deliverable under the SOW, to first choose, for a certain set of assumptions about fuel costs, electricity rates, etc. the most cost-effective CHP technology for each industry/commercial sector and size segment of the Saudi economy. With the best technology chosen, the model calculated both costs and benefits to derive net present values ("NPV"), benefit cost ratios ("B/C ratios") and payback period for each industry/commercial sector and size segment to identify projects with net economic benefits to the KSA (and/or to individual project sponsors). Aggregating projects with KSA-wide net economic benefits resulted in an estimate of the **economic potential** for CHP under a variety of assumptions.

Finally, taking into account differences in prices faced by society and individual project sponsors – such as retail rates differing from marginal production costs or wholesale prices, and using estimates about adoption rates of projects as a function of payback periods, the team developed estimates of the market potential. **Market potential** is the amount of economically beneficial CHP that would likely be adopted by private parties, for CHP in the KSA.

The following sections describe each of these steps and the resulting estimates of CHP potential in the KSA in more detail. The results of this assessment of CHP potential were presented to members of the National Team at meetings in the KSA in January 2015. The final presentation from those meetings is provided in Appendix C.

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7 Since estimates of technical potential are not constrained by economics, there are several somewhat arbitrary ways in which the most applicable technology for each customer segment can be chosen. In this case, we have chosen the technology that maximizes electrical output. This differs from estimates of economic and market potential, which choose the technology that maximizes societal cost-effectiveness.

A. THE MODELING FRAMEWORK

To assess the potential for CHP in the KSA, we developed a bottom-up market assessment model which we refer to as the CHP Potential Model.[8] The purpose of the CHP Potential Model is to identify the maximum amount of CHP that would be installed in the KSA under various market and policy scenarios. We use the model to evaluate three specific types of potential:

- Technical potential: The maximum amount of CHP that could be installed in the KSA regardless of cost-effectiveness. This establishes a technical upper-bound on the amount of CHP that could be installed; however, it is not a realistic estimate of CHP adoption.

- Economic potential: The amount of CHP that would be installed if all cost-effective projects were pursued, where cost-effectiveness accounts for all societal benefits and costs at domestic or shadow prices.

- Market potential: The amount of cost-effective CHP that would be installed after accounting for barriers to adoption; this amount changes as new policies are introduced to overcome the barriers.

The CHP Potential Model consists of two sub-modules. The Technology Cost-Effectiveness Module evaluates the cost-effectiveness of each available CHP technology option for the average customer in each customer segment. Inputs to the Technology Cost-Effectiveness Module include economic market characteristics (such as fuel prices and electricity prices), CHP characteristics (as codified in the CHP Performance database), boiler characteristics (to establish the fuel needs and costs associated with the alternative to CHP), customer characteristics (such as the average thermal load per customer), and policy assumptions (such as any financial incentives that are provided to promote the adoption of CHP).

The cost-effectiveness of CHP can be considered from two perspectives. One important perspective in the analysis is that of the CHP owner. The costs to the owner (referred to as the "participant") include the cost of installing and running the CHP plant.[9] The benefits are determined largely be the avoided cost of installing and running a boiler or chiller, the avoided retail electricity rate for on-site electricity consumption, and revenue from selling excess electricity to the grid. In other words, for the participant, the value of the additional electricity generated by the CHP facility is largely determined by the retail rate and the compensation

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8 The CHP Potential Model is provided in Appendix D.

9 An ECRA decision from January 2014 suggests that customers who cannot provide reserves of 11.5% of their total CHP capacity must pay $382,000/kW-year for any capacity needed to reach the 11.5% threshold. We do not include this charge in scenarios where retail rates are assumed to be based on marginal costs, because it is not clear that this charge is derived from marginal cost estimates. In scenarios based on existing rates, inclusion of this charge may lead to slightly smaller potential than we report in this study, but the impact would be minimal given the small size of the charge and would not change our conclusions.

mechanism that is in place for sales of excess electricity to the grid. This is different from the societal perspective in the sense that the societal benefits of the CHP facility include all avoided costs regardless of whether or not they are actually realized by the owner of the CHP facility. These benefits would include, for example, avoided or deferred need for new generating capacity and T&D capacity attributable to reductions in system peak demand.[10]

The customer economics of CHP are illustrated in Figure 5. As an example, the figure details the economics of a 28 MW gas turbine being used as CHP for a large paper mill. The benefits are assessed at current domestic prices. For this specific application, total costs are slightly higher than total benefits over the 20-year useful life of the facility, from the participant's perspective. In this example, this project would not contribute to the economic (or market) potential of CHP since it would not pass an initial benefit-cost screening test, which requires benefits to exceed costs on an annualized (i.e., discounted) net present value (NPV) basis.

Figure 5: Economics of Gas Turbine CHP for Large Paper Mill at Current Domestic Prices

Costs

	USD (thousands)
CHP capital cost, net of financial incentive ($)	30,229
CHP fuel ($/yr)	1,169
CHP variable O&M ($/yr)	807
CHP fixed O&M ($yr)	188
Total annualized cost ($/yr)	**4,800**

Benefits

	USD (thousands)
One-time avoided boiler/chiller capital cost ($)	1,042
Annual avoided on-site electricity cost ($/yr)	1,291
Annual revenue from electricity sales to grid ($/yr)	2,586
Annual avoided boiler/chiller variable O&M cost ($/yr)	153
Annual avoided boiler/chiller fixed O&M cost ($/yr)	290
Annual avoided boiler fuel cost ($/yr)	245
Total annualized benefit ($/yr)	**4,656**

A comparison of the time pattern of up-front capital cost of the CHP facility to the incremental annual cost-savings (i.e., fuel, O&M, and electricity) in Figure 5 below shows that the <u>undiscounted</u> payback period for this specific application is 12.2 years – longer than most private investors are willing to tolerate as a threshold for investment. Accounting for the time value of money further illustrates the lack of cost-effectiveness of this particular application and is consistent with the conclusion in Figure 4 above that the discounted benefits are outweighed by the discounted costs. Specifically, the discounted cash flows would require 23 years to reach positive net present value – three years longer than the 20 year life of the facility, demonstrating that this particular application is not cost-effective at current domestic prices.

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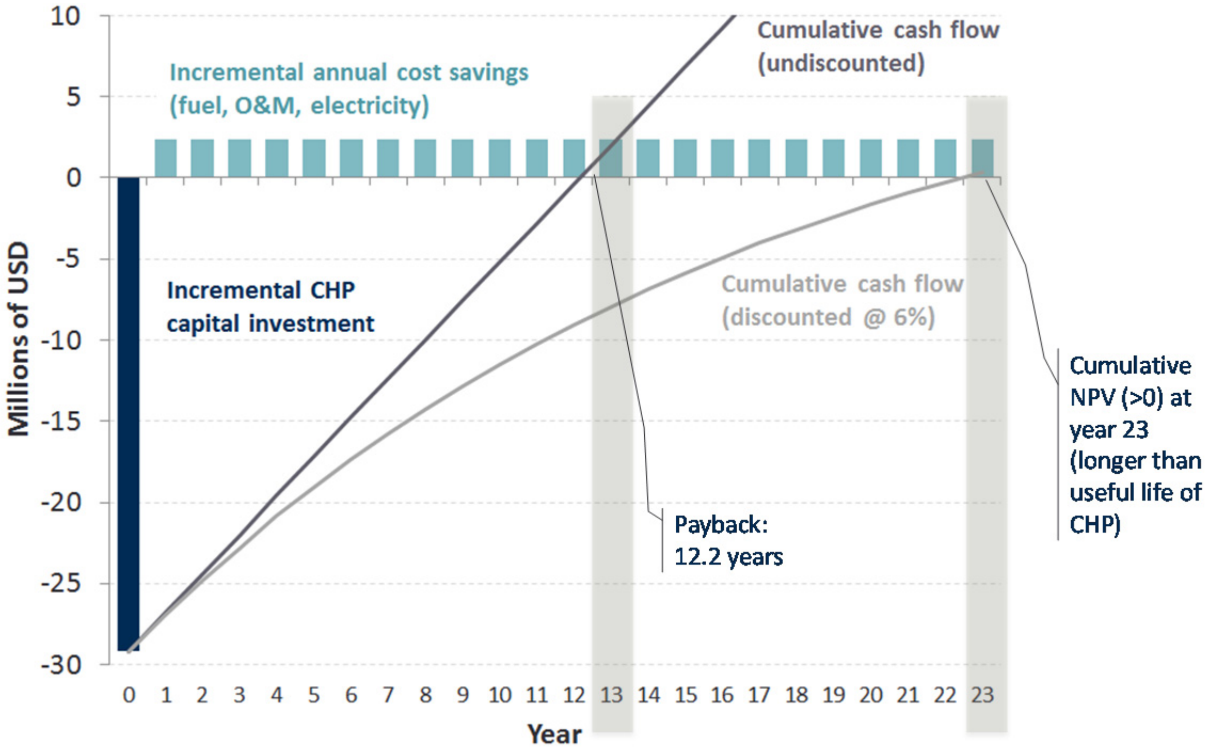
10 CHP plants may provide ancillary services benefits as well. In our modeling, we assume that the ancillary services benefits provided by the CHP plant are the same as those provided by the marginal power plant that the CHP unit is replacing. In other words, the two cancel each other out and there is no net gain or loss of ancillary services. This may slightly overstate the ancillary services benefit of the CHP plant since it is likely to face more significant operating constraints by virtue of being tied to an industrial process.

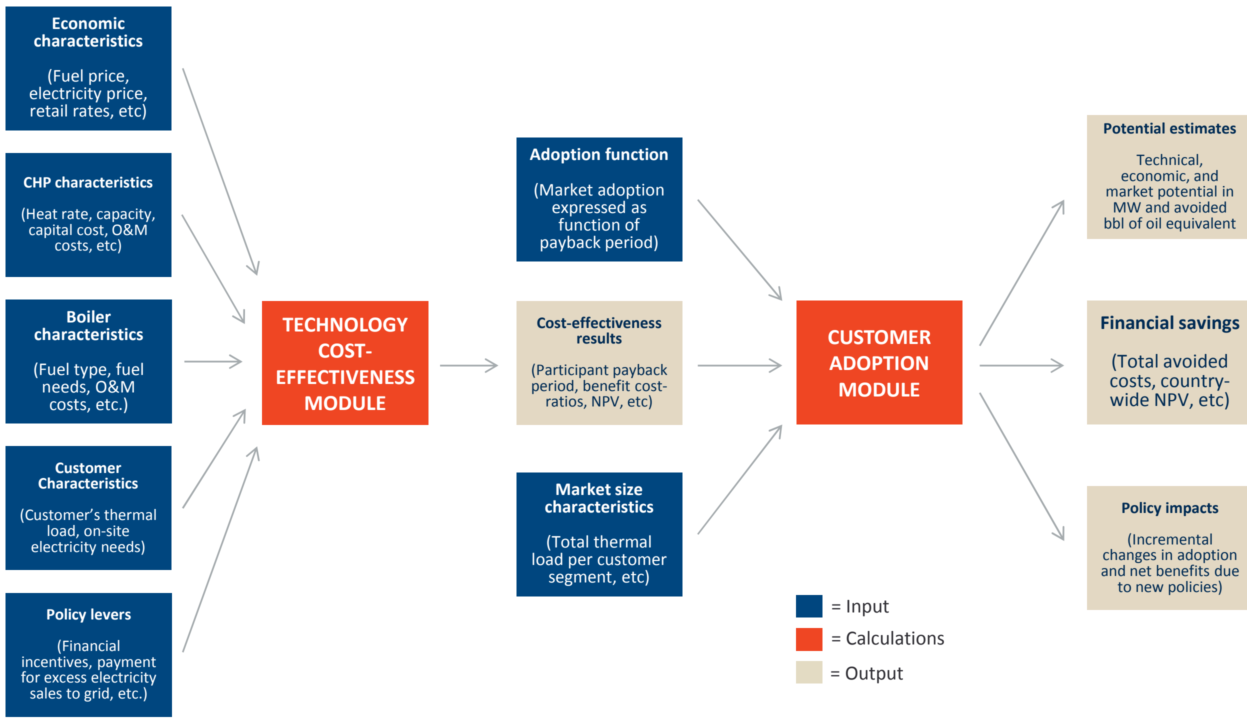
Figure 6: Cash Flows of Investment in Gas Turbine for a Large Paper Mill at Domestic Prices



The Customer Adoption Module then identifies the most cost-effective CHP technology option for each customer segment and projects KSA-wide adoption of the technology. Inputs to this module include the technology-specific cost-effectiveness results of the Technology Cost-Effectiveness Module, an assumed adoption function which expresses the likelihood of technology adoption as a function of the technology's payback period, and market size characteristics (such as the total thermal load per customer segment).

The output of the CHP Potential model is an estimate of the potential CHP adoption by customer segment and by year for the three potential scenarios described above. The model also reports financial savings associated with these scenarios (such as avoided costs of new generation capacity). A flow chart describing the inputs and outputs of the CHP Potential Model is provided in Figure 7. For more detail on the mechanics of the model, see Appendix C.

Figure 7: Illustration of the CHP Potential Model



Embedded within the CHP Potential Model are some key assumptions which were developed through several meetings with members of the National Team. These assumptions are as follows:

- All facilities are assumed to be grid connected during the analysis period. This simplifies the analysis and is consistent with an expectation that facilities that are not currently grid connected will become connected in the future.

- All conventional boilers (existing and new) are assumed to run on oil, but none are assumed to use diesel.

- All new CHP installations will run on natural gas. This is consistent with planning assumptions by various parties in the KSA.

- For industrial facilities, we assume that CHP is installed either at new facilities or when the life of the boiler at existing facilities expires. Retrofitting CHP to replace an existing boiler before the end of its useful life was considered to be prohibitively expensive. For the life of existing boilers we assume a flat distribution of vintages between 0 and 20 years old.

- For commercial facilities, we assume that CHP is only considered an option for new buildings. Through a qualitative screening process we have determined that it would be too expensive to retrofit most existing buildings.

- The vast majority of new generation capacity additions in the KSA are likely to be natural gas-fired combined cycle units. Therefore these units are considered the marginal units that are avoided through the installation of new CHP capacity. This assumption is our basis for calculating avoided energy and capacity attributable to new CHP.

B. Establishing Steam and Waste Heat Demand in the KSA

To establish estimates of CHP potential, we first determined the total applicable market for CHP in the relevant commercial and industrial sectors in KSA. The deliverable associated with this task includes a Microsoft Excel-based model which identifies total steam and waste heat demand for industrial and commercial sectors by industry and building type, respectively (which we refer to as the "Market Characterization Database"). To develop the KSA-specific inputs for the database, the Project Team leveraged the primary and secondary research conducted by Navigant and EcoSolutions to inform the CHP Performance Database. Additional secondary research from internationally recognized sources, combined with data provided by the National Team supplemented the analysis. The following section details methodology and additional data sources used to establish thermal load and waste head demand by sector in the KSA. The Market Characterization Database is provided in Appendix E.

1. Methodology – Industrial Sector

The Project Team identified industrial market segments with significant production capacities by analyzing the KSA industrial production data provided by the National Team. We developed a market size and corresponding CHP potential estimate for all industries included in these KSA-specific industrial production data.

Whether an industry requires a topping or bottoming cycle CHP plant is a key technical consideration that directly determines CHP market size in a given industry. Therefore, the Project Team segmented the industrial market sizing analysis into two different methodologies.

In a bottoming cycle, CHP potential is a function of the industrial steam demand of each industry subsector. However, for a topping cycle, CHP potential is a function of waste heat in each industry. The Project Team conducted extensive research on energy intensity, waste heat, and steam demand of each industry in the KSA, using data collected in the field by EcoSolutions combined with a variety of international sources such as the OECD, IEA, and EIA. Note that the Market Characterization Database provides a full list of the numerous sources used in this analysis. Using these energy intensities, the Project Team converted industrial production forecasts provided by the National Team into steam demand and waste heat estimates, used in the calculation of CHP potential for topping and bottoming cycles respectively.

Our analysis includes small, medium, and large facilities within each subsector of industry. The Project Team applied different "best fit" CHP technical performance attributes (e.g. capacity, load factor, utilization, etc.) to each facility size, based on the analysis conducted in the CHP Performance Database (described in Task 2). The Project Team analyzed the census of existing industrial facilities in the Kingdom and their relative production capacities to develop size class allocations specific to each industrial subsector. [11]

In our analysis, the total CHP market is characterized by the number of CHP generators (or units) that could be installed in a particular sector in a given year. The quantity of CHP units is based on the industrial waste heat or steam demand of a particular industry combined with typical CHP size and technology pairings drawn from the CHP Performance Database. The Project Team developed cumulative CHP potential units for different size classes of facilities in all subsectors of industry between 2014 and 2040.

To summarize, the industrial market analysis entailed a combination of the following factors to develop an estimate of the total applicable CHP market for different size classes of facilities in all subsectors of industry between 2014 and 2040.

1) The conversion of Kingdom industrial production forecasts into waste heat and steam demand forecasts using factors obtained from onsite research and secondary sources.
2) Analysis of a census of existing industrial facilities in the Kingdom to provide a size allocation of "small, medium, or large" facilities as a percent of each subsector's industrial production.
3) Application of technical characteristics from the CHP Performance Database to match "best fit" CHP technologies with particular industries and determine the number of CHP units necessary to satisfy waste heat or steam demand forecasts.

2. Methodology – Commercial Sector

Cooling with absorption chillers and CHP is only feasible at facilities with large cooling loads. We therefore limited our analysis to commercial market sectors that would require at least 1,000 tons of cooling capacity. Furthermore, based on data collected from primary research in KSA, we assumed that retrofit of existing commercial facilities with CHP would be cost-prohibitive due to the need to install large-scale district heating systems in urban environments. Therefore, the commercial potential for CHP is limited to new construction of commercial buildings only.

The commercial assessment considered all building types surveyed as part of the primary data collection effort, as well as buildings known to be conducive to CHP development internationally. The Project Team estimated the total cooling load in commercial buildings using KSA-specific past and forecast commercial floor space and electricity consumption data provided by the National Team. Past research informed the portion of total commercial floor space and/or electricity consumption allocated to specific building types.[12] Finally, to determine the cooling load as a percent of total electricity load for each building type, the Project Team leveraged U.S.

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11 Data provided by the National Team.

12 Brattle (2011): "Bringing Demand Side Management to The Kingdom of Saudi Arabia."

Department of Energy Commercial Prototype Building Models developed with EnergyPlus building energy simulation software to run a series of simulations by building type in the Riyadh climate zone. For certain buildings without a standard prototype model (such as refrigerated warehouses) the Project Team used secondary research to determine the portion of the facility's total electricity load that is typically used for cooling in the Riyadh climate.

As in the industrial sector, the Project Team determined the saturation of different facility sizes by building type using KSA-specific data from past research[13]. In some cases, the "small" segment of each building type did not possess sufficient cooling load (>1000 tons) for a single CHP unit, so those segments were eliminated from the analysis. For the remaining segments, the size of the potential CHP market is a function of the annual growth in cooling load in each commercial sector combined with typical CHP size and technology pairings drawn from the CHP Performance Database. Because CHP can only feasibly be applied to new construction, we used electricity growth forecasts to determine additional KSA cooling load in each year, and based our estimates on annual additional load rather than total existing load.

To summarize, the commercial assessment entailed a combination of the following factors to develop a cumulative estimate of the applicable market for CHP for different size classes and types of commercial buildings between 2014 and 2040.

1) The conversion of Kingdom commercial floorspace and electricity consumption forecasts into cooling load by building type in the Riyadh climate.
2) Analysis of past data on KSA electrical demand[14] to provide a size allocation of "small, medium, or large" facilities as a percent of each commercial sectors' electricity consumption.
3) Application of technical characteristics from the CHP performance database to match "best fit" CHP technologies with particular commercial buildings and determine the number of CHP units necessary to satisfy cooling load requirements for each building type

3. Steam and Waste Heat Demand Projections

As shown in Figure 8, there is a large demand for steam and waste heat in relevant KSA industries. The largest are the petrochemical, iron, steel, and cement industrial subsectors.

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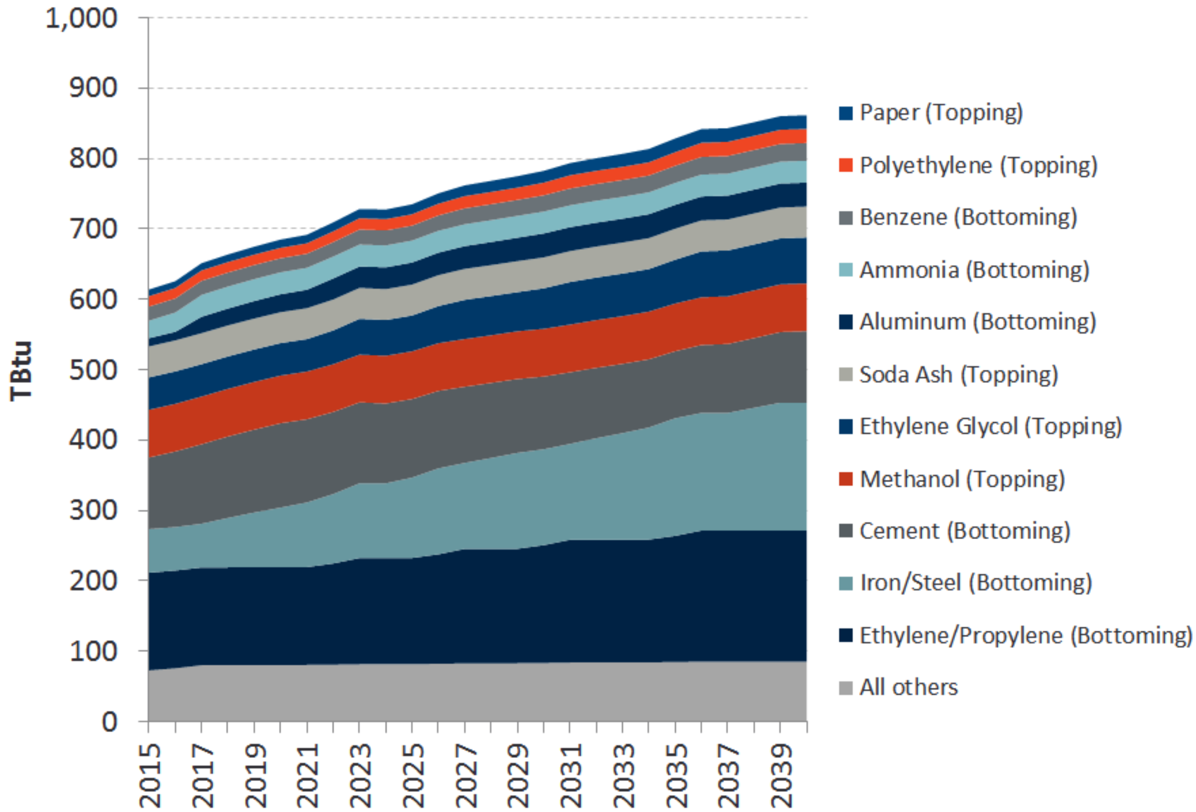
13 Ibid.

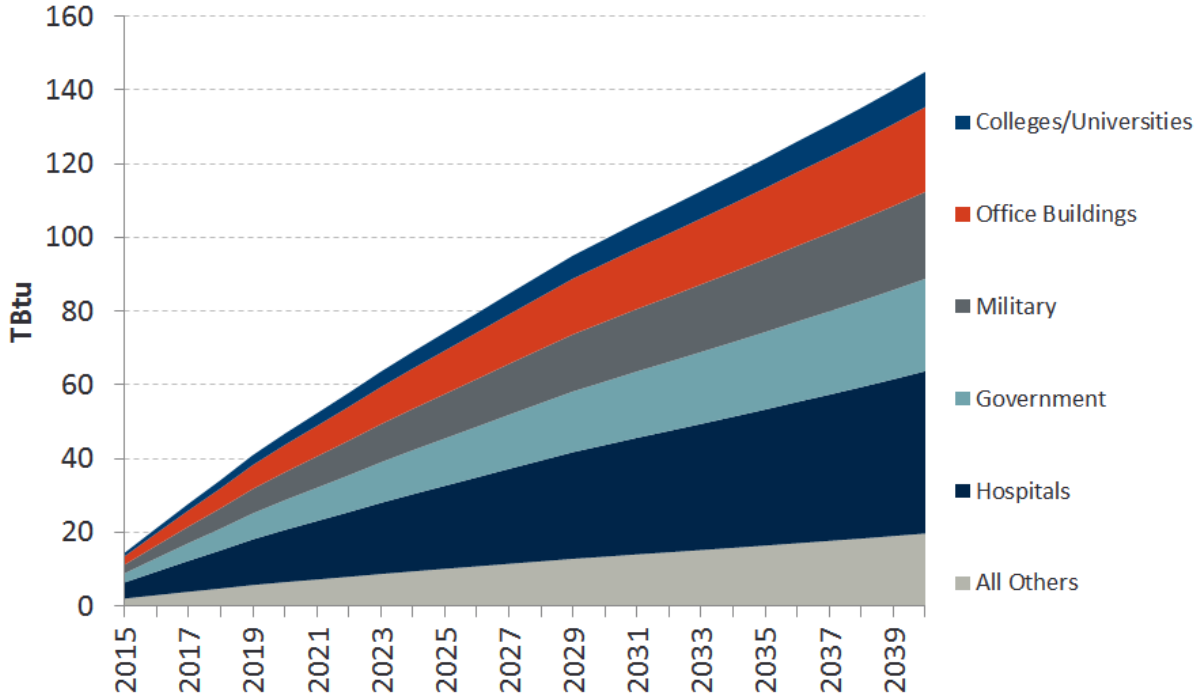
14 Ibid.

Figure 8: Eligible Industrial Steam and Waste Heat Demand



As commercial potential applies to new construction only, the applicable market for CHP is small in 2015, yet increases substantially over time as KSA's total cooling load grows with new construction of commercial facilities. This is shown in Figure 9.

Figure 9: Eligible Commercial Cooling Demand



Notes:
All commercial applications are topping cycle
Commercial cooling demand only reflects new construction

C. Technical Potential

Technical potential is calculated by applying the CHP technology with the largest electric capacity to total steam or waste heat demand in each customer segment.[15] It assumes that 100% of customers in the segment adopt the technology, regardless of cost-effectiveness. ***Technical potential is therefore a theoretical upper-bound and its only purpose is to serve as a point of reference against which economic and market potentials, defined below, can be judged.***

The technical potential for CHP in the KSA is large. By 2040, it represents roughly 50% of system peak demand and accounts for nearly 60 GW of capacity.[16] Technical potential by year is

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15 Since estimates of technical potential are not constrained by economics, there are several somewhat arbitrary ways in which the most applicable technology for each customer segment can be chosen. In this case, we have chosen the technology that maximizes electrical output. This differs from estimates of economic and market potential, which choose the technology that maximizes societal cost-effectiveness.

16 Throughout this report, our estimates of CHP potential are incremental to existing and planned installations by Saudi Aramco at its facilities.

summarized in Figure 10. To put the figure in context, it is compared to system wide peak demand and electricity consumption forecasts from the National Team. These forecasts are for a future in which moderate reforms significantly reduce demand through targeted demand-side and supply-side activities

Figure 10: Technical Potential for CHP

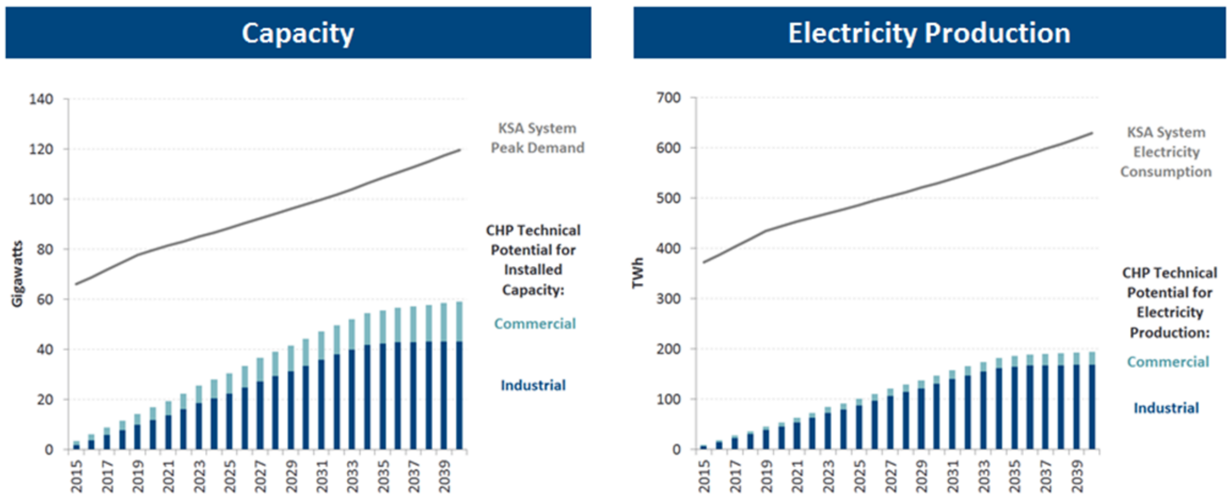


Figure 10 shows a "flattening" of the growth in potential around year 2035. This is attributable to the assumption that the lifetime of existing industrial boilers is evenly distributed over 20 years. Growth in CHP potential prior to 2035 is driven both by the replacement of existing boilers as their useful life expires and the installation of CHP in new facilities. After 2035, all existing boilers have been replaced and growth is driven only by the addition of new facilities.

Figure 10 also shows CHP contributing a proportionally higher share of capacity relative to the KSA peak than of energy relative to KSA energy consumption. This is equivalent to the CHP capacity factor being lower than the KSA system load factor. This can be partly explained by this study not considering CHP for residential applications (as long as residential demand contributes proportionally more to total system energy consumption than to system peak-coincident demand, which is at least possible given the lack of coincidence in the class and system peaks). Additionally, CHP units are sized to serve total thermal load of industrial facilities and the cooling needs of commercial facilities. Both assumptions act as limiting factors for CHP units' capacity factors - as a result, many of the industrial CHP applications analyzed have an annual capacity factor of less than 50% and many commercial application have a capacity factor of less than 20%. It is also apparent than the industrial and commercial sectors contribute different proportions of CHP capacity and energy potential. This is because industrial CHP applications tend to have higher capacity factors than commercial applications by virtue of being tied to year-round industrial processes rather than seasonal cooling needs.

It is possible that these estimates overstate the technical potential to some degree, since CHP potential could be limited by off-peak electricity demand. If CHP output exceeds system-wide demand during off-peak hours, it would either have no value or become an export (if feasible).

This effectively caps the domestic CHP economic potential at around 36% of peak, beyond which electrical output would begin to be exported in some hours (based on the 2013 system load duration curve for the SEC interconnected grid). This also assumes that CHP is running mostly to serve base load; to the extent that it is seasonal or has output concentrated more heavily in peak hours, potential would be higher. In the future, the addition of inflexible resources like nuclear and renewables could make this constraint more relevant.

We advise against drawing any specific conclusions from estimates of technical potential and provide it for completeness and as a reference point. Any policy decisions regarding CHP should account for cost-effectiveness, as is done in the estimates of economic and market potential.

D. Economic Potential

Economic potential accounts for the cost-effectiveness of CHP and assumes that CHP technologies will only be adopted if total societal benefits are greater than total societal costs over the lifetime of the CHP plant. If more than one CHP technology option is deemed cost-effective for a given customer segment, the technology with the highest benefit-cost ratio is chosen for all customers in that segment. While economic potential is less than technical potential due to this cost-effectiveness screen, it still assumes 100 percent participation for those technologies that are deemed cost-effective. In other words, ***economic potential does not account for practical considerations that limit the number of customers who will choose to adopt a cost-effective CHP technology.*** These considerations, for example, could include limited access to capital, perceived operational risk associated with self-generation, or uncertainty around access to fuel for the CHP plant. A comprehensive discussion of barriers to adoption is provided in Chapter V. Regardless, economic potential is a useful metric because it represents the total amount of cost-effective CHP potential if all barriers to adoption were overcome.

At current domestic energy prices, economic potential is roughly half of technical potential. By 2040, whereas technical potential is around 60 GW of capacity and close to 200,000 GWh of annual electricity production, economic potential is around 30 GW of capacity and slightly over 100,000 GWh of electricity production. This is still a large amount of CHP potential, representing roughly 20 percent of the projected system peak demand.

An important consideration when estimating economic potential is the assumed price of energy. Domestic fuel prices in the KSA are heavily subsidized, which leads to artificially low electricity prices. The electricity prices are further depressed through subsidies in retail rates for residential and industrial customers. Assessing economic potential at a range of multiples of the current domestic price of energy provides perspective on CHP potential if fuels in the KSA were priced at a value closer to the international market price. To capture a reasonable range of possible fuel prices, we have analyzed CHP potential at multiples of 2x, 5x, and 10x the current domestic price. The fuel costs associated with these price multiples are summarized in Table 3 below.

Table 3: Fuel Prices at Various Multiples of the Current Domestic Price

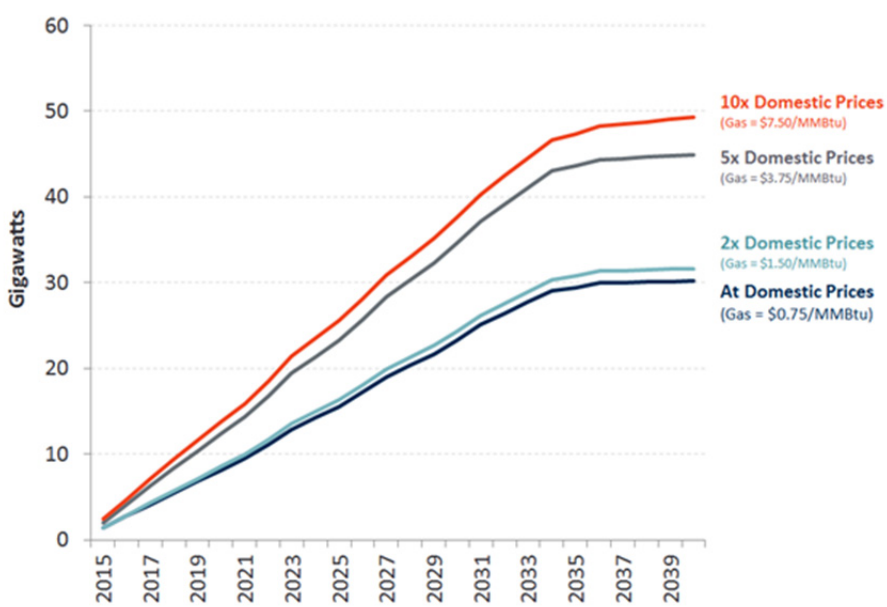
Price multiple	Natural Gas ($/MMBtu)	Fuel Oil ($/MMBtu)	Fuel Oil ($/bbl)
Current domestic	0.75	0.34	1.95
2x current	1.50	0.68	3.89
5x current	3.75	1.70	9.73
10x current	7.50	3.40	19.46

Source of current domestic price: Saudi Aramco

Note: The fuel oil price is approximately 35% to 50% of the price of Arabian Light Crude (depending on region)

Economic potential increases considerably as the price of fuel and electricity rises. At 5x the current domestic price, CHP capacity potential increases by roughly 50% and at 10x the current domestic price, it increases by more than 60% relative to the analysis at current domestic prices.[17] Figure 11 below summarizes the annual economic potential for CHP capacity at these price multiples.

Figure 11: Economic Potential for CHP Capacity

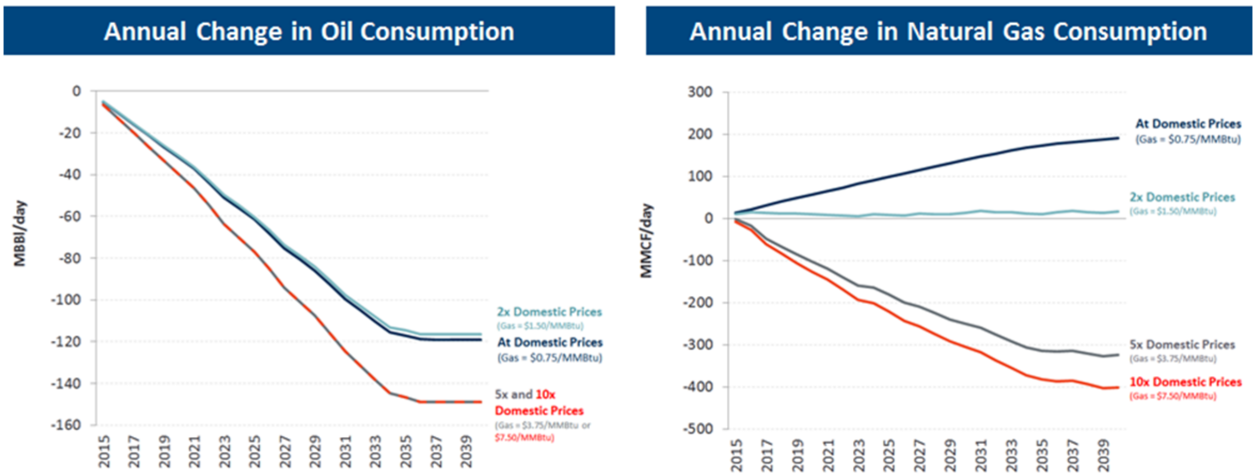


While the economic potential for CHP capacity is significant, the fuel savings associated with the operation of this capacity are quite modest. Even at 10x current domestic fuel prices, oil savings will only reach a rate of roughly 150,000 bbl/day by 2040. These oil savings are associated entirely with a reduction in the fuel that is consumed in boilers at industrial and commercial facilities, which accounts for just a fraction of the total KSA-wide oil consumption. Natural gas savings are also small and dependent on the assumed energy price. At current domestic energy

[17] This highlights that the relationship between price and CHP potential is non-linear.

prices, natural gas consumption will actually increase. This is attributable to investment largely in steam (topping) technology, which has an efficiency disadvantage relative to new gas-fired combined cycle units that are being added to the KSA's supply mix. At higher prices, investments would be made in other more efficient CHP technologies, and reduced line losses would provide some additional reduction in natural gas consumption. Investment in bottoming cycle applications would also drive a net reduction in natural gas consumption since these technologies rely on waste heat and require not additional fuel to generate electricity. The net change in oil and natural gas consumption for economic potential at various price multiples is illustrated in Figure 12.

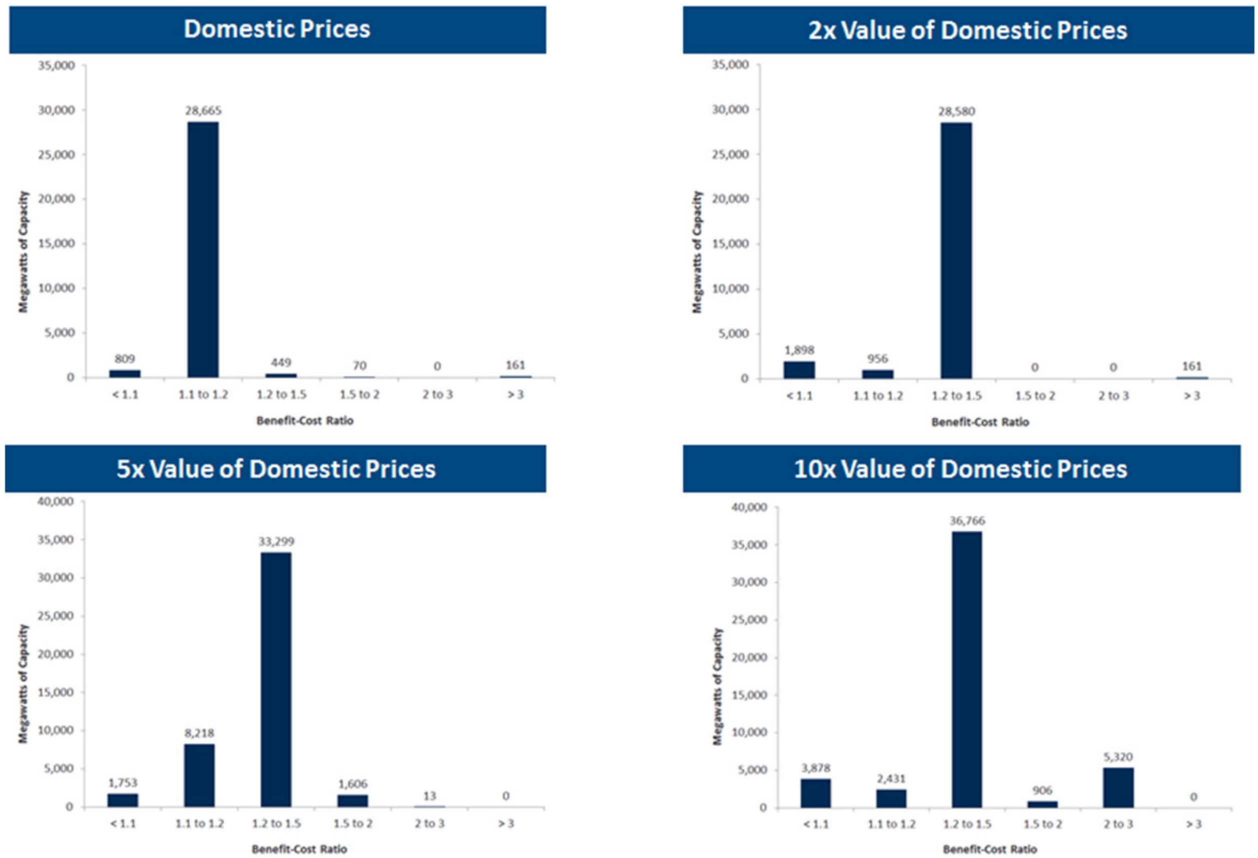
Figure 12: CHP Economic Potential - Change in Fuel Consumption



While all economic potential is by definition cost-effective, a key consideration from a policy perspective is, by how much do the benefits of CHP outweigh the costs? Projects with a higher benefit-cost ratio (and, correspondingly, a lower payback period) are more attractive targets for new policies that promote CHP adoption, relative to projects that are only very marginal in their cost-effectiveness.

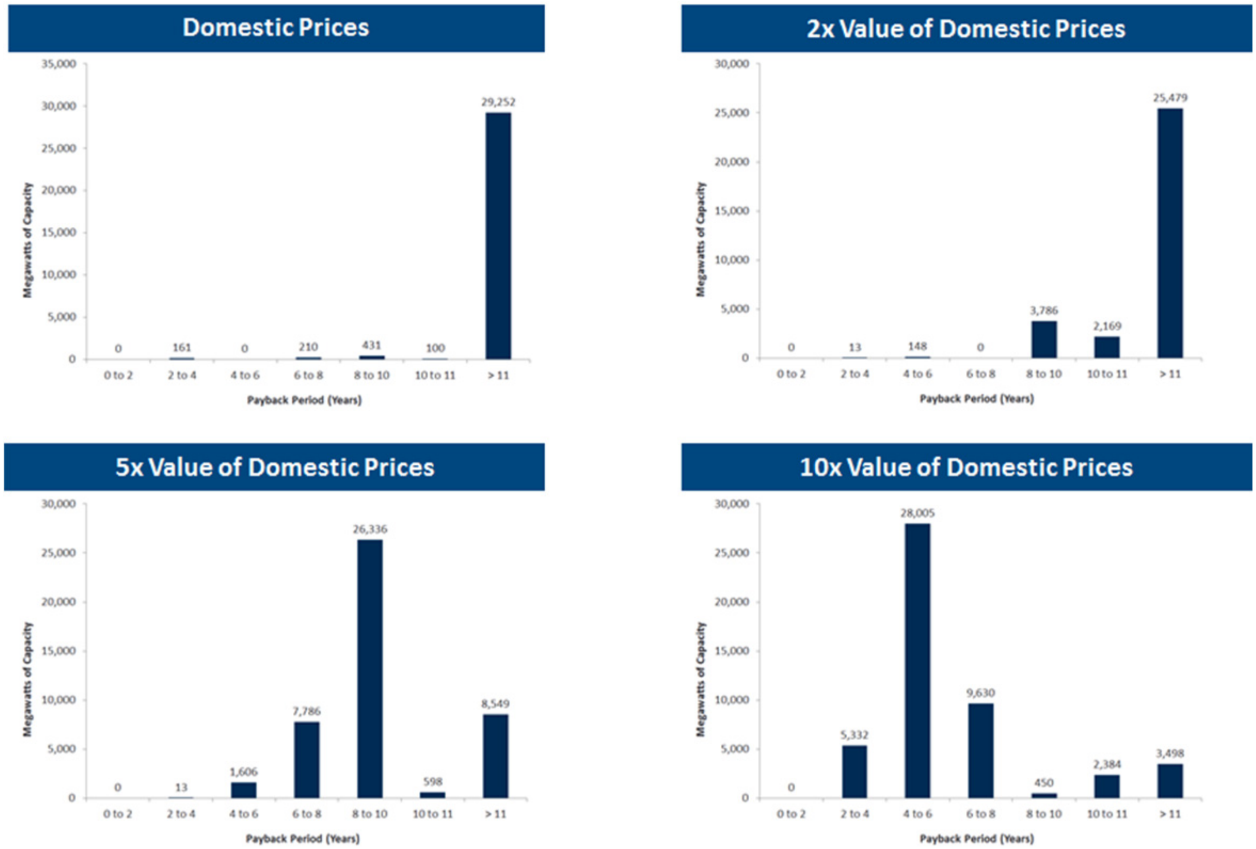
At current domestic prices, the vast majority of cost-effective CHP projects have a benefit-cost ratio of between 1.1-to-1 and 1.2-to-1. This is a relatively low benefit-cost ratio which suggests that much of the CHP potential is only marginally cost-effective. At various multiples of the domestic price, the benefit-cost ratio improves significantly. For example, at a price multiple of 5x, most of the cost-effective CHP potential has a benefit-cost ratio of between 1.2 and 1.5. At a price multiple of 10x, there is over 5 GW of capacity with a high benefit-cost ratio of between 2 and 3. The distribution of benefit-cost ratios for economic potential at various price multiples is summarized in Figure 13.

Figure 13: Distribution of Economic Potential Across Benefit-Cost Ratios (2040)



The economics of CHP can also be assessed based on the payback period for participants. The payback period is a particularly important metric because, as discussed below in the Market Potential section of this report, it is the primary driver of a customer's willingness to invest in CHP. At current domestic prices, virtually all economic potential has a payback period of more than 11 years. This means that it would take more than 11 years for a customer who invests in CHP to recover the investment. However, at higher energy prices, this outcome changes dramatically. At 5x domestic prices, there is 1.6 GW of capacity with a payback of four to six years and 7.8 GW of capacity with a payback of six to eight years. These are payback thresholds at which some customers would be expected to adopt CHP. At a multiple of 10x domestic prices, there is over 32 GW of economic capacity with a payback of less than six years. This is shown in Figure 14.

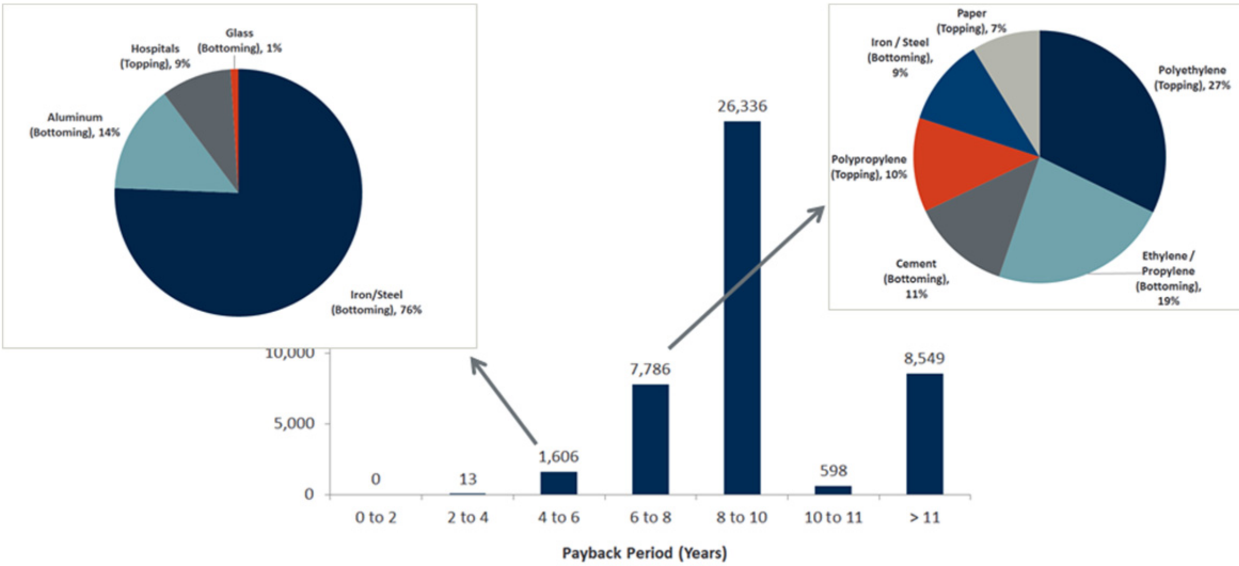
Figure 14: Distribution of Economic Potential Across Payback Periods (2040)



The economic potential can be disaggregated by industry. Of particular interest are those industries for which CHP is highly cost-effective, with relatively short payback periods. These are the industries that would experience the greatest cost savings by investing in CHP, and may therefore be the best targets for new policies to promote cost-effective CHP adoption.

Much of the highly cost-effective CHP potential is concentrated in just a few industries. At a price multiple of 5x, more than three quarters of the 1.6 GW of CHP capacity with a payback period of less than six years is concentrated in CHP bottoming applications in the iron/steel sector. Aluminum, hospitals, and glass account for the remaining potential in this segment. At a payback period of six to eight years, the 7.8 GW of potential are distributed fairly evenly across six sectors, but generally concentrated in sectors associated with petrochemicals. This sector-level disaggregation of the most cost-effective CHP potential is summarized in Figure 15.

Figure 15: Economic Potential at 5x Domestic Prices in Sectors with Shortest Payback (2040)



An important question is, how many of these customers will adopt CHP? That is addressed in the assessment of market potential.

E. MARKET POTENTIAL

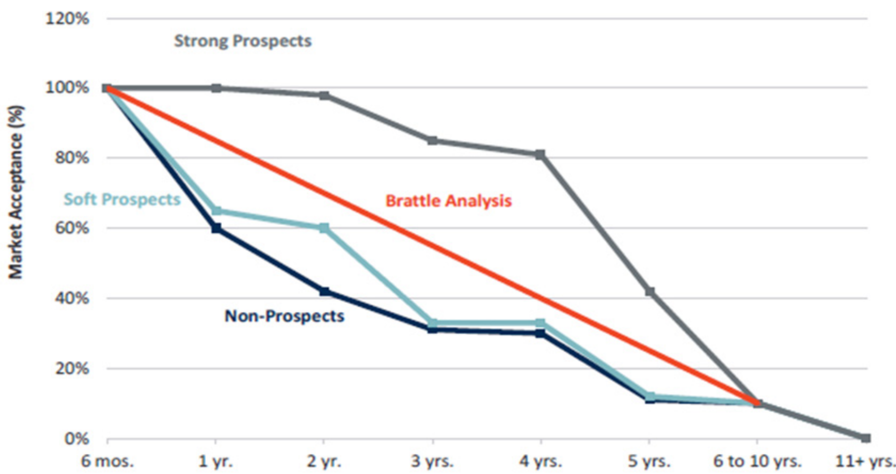
Market potential accounts not only for the economics of CHP technologies but also other barriers and factors that would prevent all cost-effective CHP from being adopted. In this sense, market potential is the most realistic estimate of CHP adoption. Examining market potential under various assumptions is helpful in projecting the likely impact that new policy options could have on actual CHP adoption.

Estimates of market potential are based on the premise that customer adoption of CHP will be a function of the investment's payback period. The shorter the payback period, the more likely the customer is to adopt CHP. This relationship between payback and adoption is based on prior empirical research that was conducted specifically in the context of the CHP market,[18] and is further supported indirectly by several studies on customer adoption of energy efficiency measures. The study on CHP adoption identified several different adoption functions associated

[18] ICF, "Combined Heat and Power: Policy Analysis and Market Assessment: 2011-2030," February 2012 and Primen, "2003 Distributed Energy Market Survey," May 2004. A number of customer adoption curves have been developed for different purposes, including for the adoption of electric heat pumps and distributed solar PV at the residential level (Kastovich et al., Advanced Electric Heat Pump Market and Business Analysis, Oak Ridge National Laboratory, 1982, and R.W. Beck, Distributed Renewable Energy Operating Impacts and Valuation Study, January 2009). They come to similar conclusions, as shown in Drury et al., Modeling the U.S. Rooftop Photovoltaics Market, NREL, September 2010, Figure 5, which shows that adoption rates drop to levels near zero for projects with payback periods above 10 years.

with customer segments that were inherently more likely ("strong prospects") or less likely ("soft prospects" and "non-prospects") to invest in CHP. We have used an average of these observed adoption curves as the basis for our analysis. As is discussed below, we have also tested the sensitivity of our results to this assumption. Market adoption as a function of payback is illustrated in Figure 16.[19]

Figure 16: Market Adoption of CHP as a Function of Payback



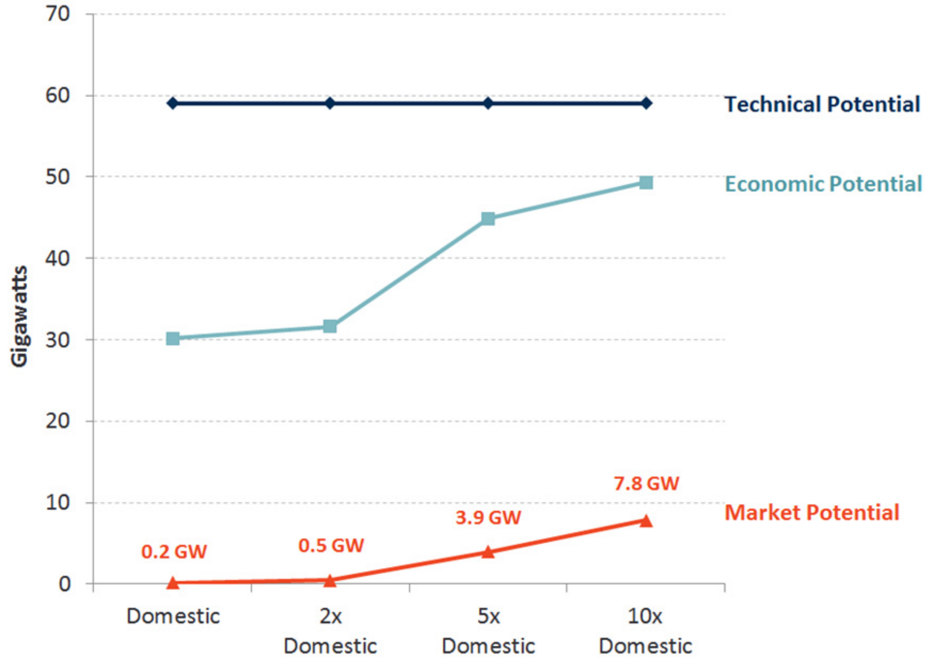
Sources and notes:
Reproduced from Figure A-2 on Page A-8, Combined Heat and Power: Policy Analysis and Market Assessment: 2011-2030, ICF, with the addition of Brattle Analysis
As noted in the ICF's report,the original source is Primen's 2003 Distributed Energy Market Survey

As was discussed previously, at current domestic prices almost all economic potential has a payback period of at least 11 years. Therefore, in stark contrast to the estimates of total technical and economic potential, there is very little market potential for CHP at current domestic prices. By 2040 there is less than 200 MW of market potential, a negligible amount compared to the peak demand forecast of nearly 140 GW.

Of course, at various multiples of the domestic energy price, payback periods are reduced and market potential increases significantly. At a price multiple of 5x there is 3.9 GW of CHP market potential and at a price multiple of 10x there is 7.8 GW of market potential. Estimates of market potential at various price multiples are summarized in Figure 17, alongside the previously reported estimates of technical and economic potential.

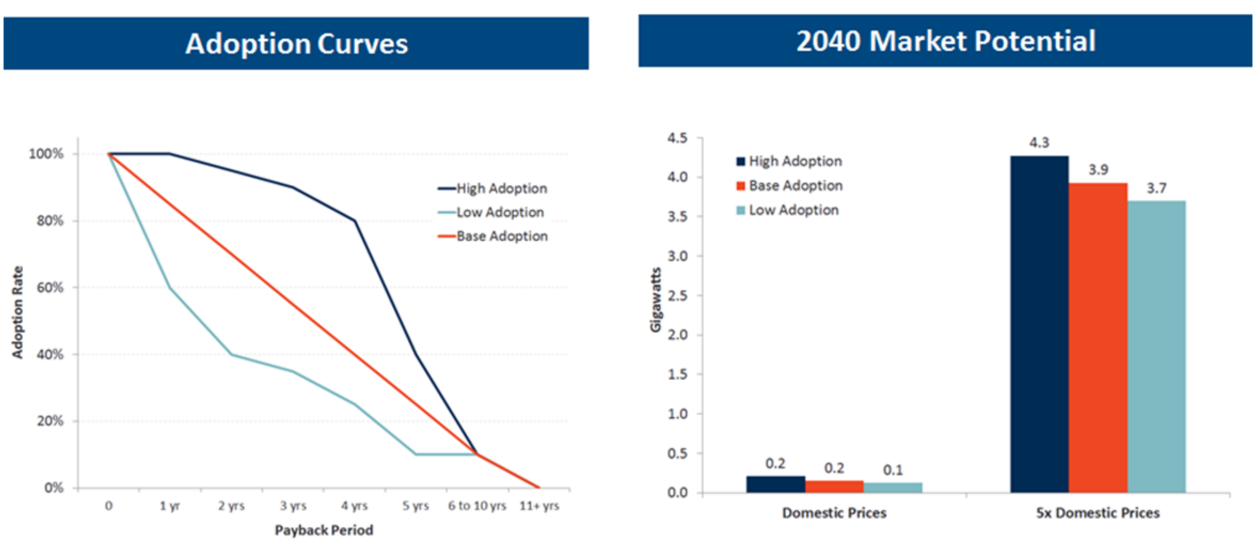
19 Note that payback periods do not take into account discounting. However, it is still generally the case that longer payback periods mean lower NPV and benefit-cost ratios.

Figure 17: CHP Capacity Potential (2040)



Market potential estimates are somewhat sensitive to assumptions about the adoption function, but only after addressing the existing energy price subsidy. To test the impact of the adoption function assumption on CHP potential, we considered a high and a low scenario, based on the range of results identified in prior studies. While market potential remains negligible at current domestic prices regardless of the assumed adoption curve, it ranges from 3.7 GW in the low case to 4.3 GW in the high case when analyzed at a price multiple of 5x. The sensitivity cases are illustrated in Figure 18.

Figure 18: Adoption Function Sensitivity Analysis (5 times current domestic prices)



In some cases, a customer's CHP plant will generate more electricity than is consumed on site. In particular, combined cycle plants have a high power to heat ratio and therefore typically generate several times the amount of electricity consumed at the facility. In these instances, the customer could potentially sell that electricity back to the grid (e.g., to SEC or through a bilateral contract with some other party). Therefore, one factor that will influence the economic attractiveness of CHP to customers is the price at which sales of excess electricity generation are compensated. We refer to this as the "export price".

To evaluate the impact of the export price on market potential, we evaluated four scenarios. In the first scenario, the export price is equal to the full retail rate. This overcompensates the CHP owner for the value of the electricity (at current domestic prices), but is an approach observed in some other regions, used in part for its simplicity and in part as a mechanism for subsidizing distributed generation adoption to encourage market growth. In the second scenario, the export price is equal to the marginal price of energy plus the marginal cost of generating capacity. This most closely aligns the export payment with the actual financial value of the electricity.[20] In the third scenario, the export price is equal to 1.3 cents/kWh (5 halala/kWh) in the summer and 1.0 cents/kWh (3.75 halala/kWh) in the winter. That is the current compensation policy in the KSA. The fourth scenario assumes that there is no payment for sales of excess electricity generation, which is the perception of some market participants in the KSA.

Export prices of the full retail rate or the marginal cost of energy and generation capacity both produce substantial market potential estimates of between 4 GW and 5 GW at a price multiple of 5x, suggesting that there could be significant adoption under these compensation schemes. Market potential is much lower under the current export pricing structure, even at a price multiple of 5x. In fact, there is no material difference between that and the scenario in which there is no export payment. The current export price is too low to make combined cycle plants economic and does little to promote CHP adoption. This analysis also highlights the fact that there is some market potential in bottoming cycle CHP applications and, since these applications typically generate less electricity than is consumed on-site, their cost-effectiveness is mostly unaffected by the magnitude of the export price. These results are summarized in Figure 19.

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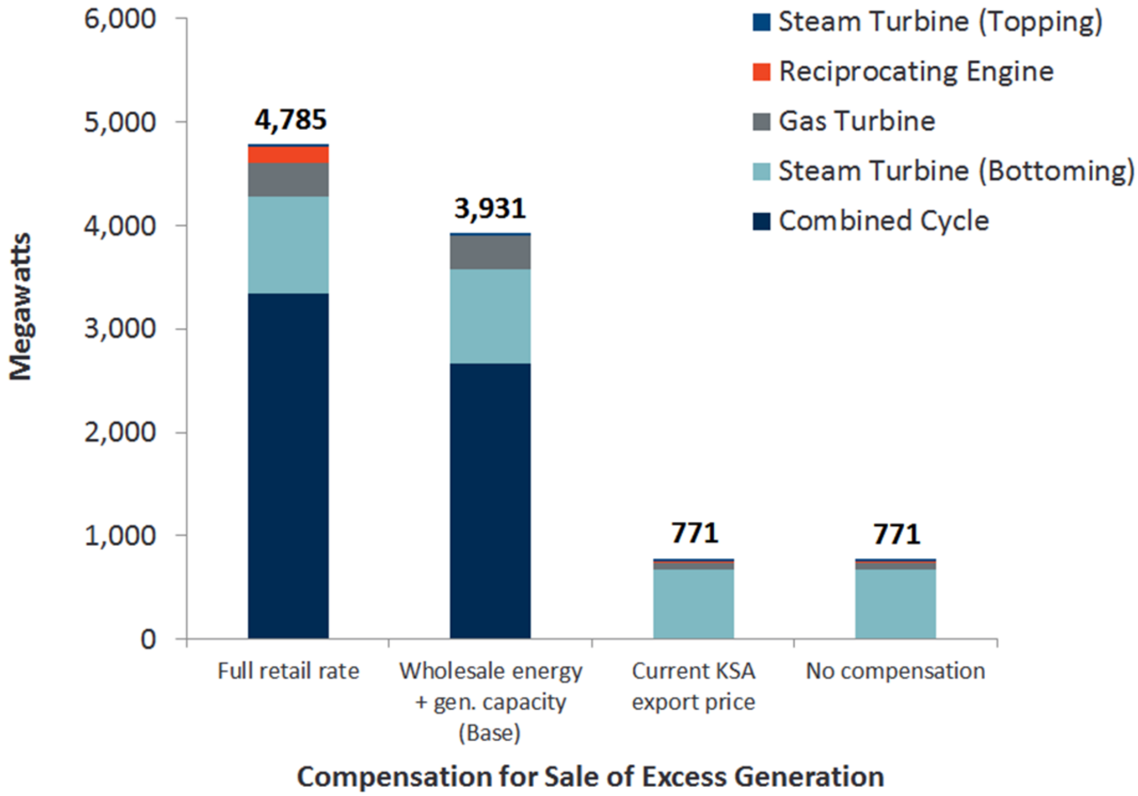
20 The assumption in the second scenario is used throughout our analysis unless otherwise specified.

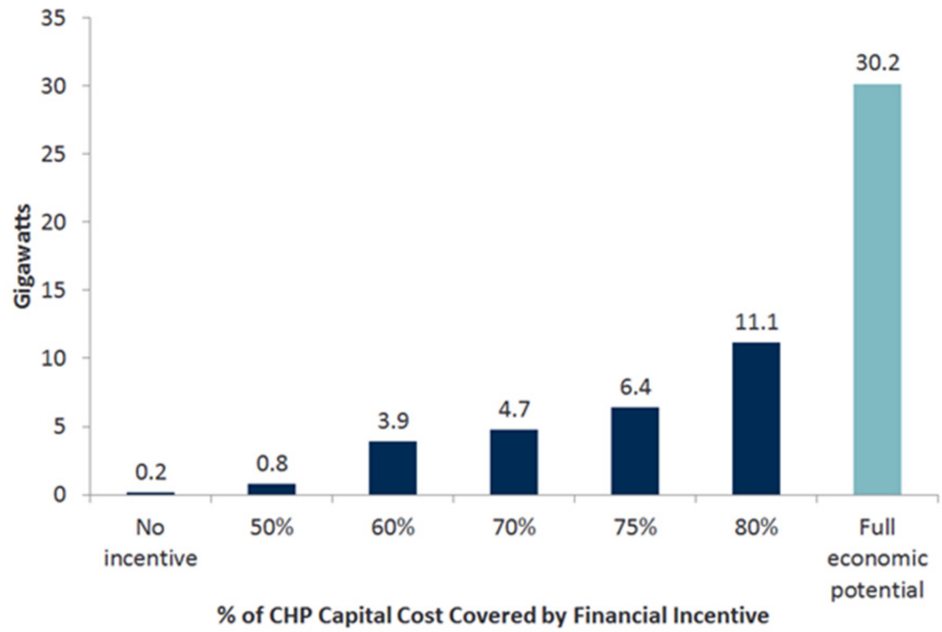
Figure 19: Market Potential at Various Export Prices and Price Multiple of 5x (2040)



This analysis of market potential raises an important policy question. To the extent that there is significant untapped economic CHP potential in the KSA but current conditions are preventing that potential from being realized, what policy options are available to overcome the barriers to adoption? These policy options are explored in detail in Chapter VI, but we have quantitatively analyzed one such option - a capital grant for CHP investment – to illustrate the potential impact of new policy initiatives. The analysis evaluates the impact on market potential of capital grants that cover different shares of the capital cost of a new CHP plant at current domestic energy prices.

Capital grants are likely to lead to a significant increase in CHP adoption, but only when they cover the majority of the capital cost of the CHP facility. A capital grant of 75 percent of the CHP cost would be required to bring the payback period below six years for most of the economic potential at current domestic prices. This equates to a payment between $750/kW and $1,000/kW for large customers (depending on the CHP application). This highlights the need for careful consideration of the mechanism that is used to promote CHP adoption and also may be an argument for targeting those specific customer segments that are the best candidates for highly cost-effective CHP. The results of the assessment of capital grants are summarized in Figure 20.

Figure 20: The Impact of Capital Grants on Market Potential at Current Domestic Prices (2040)



F. Summary of Conclusions from Economic/Market Potential Analysis

At current domestic prices, there is a significant amount of economic potential in the KSA but with only very marginal cost-effectiveness. The benefits of CHP only slightly outweigh costs and the vast majority of CHP applications have a benefit-cost ratio of less than 1.2-to-1. For most customers, the payback period associated with CHP investment is long (more than 11 years in most cases). This will lead to very little adoption of CHP outside the refining sector, as is currently the case in the KSA.

However, if fuel is valued at multiples of the current domestic price that are more aligned with the unsubsidized prices of the international market, there is an opportunity for a significant amount of highly cost-effective CHP adoption. Specifically, at multiples of 5x to 10x current domestic prices, there are between 1.5 GW and 6 GW of CHP projects with a payback of less than five years, making these projects attractive candidates for new CHP policy. Most of this cost-effective potential is concentrated in bottoming cycle applications. Since bottoming cycle applications typically do not generate more electricity than would be consumed on-site by the facility, the export price is not an important consideration for these customers. Iron and steel is the industry segment with the largest share of this potential.

CHP potential is even larger at slightly longer payback periods. At multiples of 5x to 10x domestic prices, there is more than 30 GW of potential with a payback of six to eight years. This potential is concentrated largely in the petrochemicals segments and much of it is in topping cycle applications. For these customers, unlike with bottoming cycle applications, the export price is a critical factor driving the payback, since the CHP plant is likely to generate significantly more electricity than will be consumed on-site.

Energy prices are the key driver of these findings. If fuel prices rise, the economic attractiveness of CHP will improve. This applies not only to the price of fuel but also to the price of electricity. From the perspective of the private investor in CHP, retail electricity rates that are subsidized even below the already subsidized cost of producing electricity are further limiting willingness to invest in the technology. Additionally, the export price will be a key determinant of whether or not investment is made in large topping-cycle applications. The current export price in the KSA undercompensates sales of electricity to the grid and is too low to support significant investment in CHP.

While changing the prices and removing rate subsidies is the economically efficient way to address these issues, it is not the only option. Policies such as capital grants are another way to facilitate the adoption of cost-effective CHP. Other non-financial barriers exist and should be addressed through new policy initiatives. That is the focus of Chapters V and VI.

V. Barriers Assessment

The assessment of barriers to CHP deployment in the KSA represented the third step of our analysis.

In the context of our overall task of developing a CHP roadmap for the Kingdom of Saudi Arabia (KSA), this report identifies key barriers to the deployment of cost-effective (either privately or from the Kingdom's perspective) CHP applications. Barriers are identified in part based on a review of international experience with CHP, since it is likely that some of the barriers identified elsewhere, especially in places with significant economic potential for CHP, will also be applicable to the KSA. This international barriers benchmarking is complemented with a KSA-specific barriers assessment, which in turn is based on qualitative stakeholder interviews in the KSA. The primary conclusions of our barriers assessment were presented in Riyadh in January 2015. Those conclusions are summarized below. The full presentation is included in Appendix F.

A. International Barriers Assessment

Since many barriers to deployment of cost-effective CHP will likely be similar across countries and jurisdictions, we conducted a review of the international literature on CHP barriers (as well as proposed policy solutions) as a starting point of our KSA CHP barriers assessment. The multiple studies we reviewed are listed at the end of this report. They broadly reflect the experience in the United States and many of the key European countries having deployed, or attempted to deploy, significant amounts of CHP.

Broadly speaking, the barriers identified fall into the following categories:

1. Economic and Financial
2. Regulatory
3. Informational/Behavioral

Below we address each set of barriers in more detail.

1. Economic and Financial Barriers

Several economic and financial barriers to deployment of cost-effective CHP applications have been identified. They include:

1. **Large upfront capital investments**

   Like many energy efficiency investments, CHP requires significant incremental upfront investments resulting in cost savings that accrue over sometimes many years. Financing such upfront investments can be particularly challenging for smaller companies without full access to capital markets (i.e. without the ability to borrow easily from banks, especially since the savings from CHP don't result in an explicit cash flow that can be used as collateral for bank loans).

2. **High Hurdle Rates for CHP**

   Many CHP projects, even if they have net economic benefits to the project owner (in the sense of having a positive net present value if discounted at rates reflecting the objective risks of such projects) do not get pursued because potential project owners require short payback periods. Short payback periods are essentially equivalent to private CHP owners applying significantly higher discount rates than those reflecting the objective risks of such projects. It could of course also be true that actual risks of CHP projects are higher than those assumed by standard analyses of CHP, which essentially use discount rates that are similar to discount rates used for similar investments, such as for power generation sources more broadly. There is considerable evidence that CHP project costs are highly project specific and can only be known with certainty well into the CHP development process. A higher range of likely project costs at the point of decision making could lead to objectively higher project risks. Beyond project specific risk factors, private CHP owners may also be worried about the risks related to CHP performance relative to the risks of alternative sources of the same inputs (steam, power). If boilers can be operated with very high levels of reliability and grid-supplied electricity is also relatively reliable, CHP may be perceived to cause interruptions in production with higher probability than using conventional boilers and grid-supplied electricity. The resulting financial damages could lead to private perceptions of risk related to CHP that far exceed the risks of conventional operations. Finally, even though economic theory suggests that firms should pursue all projects with positive net present value, in reality firms operate with limited organizational capabilities and well defined annual capital budgets. These constraints mean that CHP projects have to compete both for organizational attention and money with other projects a company could pursue. This often legitimately leads to hurdle rates above project-specific discount rates for CHP.

3. **Unfavorable economics of financial interactions with the rest of the grid**

   Beyond capital costs, there are a number of other factors affecting the overall economics of CHP projects. Unfavorable conditions are generally identified in three areas: rates for selling excess power from CHP to the grid/market; the design of stand-by rates in ways that are perceived to discriminate against CHP; and power prices not fully reflecting various benefits provided by CHP, such as avoided greenhouse gas emissions.

   A discussion of the value of CHP power injected into the grid is beyond the scope of this report. However, internationally, the absence of an attractive rate for excess power sales is cited as a barrier. Whether or not this barrier is legitimate depends on whether not terms for selling excess power represent the actual value of such power or not. In some countries, access to net energy metering (NEM) offers relatively attractive conditions for selling excess power in that NEM allows CHP customers to avoid the full variable retail electric rate, which tends to represent more than just the value of energy.[21] Often, NEM

[21] In particular, in many instances various types of fixed costs for energy, transmission and distribution are recovered through volumetric rates that can be avoided through NEM.

rates are more attractive than wholesale prices for power (and capacity), so absence of NEM opportunities is cited as a barrier, even though it is unclear how much the value of excess sales of CHP power to the grid exceeds wholesale prices (if at all).

A second and more important topic concerns the levels and types of stand-by charges that are levied on CHP customers for the provision of various services. Stand-by rates, when properly designed, compensate the electric system for providing services to CHP customers. However, there is a concern that stand-by rates can be designed in ways that discriminate against CHP. If this is the case, discriminatory stand-by rates can constitute an important barriers to CHP development. We discuss stand-by charges as a regulatory barrier in more detail below.[22]

Finally, it is argued that as long as market prices don't fully reflect various externalities avoided by CHP, compensation for CHP based on market prices does not provide revenues equivalent to the value of power produced from CHP plants. The most frequently cited example is greenhouse gas emissions. By increasing the overall efficiency of electricity and heat production, CHP typically lowers total greenhouse gas emissions relative to alternative and standard power and heat generation approaches. In many countries, the value of greenhouse gas emissions is either not or not fully internalized in electricity prices. In other words, the estimated damaging effect of greenhouse gases is not reflected as a cost in market prices and therefore CHP is not compensated for helping avoid these costs.

4. Natural Gas Price Volatility

Another financial barrier for CHP identified internationally is the relatively higher volatility of natural gas prices when compared to electricity prices. This barrier affects the riskiness (and hence the implied discount rate) of CHP projects relative to purchasing power from the grid and making steam conventionally. It is likely true that in general natural gas prices over the relevant time horizon of several years tend to be more volatile than electricity prices. This is because in most electric systems electricity is generated from a portfolio of technologies and thus prices in electricity markets tend to provide some diversification against the volatility of fuel prices for any one of the several fuels used in production. As a consequence, the cost of fuel for CHP may be less certain than the cost of purchasing electricity, which in turn increases the risk, or at least the perceived risk, of CHP.

5. Cost impact on rest of electric system

One final area of barrier that could be considered economic is that there could be higher costs to the overall electric system not captured by the economics of CHP alone. In particular, comparing power generation from CHP with power generation from stand-alone power generators, CHP generation profiles will be governed by the underlying

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[22] For a broader discussion of stand-by rates and stand-by rate design, see SEE, Guide to the Successful Implementation of State Combined Heat and Power Policies, Chapter 2, March 2013.

steam demand of the industrial (or commercial) steam host. This restricts the flexibility of operating the electric power system overall and hence may create additional costs of maintaining system reliability, which, at significant levels of CHP penetration and depending on other constraints on system operations, could become significant.

2. Regulatory Barriers

Beyond economic and financial barriers, there are also a number of regulatory barriers frequently cited as obstacles to the deployment of cost effective CHP.

Primary regulatory barriers include:

1. Discriminatory Interconnection Practices

   Internationally, the complexity of the interconnection process, the time required to obtain interconnection, and the costs associated with interconnection for CHP are all cited as significant regulatory barriers for CHP.

2. Unfair stand-by charges and other unfair utility rates

   In addition to the economic barrier they represent, internationally, rates/tariffs offered to CHP plants are also mentioned as a major regulatory barrier to CHP deployment. For the most part, these rates concern payments other than the volumetric payments per MWh of electricity consumed. In particular, in most advanced electricity markets, rates for commercial and industrial customers, i.e. those customer groups most likely to install CHP systems, are composed of fixed customer charges, some form of a demand charge, and energy charges. There are also instances where utilities are requiring CHP customers to be subject to a different rate altogether and, under this rate, are required to pay additional charges, such as stand-by charges, which in turn tend to be a function of the maximum demand from the utility during a defined time period. It is important to be aware of the issues that arise under more complex retail rates as the KSA moves forward with electricity market reforms.

   In general, from a CHP project's perspective, the benefits of CHP are increased the more electricity bills are reduced proportionally with the reduced electricity purchases from the utility/market. The current KSA practice, i.e., a simple volumetric electricity rate, means that CHP electricity production reduces a CHP customer's electricity bill proportionally to the CHP unit's electricity production. From society's perspective, savings may be lower if and when volumetric electricity rates include costs that are not avoided by the CHP electricity production. For example, stand-by charges attempt to capture the need by the incumbent utility to provide back-up generation in case of an unexpected outage by a customer's CHP unit. As long as the utility is required to provide a CHP customer with electricity in such an outage event, the costs corresponding to providing this electricity (and the associated capacity) do not disappear with the installation of a CHP unit. Hence, rate structures that recover unavoidable system costs from CHP customers will reduce the incentives to private CHP developers and therefore are a barrier to CHP deployment, but they are not necessarily the type of barrier that should be removed since, from society's perspective and if properly constructed, they may represent societal costs that reduce the value of CHP.

Differentiating discriminatory rate structures from economically efficient ones is a complex task beyond the scope of this report. At a high level, the design of rates including stand-by rates should be based as much as possible on underlying costs and recognize the ability of both the electric system and a CHP plant to provide services that may be partial substitutes. Stand-by rates should be guided by actual costs imposed by a CHP plant on the larger electric system and allow for CHP plants to choose whether to demand services from the electric system or to either live without or self-provide certain services typically provided by the electric system – such as back-up power during various situations such as scheduled or unscheduled outages.

3. **Regulatory Treatment of CHP**

   A hurdle related to standby rates and interconnection involves the treatment of CHP for purposes of determining interconnection and stand-by rate terms. In particular, in some states in the United States, CHP facilities are assumed to have no local load when determining the size of required interconnection or stand-by services. In other words, if a 100 MW CHP plant has a minimum local electricity demand of 50 MW, the interconnection may be required to sized for a 100 MW plant instead of a 50 MW plant. This is mentioned as a hurdle since it may increase the cost of interconnecting to the grid. Whether or not this concern is justified potentially depends on the way the CHP unit is used as part of the broader electric system.

4. **Environmental permitting rules**

   Finally, CHP units above a certain size tend to require a number of permits, including various environmental permits (air emissions, noise, etc.). In many countries, environmental and other permits are determined locally and hence are subject to significant variation depending on where a CHP project is located. The variation in local permitting requirements by themselves create a barrier to CHP deployment, since maneuvering a multitude of local permitting rules leads to significant costs for potential CHP developers.

3. Informational/Behavioral Barriers

Finally, a number of informational/behavioral barriers have also been cited as obstacles to the deployment of cost effective CHP. The most often cited informational barrier to CHP is simply the absence of sufficient knowledge and awareness about the costs and benefits of CHP. This is sometimes related to the fact that potential CHP host's core business is not CHP so that organizational focus is not on CHP opportunities, but on expanding the profitability of core business operations. A third behavioral barrier mentioned in the literature describing CHP barriers is general organizational inertia, i.e. the fact that (especially outside the core business) companies tend to be slow at adopting new technologies and approaches, even if they are cost-effective.

B. Specific CHP Barriers in the KSA

To understand to what extent internationally identified barriers were applicable to the specific KSA context and to what extent there were KSA specific barriers to CHP deployment in the KSA we conducted a number of stakeholder interviews. A number of these interviews were conducted on an individual basis by EcoSolutions. Also, several stakeholder workshops conducted at ECRA involved sessions identifying perceived KSA specific barriers. In practice these barriers may or may not accurately reflect true conditions and in themselves could be part of a wider set of informational barriers.

Among the international barriers identified above, a number do not (currently) apply at a significant level to the KSA. In particular, the very significant barriers related to stand-by rates do not currently appear to be a major barrier by themselves as the KSA's rate structure is largely volumetric and current stand-by charges relatively modest.[23] However, as the KSA reforms its broader energy system, it is quite possible that stand-by rate design will become a more significant issue.

Another barrier not currently directly important for the KSA is the concern that various externalities are not fully priced into wholesale market prices. Not only does the KSA currently not have a wholesale market for electricity, greenhouse gas emissions currently do not play a major role in determining either capital investment or the dispatch of power generation.

Nonetheless, the idea that not all social costs are fully priced into electricity prices is a very important barrier in the KSA, namely in the form of the electricity retail rate not fully capturing the value of domestic fuel prices and domestic fuel prices not representing national fuel values. Indeed, as shown in Section IV above, this likely represents the single most important barrier to CHP development in the KSA.

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[23] Per ECRA's Administrative Decision #4 dated December 4, 2013, Transmission Use of System (TUS) charges for customers fully or partially self-supplying electricity (which would include CHP hosts) are responsible for providing 11.5% reserve capacity or else pay SEC SAR 382,500/MW of reserves per year, which translates into a charge of approximately $11.71 per MW of installed CHP capacity per year. CHP hosts are also responsible for paying SAR 125,000 per MW of peak demand, which is equivalent to approximately $33.33/kW of peak demand per year. For CHP, peak demand is the maximum withdrawal from the grid (i.e., the maximum amount needed on-site and not provided by CHP). In most cases, CHP capacity results to net exports to the grid so that the TUS charge would typically for an amount of MW less than the CHP capacity.

A second important KSA-specific barrier is the difficulty and uncertainty associated with selling excess power generated from CHP units to the grid. In the absence of a functioning wholesale market compensation for electricity injected into the grid by third parties is limited to the prices currently stipulated in the Transmission Use of System (TUoS) charges. These rates, while providing some certainty, require further work to better reflect the value that CHP provides to wider Kingdom objectives such as improving utility sector efficiency and diversifying electricity supply.

A third important KSA specific barrier identified in stakeholder interviews is the uncertainty about fuel allocation for fuel needed to power CHP. In the KSA, there is no open market for fuels such as liquids or natural gas. CHP projects must apply for a fuel allocation. Uncertainty about whether or not fuel will be allocated significantly increases the risk to a potential CHP project.

A forth KSA specific barrier is related to the existing cross-subsidies between rate classes. Specifically, at present commercial (and certain industrial and government customers above a certain size) tend to cross-subsidize customers in other rate classes. Because of this, reduced sales to commercial customers reduce the revenues required to cover costs while maintaining the rates to other customer classes. In essence, the revenue shortfall would result in SEC not covering its costs. Our interviews with key stakeholders suggest that in light of this issue ECRA is being perceived as being reluctant to grant cogeneration licenses in particular to commercial applicants.

A final potential barrier cited by our stakeholders was the uncertainty related to the availability and cost of important CHP replacement parts, many of which would typically need to be imported.

C. Conclusions from Barriers Assessment

Our barriers assessment suggests that CHP faces a number of barriers, many of which are also important in the specific context of the KSA. The combination of high upfront capital costs, relatively high private hurdle rates translating into relatively low adoption rates for projects with long payback periods, very low domestic fuel prices and additional subsidies embedded in retail electric rates create a difficult environment for CHP in the KSA and explain the relatively small market potential we found at current domestic prices.

Additional important barriers to CHP deployment in the KSA, which could further reduce market adoption, are uncertainties about fuel allocation and the received value of power exported to the grid.

Also, a number of informational barriers, present in many countries including the KSA, suggest that the level of information about CHP will need to increase significantly to help CHP projects become options that are being evaluated on a regular basis.

In the final section of this report, we summarize policy solutions that have been proposed and applied in the international context and, finally, our own set of policy options we deem most appropriate in light of the specific circumstances in Saudi Arabia.

VI. Policy Recommendations

Accounting for the economic and market potential for CHP in the KSA as well as typical barriers to CHP deployment, both from an international and KSA-specific perspective, our final task was to develop recommendations for policy solutions to support development of CHP opportunities deemed sufficiently beneficial to the KSA but likely not adopted (or not sufficiently adopted) by private parties given the presence of barriers to their realization in the KSA. In the context of these policy solutions, Appendix G includes a review of electricity laws and regulations related to CHP in the KSA.

A. Appropriate Scope of Policy Given Economic/Market Potential

Rather than simply proposing that the KSA adopt policy measures used elsewhere to support the development of CHP, it is important to base policy recommendations on the specific set of challenges and opportunities in Saudi Arabia.

Our previous discussion highlighted that many of the barriers identified elsewhere in the world are also relevant in the KSA. However, in addition, the following KSA-specific factors should drive the development of policy options:

- First, the Kingdom is currently undergoing significant sector reforms. We are in particular aware of ongoing efforts to create a well-functioning wholesale market for electric power. Since the issues for CHP in a wholesale market environment are different in several ways from the issues for CHP under the current, vertically integrated system (and without a real system of prices), the future design of wholesale markets is likely to have a significant impact on the incentives for CHP.
- Second, since CHP is a technology that in general uses additional capital expenditure to create a more energy efficient system (and thus save fuel), the cost/value of fuel is a crucial factor influencing the economics of CHP from the perspective of both a private party and society. We understand that there are ongoing discussions concerning how domestic fuel should be priced in the future, given current and expected future production costs on the one hand, and global market prices on the other hand. As our CHP potential analysis has shown, whether or not domestic fuel prices rise has a significant impact on likely private adoption of CHP. In particular, if CHP policies are put in place to overcome barriers that prevent the deployment of CHP that is beneficial from society's perspective while fuel prices remain low, policies will likely be necessary to change the decisions of private parties facing lower fuel prices.
- Third, the assumption that future baseload electricity generation sources will be powered by natural gas has a significant impact on the benefits of CHP from the Kingdom's perspective. Since the most widely used fuel for CHP is also natural gas, assuming that future central station power generation will be fueled with natural gas implies that CHP produces less fuel savings than under the assumption that natural-gas fired CHP would

displace some oil-fired generation.[24] As a result of this assumption, the economic benefits of CHP are largely driven by natural gas savings and oil savings due to not having to burn oil in boilers. These savings are not sufficient under current domestic fuel prices to overcome the increased capital expenditures due to CHP. Even at multiples of five or ten times current domestic fuel prices, cost-effective CHP with acceptable payback periods is limited to a relatively small number of industrial sectors.

This suggests that the focus of policy in the Kingdom should likely be on providing policy support for CHP deployment in those sectors. In addition, broad power sector reforms should help improve the economics of CHP in ways described below. Also, as we will suggest, there are likely some relatively simple policies targeting CHP more generally that could easily be adopted and which would help CHP development where CHP is economical, now and in the future.

Against this backdrop, we provide a brief overview of policy solutions pursued internationally, followed by a discussion of how energy-sector level reforms (wholesale and retail) would help improve the landscape for CHP, and finally discuss specific CHP policy approaches we recommend for the KSA.

B. International Policy Options

Before discussing KSA-specific policy proposals, in this section we provide a brief overview of CHP policies deployed internationally. To the extent KSA barriers to CHP deployment are similar or identical to barriers encountered elsewhere, these policies represent important options for the KSA to consider when implementing its own CHP policies.

Broadly speaking, policy choices fall into three categories. They are policy choices to address (a) financial/economic barriers, (b) regulatory barriers, and (c) information and behavioral barriers.

To address financial and economic barriers, the primary policy tools used internationally include production subsidies in the form of feed-in-tariffs for CHP, certificates or net metering as well as capital support, which can take the form of tax incentives, direct capital grants, or access to low interest rate debt.

In the United States, federal support for CHP includes a 10% investment tax credit for qualifying CHP facilities with capacity of 50 MW or less.[25]

States have various local and regional policies to incentivize CHP technology investments. Primary state level policies that motivate the development of CHP and Waste Heat to Power (WHP) are: Renewable Portfolio Standards (RPS), Alternative Energy Portfolio Standards (APS)

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24 In industrial application, CHP will still save some liquid fuels as CHP will typically displace a boiler used for steam production, with boilers predominantly burning heavy fuel oil.

25 http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F (accessed February 12, 2015)

and Energy Efficiency Resource Standards (EERS). State targets for CHP capacity are usually determined as a share of quantity of the total renewable generation. About half of the states in the union include CHP in their policies. Figure 1 and Figure 2 show the states with RPS and EERS programs with CHP. In general, CHP plants that qualify under a state's RPS, APS or EERS earn credits per unit of power generated from the CHP facility. These credits are purchased by utilities, which by law have to procure a certain number of certificates in any given year. In this sense, these programs have the effect of providing a per kWh production support similar to a feed-in bonus (a fixed premium above market revenues), with the amount of the premium determined by the market price for certificates.

In addition, states also provide capital grants to CHP plants. For example, Massachusetts offers capital grants of between $750/kW and $1,200/kW for CHP systems smaller than 150kW, with the amount of the grant depending on the benefit-cost ratio of the project.[26] There are also incentives for both new CHP projects and retrofits, again with grants depending on the perceived level of benefits relative to costs. Under California's self-generation incentive program, which covers CHP and other technologies, CHP units powered by non-renewable fuel receive up to $480/kW. The maximum incentive to any CHP facility is $5 million and requires a minimum customer investment of 40% and the payment is capped at 3 MW.[27]

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26 KEMA, 2013. Massachusetts Combined Heat and Power Program Impact Evaluation 2011-2012. See also Combined Heat and Power (CHP). A Guide to Submitting CHP Applications for Incentives in Massachusetts 2013

27 See EPA Database of Combined Heat and Power Partnership (dCHPP), 2014. CHP Policies and incentives database. (http://www.epa.gov/chp/policies/incentives/caselfgenerationincentiveprogram.html)

Figure 20: States with RPS or APS Programs for CHP

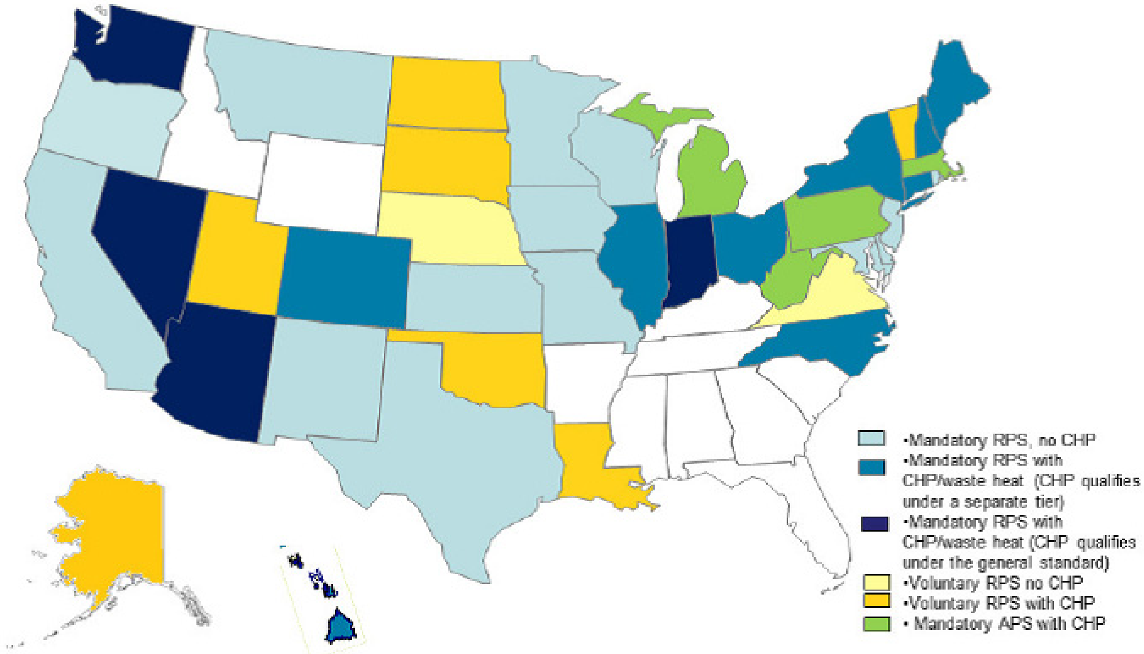
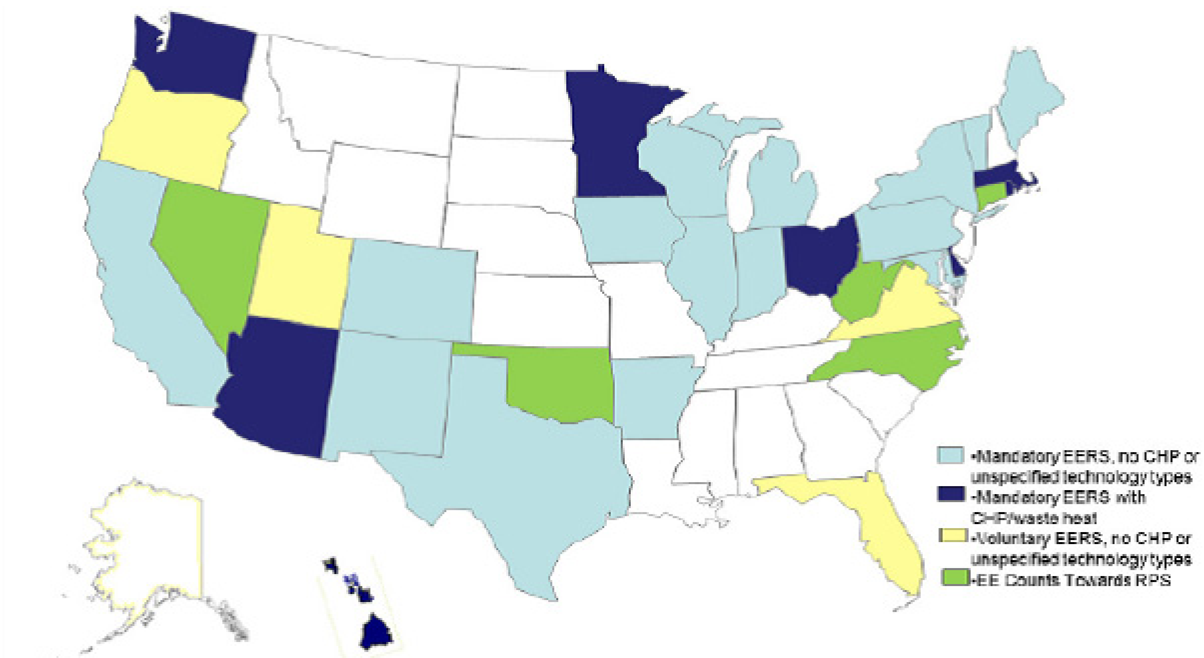


Figure 21: States with EERS Programs for CHP[28]



28 The Alliance for Industrial Energy Efficiency 2014. Recommendations for Advancing Combined Heat and Power and Waste Heat.

Soft loans are an alternative to direct capital grants and have the advantage that they don't require large net outlays for the supporting entities. Soft loans are a tool that is often being used to support infrastructure development deemed in the public interest. For example, major development banks such as the European Bank for Reconstruction and Development provide low interest rate loans for a multitude of such projects. Soft loans are often available for certain types of CHP projects. For example in the United Kingdom, zero interest rate loans are available for various public sector energy efficiency investments including CHP.[29] Similarly, both the World Bank and the Asian Development Bank have been providing soft loans for CHP and district heating investments in China and other Asian countries.[30] Kreditanstalt für Wiederaufbau (KfW), Germany's internal development bank, provides low interest loans for small scale CHP projects.[31]

Some U.S. states allow net metering for smaller CHP applications. Under net metering, CHP customers can offset retail rates (which tend to include various network fees in addition to energy charges) for all power generated by a CHP unit including power exported to the grid, as long as total energy production from a CHP unit is less than or equal to total energy consumption over some time period. Minnesota has an explicit net metering policy in place for CHP systems smaller than 40 kW.[32]

Finally, California offers a feed-in tariff for CHP output. The program covers new, small CHP systems (less than 20 MW) operating above 62% efficiency.[33]

Feed-in tariffs or rather premiums are used as the primary financial support mechanism for CHP in Germany. The law governing the support of CHP in Germany has been modified repeatedly. In its latest version, new CHP projects receive a feed-in premium between 1.8 and 5.4 eurocents/kWh of gross electric production, with the premium smaller for larger projects (1.8 eurocents/kWh for projects above 2 MW). For electricity consumed on-site, CHP units not only receive the feed-in premium, but also avoid energy and network charges they would otherwise incur. For electricity exported to the grid, CHP owners also receive the market price for electricity as determined by the wholesale market. Total support through feed-in premiums is limited to €750 million per year.[34]

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29 Salix is a publicly funded UK lender providing zero interest rate loans to qualifying CHP projects. See http://www.salixfinance.co.uk/knowledge-share/technologies.

30 http://www.cospp.com/articles/print/volume-10/issue-5/features/supporting-chp-and-district-energy-system-development-in-asia.html

31 http://www.blockheizkraftwerk-bhkw.net/foerderung (in German).

32 Minnesota Combined Heat and Power Fact Sheet 2013. Great Plains Institute and American Council for an Energy-Efficient Economy.

33 http://www.cpuc.ca.gov/PUC/energy/CHP/feed-in+tariff.htm

34 For more details on the German CHP law and its provisions, see IHK Projekte Hannover, Förderung Von Kraft-Wärme-Kopplungsanlagen (in German).

To address or overcome *regulatory barriers*, a number of countries have created simpler permitting processes, interconnection standards and to improve design of standby rates[35] (or exempt certain CHP facilities from such standby rates.

The literature on the proper design of stand-by rates is large and complex, and while a detailed discussion of the many issues involved in designing stand-by rates is beyond the scope of this report, a recent report by the State & Local Energy Efficiency Action Network (SEE Action) provides a detailed overview of stand-by rate design issues as well how to design such rates in ways that don't discriminate against CHP.[36] In the spirit of creating simpler regulations for smaller installations, relatively small CHP systems are sometimes exempt from some or all standby rates. For example, Minnesota exempts CHP systems under 100 kW from any and all standby rates.[37]

Streamlining interconnection standards is another element of creating a more favorable regulatory environment for CHP. As with standby rates, regulatory practice for interconnection in particular of small CHP systems has evolved significantly. In many cases, very small CHP systems can be connected for small interconnection fees and using simple and quick interconnection protocols.[38] To name just one example, the state of Maine has implemented a simplified interconnection standard that also charges very low fees for small CHP units ($50 for systems smaller than 10 kW).[39] It should be noted that most incentive measures in countries with significant CHP programs target smaller CHP applications since markets are generally deemed to be well established to provide sufficient signals for larger scale CHP applications. The measures used to address barriers nonetheless provide useful information for the KSA, where the largest amount of economic potential is for larger scale CHP plants as described in Section IV above.

In terms of addressing informational barriers, several countries and regions use technical assistance programs. For example, the United States launched seven regional Technical Assistance Partnerships (TAPs) to help increase CHP awareness and ultimately deployment.[40] Several U.S. states also have CHP pilot programs, which provide cash incentives and are intended to increase awareness and the understanding of CHP in general or in specific sectors. For

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35 Standby rates are rates charged by utilities for services used by CHP and other distributed generation sources. They include payments for back-up power and capacity during planned and unplanned outages.

36 See SEE Action, Guide to the Successful Implementation of State Combined Heat and Power Policies, March 2013, Chapter 2.

37 Minnesota Combined Heat and Power Fact Sheet 2013. Great Plains Institute and American Council for an Energy-Efficient Economy.

38 For a detailed discussion, see SEE Action, Guide to the Successful Implementation of State Combined Heat and Power Policies, March 2013, Chapter 3.

39 For a description of Maine's rationale for picking a standardized interconnection standard, see Todd J. Griset, Maine's CHP Interconnection Standards: Lessons and Best Practices, October 8, 2012

40 http://www.energy.gov/eere/amo/chp-technical-assistance-partnerships-chp-taps

example, a CHP pilot program in the state of Illinois provides cash incentives for CHP projects aimed at increasing energy efficiency of local governments, municipal corporations, public school districts, community college districts, public universities, and state/federal facilities.[41]

While not being a complete list of international practices, the above policy solutions represent a good cross-section of the types of policies applied internationally to overcome identified CHP barriers. In the next section, we discuss which of these policy approaches are likely most appropriate for the KSA and to what extent KSA-specific policy solutions should also be developed. We divide our discussion of policy options for the KSA into a discussion of how general energy sector reforms could and should include measures that will help address some barriers to CHP deployment before discussing policy options specifically targeting CHP in the KSA.

C. Policy Recommendations in the Broader Context of Energy Sector Reform

Based on our review of international policy options and our previous work on and current understanding of ongoing efforts to reform elements of the KSA's electricity (and larger energy) sectors, we suggest that elements impacting CHP, in particular in terms of overcoming existing barriers to the deployment of cost effective CHP, be carefully considered as part of ongoing reform efforts. The list of recommendations provided below does not apply to CHP alone, but rather represents steps that will create a more level playing field for CHP alongside other solutions by removing barriers largely related to KSA-specific circumstances, most notably the lack of fully developed wholesale markets, relatively simple retail rate structures, and a policy of pricing fuels domestically at rates likely below national values (and certainly below international prices).

Simplified Interconnection Process

The vast majority of power supply sources in the KSA are connected to the system at the transmission level. Internationally CHP tends to be a resource located at the distribution level and not necessarily based on the optimal network location, but rather based on the location of an appropriate host for the waste heat or steam of a CHP facility. In Kingdom most of the identified opportunities are large-scale and as such likely to be connected at higher voltage levels. For smaller scale plant the required interconnection process is similar to the ongoing efforts to allow large scale (and potentially distributed) renewable energy resources to connect to the grid. To the extent there is a broader move away from SEC-led power plant construction and towards an approach more heavily relying on Independent Power Producers (IPPs), location choices in the future may also be driven by factors other than those traditionally considered by SEC. As a consequence, we recommend developing a more general framework guiding new generator interconnection that appropriately balances the need for detailed information about any new

41 https://www.illinois.gov/dceo/whyillinois/KeyIndustries/Energy/Pages/CHPprogram.aspx

generators impact on the grid and the need by applicants to have clarity about costs and timelines for interconnection. We understand that proposals for interconnecting renewable (including DG) sources have been submitted to ECRA and we suggest that these proposals could serve as a basis for developing more general principles of interconnection. Streamlined interconnection processes (and inexpensive interconnection for small scale CHP) have been an international response to a perceived barrier to CHP deployment. Based on our analysis, it is likely that the near term potential for economic CHP in the KSA is for relatively large-scale CHP plants. Nonetheless, it is likely that the location of the steam host (or provider in the case of bottoming cycle applications) will be the primary driver of location choice so that the discussion underlying the proposed interconnection protocol for grid-connected renewable energy sources (and for IPPs) should serve as useful guidance.

Sidebar 1: Evidence of Successful CHP Policies

Understanding which CHP policies have proven successful elsewhere is obviously an important basis for designing CHP policies for the KSA. Unfortunately, the evidence on what policies have been successful is sparse, in part because success can be measured in many ways and because, to our knowledge, there has been little effort to understand quantitatively which policies work better than others.

Perhaps the recent Call for Evidence by the U.K. Department of Energy and Climate Change regarding tackling non-financial barriers to CHP[42] is an indicator of the need for a more empirical investigation of the success of CHP policies to-date. Also, in a response to this Call for Evidence, the Association for Decentralised Energy stated that it is unaware of any evidence of the success of policies in other countries tackling non-financial barriers.[43] Two items mentioned in the Association's response are the likely beneficial effects of funding feasibility studies and awareness efforts. However, the Association makes no claims about the evidence of such activities being successful.

In 2009, the International Energy Agency (IEA) published what it termed the most effective CHP policies, based on a number of country case studies.[44] The IEA groups policies into six categories and identifies best practices for each. For financial and fiscal support (1), capital grants (New York) and feed-in tariffs (Germany) are identified. For utility supply obligations (2), the green certificate scheme in Belgium is mentioned. For local infrastructure and heat planning (3), UK building regulations are mentioned. For climate change mitigation (4), the EU Emissions Trading Scheme is highlighted. For interconnection measures (5), the United States interconnection standards are picked. And for capacity building and outreach (6), Japan's fuel cell CHP Research and Development Programme is mentioned.[45]

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42 U.K. Department of Energy & Climate Change, Call for Evidence: Tackling Non-Financial Barriers to Gas CHP, February 2015

43 The Association for Decentralised Energy, Response to non-financial barriers to gas CHP, March 30, 2015, Answer to question 11, page 5.

44 IEA, Cogeneration and District Energy, 2009, page 18.

45 Ibid, pages 18-29, which provide best practice examples in more detail for each category.

Predictable price and terms for excess power sales

An important barrier identified in the KSA (and to some degree internationally) is the absence of certainty regarding the value exported electricity provides and related conditions of selling excess power from a CHP plant. Internationally, the issue tends to be that, unlike self-consumption of electricity generated by the CHP unit, excess sales are not compensated at the full retail rate and hence tend to have lower value. This relates to some extent to the broader rate structure including standby rates discussed above.

In the KSA, because of low domestic fuel prices the current price for exports does not accurately reflect the value that CHP provides and as a consequence, revenues from such excess sales particularly for CHP technologies with high power to steam ratios (the most efficient ones for topping cycle applications) are likely to be uneconomical.

In countries with well-established wholesale markets for electricity, it is generally possible for at least bigger CHP plants to sell excess power directly (or indirectly via some aggregator/broker) into wholesale markets at prevailing market prices. We understand that efforts are underway in the KSA to transition towards more competitive wholesale markets over time. Ultimately, these markets should provide a platform for selling excess power. In the meantime, however, promising topping cycle CHP applications are unlikely to be implemented (and for that matter are not economical) in the absence of a mechanism for accurately compensating excess power sales to the Saudi electric system. For this reason, we recommend reviewing the standard tariff rates for selling excess power generation from CHP to the grid (SEC/NGSA). To better develop such a rate, we recommend as a starting point the methodology proposed to ECRA for selling electricity from renewables to the grid. This methodology recognizes the energy and capacity value of resources, but also that at this point relatively simple approaches are likely preferable to more complex tariff designs. For example, sales of excess energy to the grid should be compensated at SEC's avoided (variable) costs including the value of both energy and capacity and to the extent possible be differentiated by time period (peak and off-peak). To provide consistency, tariffs should be similar or identical for any and all resources proposing to inject power to the Saudi grid.

Remove cross-subsidization in retail rates

One important KSA-specific issue impacting private incentives for CHP is the current retail rate structure for electricity. In particular, residential rates are below the average cost of providing service. On the other hand, commercial and some government/industrial rates are currently potentially above the average cost of providing service. This means that in practice some rate classes (commercial, some government/industrial) are cross-subsidizing other rate classes (residential). In this environment, loss of sales from customer classes that cross-subsidize other customer classes can lead to a shortfall in total revenues relative to those revenues needed to cover the total cost of providing service. As described above, our stakeholder interviews suggest this cross-subsidization is perceived as having likely prevented ECRA from granting cogeneration licenses in the past – primarily on the grounds of avoiding revenue shortfalls for SEC that would result from lower sales to commercial customers.

More general reforms to the retail pricing structure would help remove the current impediments to granting cogeneration licenses due to fears about loss of revenue needed for cross-subsidization. There are two levels of reforms that would be beneficial:

- First, finding ways to remove the cross-subsidization across rate classes would minimize the impact of losing sales from a rate class cross-subsidizing others as a result of CHP applications. This can in theory be accomplished by increasing subsidized and decreasing subsidizing retail rates so that ultimately rates within each rate class represent the average cost of providing service to that rate class.
- A second approach, which is complementary to the first, is to reform the structure of retail rates to make them more reflective of underlying costs. More specifically, it is our understanding that at present retail rates in the KSA are entirely volumetric across all rate classes, i.e. that the only charge for customers is a charge per kWh of electricity consumed. While simple, this rate design introduces various risks to the provider of electric service and provides poor incentives for retail customers. The main problem with purely volumetric rates is that sales below expected sales at a given rate result to revenues below those needed to cover all costs since some of the costs of providing electric service are fixed (notably the capital cost of generating plants and the fixed transmission and distribution infrastructure, plus various fixed costs of operating the electric system). In many countries industrial and commercial retail rates have a three-part structure, made up of a monthly fixed payment per customer, a monthly demand charge, which depends on a customer's maximum demand during a given period (or the demand during the system's peak demand), and a volumetric component. Most residential rates have at least a monthly fixed charge and a volumetric charge and some do have a form of demand charge. Moving towards a two-part or three-part tariff would enable the KSA to recover fixed costs through the types of charges that do not decline with consumption. For example, a commercial retail rate with a demand charge and a monthly customer charge would help provide revenues to cover fixed costs even if a commercial customer installs a CHP unit and thus reduces his volumetric demand from the grid. It is important to point out that when retail rates are redesigned it is likely that stand-by rates discussed above will also need to be considered.[46]

Create retail rates that correspond to domestic fuel prices

A related issue concerns our understanding that that at present average retail rates across all rate classes are lower than those that would be implied by domestic fuel prices. Put differently, SEC

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[46] It should be noted that, as described above, Transmission Use of System charges currently in place do represent a form of fixed cost recovery through a non-volumetric charge. Hence, these TUoS charges could easily form the basis for further developing more cost-based rate structures that differentiate between fixed, capacity-based and volume-based (variable) costs.

does not recover enough revenues through sales of electricity to pay for the fuel it needs at prices equal to the current local prices of fuel. This means that customers in essence receive fuel transformed into electricity delivered through the grid at a discount relative to the local price of fuels. Assuming customers have access to fuels directly and that they would have to pay the local price for such fuel for generating power in a CHP system, they would not have access to the same subsidy and hence the economics of a CHP unit are made worse. Therefore, removing the current implicit discount of fuel prices embedded in retail rates would remove this barrier. We mention this issue here since it similarly affects other measures such as energy efficiency and distributed generation sources other than CHP.

Align domestic prices with national fuel value

We understand that there are ongoing discussions about how to align domestic fuel prices with national fuel values over time. While we understand the many complexities associated with such efforts, it is important to point out that aligning the two would remove a significant KSA-specific barrier to CHP and many other fuel saving measures in the energy sector. Without alignment, fuel savings by consumers facing domestic prices will be valued lower than national policy goals suggest. Therefore, in the absence of fuel price alignment other tools will likely be needed to create incentives at the individual level that mirror society's goals. We next discuss some options for doing so in ways that are targeted to CHP applications in the KSA specifically.

D. Specific Policy Recommendations

In this section, we provide some specific policy recommendations to support cost-effective CHP applications in the KSA (from society's perspective).

Fuel allocation

Since essentially all industrial customers with high CHP potential require fuel for their operation, the existing fuel allocation mechanism can and should be used as a tool to incentivize and potentially provide support for most promising sectors until broader market reforms in place.

Going forward, new industrial projects in certain industries (those identified as potentially suitable for CHP), independent of whether or not they are suitable for topping or bottoming cycle applications, could be required to demonstrate that they have studied the economics of using CHP as part of their operation as part of their fuel allocation request. Even though theoretically possible, we do not recommend making CHP generally mandatory for certain categories of facilities, even if our analysis suggests relatively robust societal benefits in excess of cost.[47] The primary reason for not recommending a mandatory approach is that the actual costs

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47 We understand that CHP is already mandatory for certain types of situations, in particular for seawater desalination projects (See Amended Electricity Law Article 5-3). We do not recommend passing a similar requirement into law for more general industrial sectors since the specific

Continued on next page

(and benefits) of CHP are, as mentioned above, often relatively site- and application-specific. To support such a study and make sure studies across different applicants are comparable, the KSA (either ECRA, the Ministry of Petroleum, Aramco or some combination of entities with regulatory oversight and decision rights over fuel allocation) could develop standard assumptions to be used in such analyses, for example concerning the value of fuel saved and certain performance characteristics of CHP technologies. An alternative approach would be to require applicants to present business cases with and without CHP technology taking into account available incentives for CHP put in place and further discussed next.

It should be noted that using the fuel allocation process will likely not be a feasible mechanism for fostering the development of commercial CHP applications. This is because most commercial CHP users in general do not require allocated fuel to operate, but rather would use CHP to displace electricity purchases for cooling (and occasional heating) demands. We understand that there are notable exceptions in the KSA where commercial properties use diesel fired distributed generation for their electricity supply due to difficulties accessing electricity supplies through the grid. Also, as noted above, cooling CHP applications, which substitute some portion of electric chillers with thermal chillers (absorption), tend to increase total fuel use rather than "save" fuel – with CHP savings coming from capital expense savings instead. In that sense, thinking about CHP through the lens of fuel allocation is inappropriate. However, in the broader context of exploring under what circumstances commercial CHP may be economically beneficial from the Kingdom's perspective, we suggest that a similar process could be used through authorities granting important permits or licenses to new commercial facilities. In particular, for certain key commercial sectors (such as large hospitals, large airports, etc.) license approval/permits could be made conditional on demonstrating the relative economics of "business as usual" versus district cooling versus district cooling with CHP. Given the significant effort that would have to go into such studies, we also suggest that only facilities above a significant minimum size level would have to complete such an assessment. Since electricity is the alternative "fuel" supply for such entities, SEC (or NGSA) could condition interconnection on such a study being completed.

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circumstances for each industrial application are likely to create a wide range of economic benefits from using CHP, not in all cases in excess of costs.

Sidebar 2: CHP for new industrial cities

A concept that was identified during workshops with stakeholders is to integrate CHP into new industrial developments for multiple hosts, in particular in situations where a new industrial cluster is being developed without prior grid connection. Given our overall finding that the economic benefits of CHP tend to increase with the size of the steam host, and given that part of the KSA's economic development efforts consist of the development of large industrial clusters –called industrial or economic cities – sometimes located at substantial distances from existing electric grid infrastructure, it would appear that the economic benefits of meeting the combined electric power and steam needs of industries expected to locate in any given cluster could be met most efficiently with the use of CHP, which might also allow for avoiding the cost of providing large scale grid connections.

While avoiding the construction of transmission infrastructure to connect remote industrial cities would certainly improve the economic benefits of CHP relative to our analysis underlying our estimated economic (and market) potential for CHP in the KSA, we recommend that while the use of CHP in such circumstances should be carefully studied there are important factors to be considered prior to encouraging or requiring the use of CHP in such circumstances.

In particular, the use of a centralized CHP plant for multiple hosts could create complex sizing issues at the planning stage and complex liability issues in operations. During planning, the difficulty lies in right-sizing CHP facilities for both electric and steam demand of a set of hosts which may well be unknown at the time CHP infrastructure would have to be deployed. If CHP infrastructure is too small to meet the needs of potential hosts, a grid connection or individual boilers may still be needed and thus the benefits of CHP could be diminished significantly. If CHP infrastructure were only constructed once hosts have committed to locating in a given new industrial city, a different risk may arise, namely that CHP hosts will need to rely on CHP infrastructure being completed before beginning commercial operations, when the economics of CHP infrastructure relies on hosts beginning operation on a timely basis.

Another and perhaps more significant concern relates to the management of the CHP system serving multiple hosts. To our knowledge, most CHP systems have dedicated hosts (one CHP system per customer). This is likely because steam is a critical process input and loss of steam can result in significant economic loss well in excess of the value of steam. Consequently, the liability issues associated with not receiving steam during abnormal circumstances such as a partial or full outage of the joint CHP facility could create important commercial risks for both CHP providers and hosts.

Bridging the gap between domestic prices and national values

As long as domestic fuel prices do not closely match national values of fuels, private benefits from implementing CHP will be lower and in many cases significantly lower than the benefits to society overall. While in theory CHP could be required to obtain fuel or another license or permit, we do not recommend requiring the installation of CHP. Rather, we propose that as an interim strategy (until such time when fuel prices in the KSA might be changed to more closely approximate national fuel values) limited financial incentives should be used to close the gap between domestic fuel prices and national fuel values. These incentives would ultimately have to be provided or backed by an entity that realizes the benefits of cost savings measured as national fuel values rather than current domestic prices, i.e. likely a government or quasi-government entity. A number of options exist for doing so. We suggest three potential avenues that could be used (and which have been used and are being used internationally) to do so: capital grants, soft loans, and production support in the form of a heat credit or feed-in adder. We discuss each in turn.

Capital Grants

In theory, capital grants can be structured to approximate the national value of fuel from the perspective of a private CHP client who is exposed to domestic fuel pricing. While we have not determined the value of a capital grant – which can be either absolute, in $/kW of CHP capacity installed, or relative, say 30% of the capital cost of a CHP project – we did analyze the level of capital grant needed to reduce the payback periods for CHP projects to levels where private adoption rates would likely be sufficient, given our assumptions about adoptions as a function of payback discussed earlier.

Soft Loans

Soft loans, or access to low interest rate loans, are another and similar mechanism for lowering the capital cost of a CHP project to the project owner. Both the ability to obtain a loan and a relatively low interest rate can be helpful since in some cases merely obtaining third-party financing can be a challenge (given that much of the benefit stream is in the form of avoided costs, which cannot easily be secured for the purpose of lowering the risk to lenders). The amount and conditions of soft loans can be structured to significantly reduce the difference between private and public benefits of a CHP project facing domestic fuel prices rather than national values.

Heat Credits

Unlike capital grants or soft loans, output related support does not lower the upfront capital costs of a CHP project, but can help improve the overall economic benefit of a CHP project to a private entity, by increasing its overall Net Present Value and reducing payback periods. Heat credits are structurally identical to feed-in adders like those provided for CHP in Germany and discussed above in that they pay a premium per kWh of electricity produced by a CHP project. In theory, the credit could be restricted to net exports in case electricity consumed on-site is harder to measure, but the basic concept is to provide a credit for the fact that steam/heat is being produced at the same time as electricity. The heat credit level could in theory be set to exactly compensate for the difference between domestic fuel prices and national values or to some portion (smaller or greater). The heat credit would have to be increased if only applied to excess power sales, which would incidentally make a heat credit unavailable for applications not resulting in excess power sales, such as for most if not all bottoming cycle applications. Our recommendation is therefore that heat credits, should they be used, be based on total metered electricity production from a CHP facility. One major advantage of a heat credit over capital support is that it creates production incentives over time. In other words, heat credits are only awarded based on actual production and thus create an incentive to operate and maintain CHP facilities in ways that maximize output. In this way, heat credits would also create incentives to produce electricity beyond what is needed to meet on-site steam/heat demands during situations where incremental electricity from a CHP unit can be supplied at a cost below the cost of grid-generated electricity.

Aligning infrastructure and CHP

As discussed above, one critical question related to CHP in the KSA is access to natural gas. Given historic energy supply, natural gas infrastructure is currently limited to various areas and certainly not widely available at the distribution level. Our assessment of the economic potential for CHP in the KSA did not consider any costs of expanding natural gas for the sole purpose of supplying natural gas to CHP units. It is likely that if future power demand will indeed be met from natural gas fired power generation, some additional infrastructure investments will become necessary. Both the existing and planned future gas pipeline infrastructure should be used to support the development of CHP. Clearly, from society's perspective CHP projects are more beneficial, all else equal, if they do not require dedicated investments in gas infrastructure. Any of the financial support mechanisms described above could thus be either available only to potential CHP hosts located (or planning to locate) in close proximity to existing or planned gas infrastructure. Alternatively, any support could be lower for projects requiring new gas pipeline investments (alternatively, CHP projects could be required to finance the gas infrastructure enhancement needed to provide natural gas to a site, similar to generators having to pay for grid investments needed to connect new generation sources.

Encourage third party ownership and operation

One of the important barriers identified for the KSA (and more broadly) is a lack of knowledge and skill related to the operations of CHP. This barrier exists primarily when industrial (and commercial) customers contemplate the use of CHP and reflects the fact they inside their own organizations there may be important skill gaps relative to being able to plan, build and operate CHP facilities. One obvious solution, and one we suggest the KSA contemplate, is to encourage third parties to build, own and operate customer-sited CHP plant. In many countries, CHP facilities are owned and operated by either incumbent utilities (as part of their fleet of generating stations) or by independent subsidiaries of utilities operating CHP facilities outside their traditional service territories. At present, the KSA is still characterized by the majority of generating capacity owned and operated by SEC, with IPPs playing an increasing role. We understand that there are ongoing reform efforts, which may result in a different role for SEC. Independent of the ultimate results of ongoing reform efforts, the current mix of SEC and IPP ownership should provide a sufficient basis for allowing both SEC and IPPs to operate CHP facilities. One approach that could be used is tendering for CHP and allowing both SEC and IPPs to participate in such tendering processes. Given that most promising CHP applications in the KSA are for larger scale facilities, the existing experience by both SEC and IPPs in operating similar facilities should help address concerns about lack of skills and knowledge.

Increase awareness and technical competence

Finally, as is the case even in countries with well-established CHP industries, there remain important overall awareness gaps with respect to CHP. The most often used approaches to build awareness and technical competence is through the provision of technical assistance and through the construction of pilot CHP projects. The KSA could learn from international experience and adopt best practices for developing and then providing technical assistance programs, which could be housed in some of the KSA's existing energy-related public research institutions. We also propose that a limited number of pilot projects for CHP in various applications (topping cycle, bottoming cycle, commercial) could help build awareness and technical expertise that would help kick-start technical assistance programs.

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