Developing a Data-Driven National Development Plan for Combined Heat and Power in Saudi Arabia

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ABSTRACT

The Kingdom of Saudi Arabia (KSA) is a highly-industrialized and rapidly-developing economy with myriad opportunities for large scale energy-efficiency investments. In this economy, public and private industrial actors operate in markets with highly regulated electricity prices and subsidized fuel prices. As such, policymakers create the price signals that significantly influence investment decisions in the KSA's industrial sector. With a burgeoning petrochemicals sector, growing need for desalination, and development of master-planned mixed use communities in the desert, there are ample opportunities for Combined Heat and Power (CHP) technologies to serve electricity, steam, and district cooling demands. Policymakers now face the challenge of prioritizing the most cost-effective CHP investments over their 30+ year lifetime, and developing the appropriate market signals to encourage those investments.

This paper begins with an overview of the market characteristics that would be conducive for CHP deployment in the Kingdom. The assessment then continues with a technical review of the various CHP technologies and applications that could be deployed in the KSA. This bottom-up technical assessment is informed through KSA-specific data sources, including field investigations. A technology- and market-specific cost-benefit analysis enables the quantification of the CHP market potential under different pricing and policy scenarios. As informed by in-country interviews with key industry stakeholders, the paper then assesses specific barriers to achieving CHP development goals in the industrial and commercial contexts. An assessment of the barriers finally leads to policy recommendations for the Saudi Electricity and Cogeneration Regulatory Authority (ECRA) intended to develop macroeconomic and market segment conditions ideal for encouraging upfront investment in cost-effective CHP by public and private institutions.

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, biomass, biogas, coal, waste heat, or oil. According to the US EPA,[1] CHP is not viewed 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 KSA, ECRA wished to assess whether it would be feasible to adopt policies and programmatic frameworks that would lead to wider adoption of CHP technology resources in the Kingdom.

CHP is potentially applicable in the KSA in two important areas:[2]

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[1] US EPA, "Combined Heat and Power: A Clean Energy Solution", August 2012.

[2] Potential CHP applications related to the KSA's significant water desalination industry were also assessed. Unfortunately, due to the nature of the KSA's desalination process, opportunities for CHP were not deemed feasible and no further assessment was conducted.

- Conventional applications: CHP is deployed to capture the heat generated from single- and combined cycle oil or gas-fired power plants. These plants could be part of the Saudi national grid or part of captive generators (e.g., Aramco) where the heat is supplied to the industrial process.
- District cooling applications: CHP is deployed in urban zones to capture the heat generated from single- and combined cycle oil or gas-fired power plants in order to supply the end-use cooling needs of certain residential and commercial/institutional building segments. There might also be a connection to hybrid-renewable solutions in this context. For example, excess heat from solar thermal installations would be used specifically for district cooling applications.

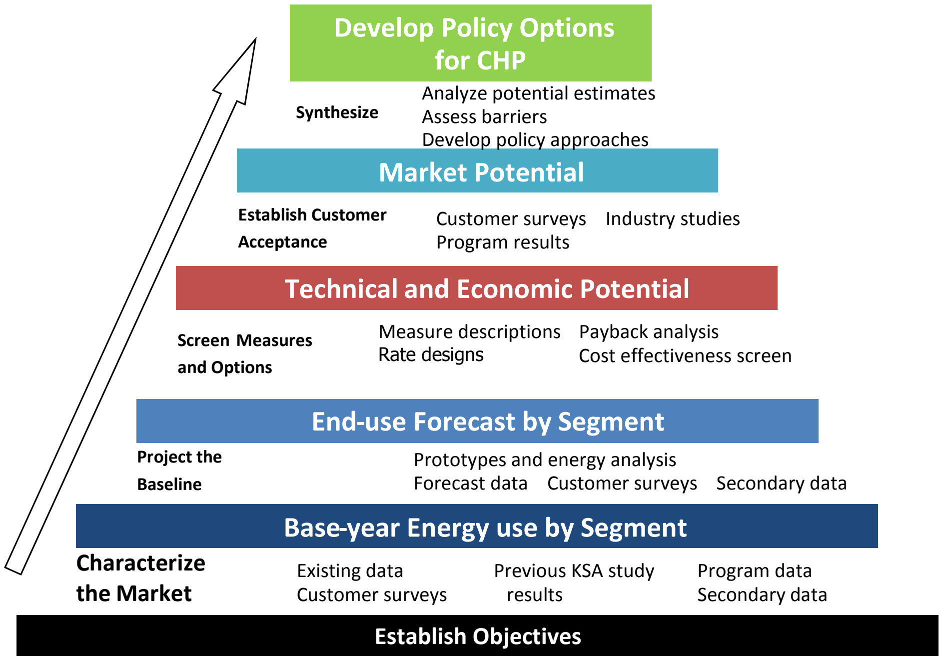
The purpose of this study was to assess the variety of available technical options and then draw on primary data to assess the applicability of those options in the Kingdom considering the cost-effectiveness of the technologies, the existence of various barriers and the identification of policies to overcome those barriers, the market or achievable potential to ensure the development of a high quality CHP resource, and regulatory infrastructures that would be needed in order to more firmly establish the resource. ECRA retained a team comprised of US-based consultancies Brattle Group and Navigant, along with KSA-based Eco Solutions, to carry out the study.

Approach

The approach taken for the study was to conduct the assessment using a framework that centered primarily on KSA-specific data sources and expertise complemented by secondary data sources from the broader Gulf region as well as North America and Europe. To that end, the study team developed a data-driven approach that principally relied on the significant expertise about CHP technologies and applications coupled with field investigations of end-user facilities that either already have CHP deployed are would be ideal candidates for CHP deployment. The primary focus of the existing expertise resided with an expert group assembled by ECRA known as the National Team. The National Team was comprised of professionals from ECRA, other government agencies, Saudi Aramco, the Saudi Electricity Company, and other stakeholders representing various industry interests.

The methodology employed for the study utilized a standard approach for conducting such assessments, as illustrated in Figure 1. The foundation for the assessment was to first conduct a comprehensive characterization of the available market for CHP deployment in the KSA. This characterization addressed the question of how customers use energy today—particularly with regard to heating (i.e., domestic hot water and steam for industrial applications) and cooling. To effectively carry out this task, we conducted a field assessment that involved surveying representative end-use customer sites throughout the Kingdom to assess the current energy use characteristics, customer practices in terms of operations, and their plans for future end-use equipment upgrades.

Figure 1. CHP Analysis Project Approach



Once the market characterization was completed, we then proceeded to develop projections of energy use at the applicable end-use level into the future. This baseline projection was developed to answer the following questions:

- How much energy would customers use in absence of future CHP deployment?
- How much reduction in energy use would result from naturally-occurring conservation/efficiency? (e.g., how many customers would install high-efficiency air conditioners without direct intervention by the Government or the Saudi Electric Company?)
- What is the effect of KSA's building codes and appliance standards that are currently on the books?

This baseline projection was the springboard for assessing the three primary areas of CHP potential – technical, economic and market. The next step was to characterize and screen the specific measures and options and to estimate technical and economic potential. For each CHP measure, we described what it is and how it works qualitatively. Then we proceeded to define the customer segments and end uses to which each measure applies, how much energy and demand does it save, how much does it cost, and what is its average lifetime. As part of our data collection efforts, we conducted surveys of applicable end-use customers to understand their interest in possible future CHP program offerings. The results of these surveys were then used to estimate take rates for each measure and customer segment. These take rates represented the fraction of customers that would participate in potential CHP programs for each option in the forecast period, resulting in the market potential.

We then used the results of the market potential analysis to assess the various barriers known to currently exist which might serve to inhibit the realization of the stated market potential. Finally, we developed policy options that could be implemented by a variety of institutions within the KSA.

Market Characteristics

The primary data collection 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 insights at a few key facilities rather than provide a statistical analysis of the entire country. The on-site visits included interviews with staff able to provide technical details on their industrial process or commercial operation. The study team used these data to supplement and verify secondary research data, to calibrate assumptions used to model technical impacts, and to calibrate energy intensity values as needed. Likewise, some of these primary data were used to directly develop values for inputs for the model where secondary data was missing or not available. The study team developed surveys to aid the on-site visits and provide a level of consistency in questions asked.

CHP is best applied at facilities that have significant and concurrent electric and thermal demands. 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. The study team selected industrial market segments with significant production capacities. These were 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.

As a result, KSA-specific operational characteristics of CHP systems were developed vis-à-vis a CHP performance database. The study team leveraged survey results to develop inputs for the performance of CHP technologies when employed at industrial and commercial sites. In general, sites that had significant and relatively constant heating and/or cooling loads were visited, as they typically are the best candidates for CHP. Table 1 identifies some of the key characteristics for the industrial customer sampling of primary data.

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. The study team 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.

In the KSA, the petrochemical, steel, and cement industries jointly account for 85 percent of industrial electricity consumption. 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.

Commercial and government buildings account for over one third of electricity usage in the KSA, with half of this usage going to cooling. 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 the commercial survey sample. The sample represented 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. It was not possible to conduct interviews with military buildings due to difficulties in receiving the necessary authorizations. 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.

Table 2. Summary of Commercial/Institutional Sample

Building Type	Total Interviewed	Total Conditioned Area (m^2)	Cooling Load (Tons)	Primary Equipment Used To Cool	On-site Generator/CHP
Large Retail Malls	3	165,000	16,900	Chiller, Packaged, Unitary/Split	Standby Diesel Generator
Hotel Complexes	2	33,000	3,500	Chiller	Standby Diesel Generator
Large Offices	2	140,000	3,500	District Cooling, Chiller	CHP
Large Hospitals	2	54,000	2,575	Chiller, District Cooling, Packaged Unitary/Split	Standby Diesel Generator
Airports	1	100,000	22,500	Chiller	Standby Diesel Generator
Govt. Buildings	1	24,000	1,500	Chiller, Packaged, Unitary/Split	Standby Diesel Generator
Universities	1	N/A	13,000	District Cooling	Standby Diesel Generator
Stadiums	1	150,000	1,000	Chiller, Packaged, Unitary/Split	Standby Diesel Generator
Multi-Family Bldgs.	1	Not available	Not available	Not available	Not available
Total	**14**	**666,000**	**64,475**	**N/A**	**N/A**

Technical, Economic and Market Potential Assessment

The assessment involved three steps. First, data on the current on future composition of various industrial and commercial sectors in the KSA economy were developed to derive estimates 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 (technical potential). Second, using assumptions about CHP-specific costs, the team developed KSA-specific estimates of the economic potential for CHP between 2015 and 2040. To accomplish this, an economic model that was driven by assumptions about fuel costs, electricity rates, etc. was developed in order to determine the most cost-effective CHP technology to deploy 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 periods 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. Third, 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, i.e. of the amount of economically beneficial CHP that would likely be adopted by private parties, for CHP in the KSA.

To assess the technical characteristics of CHP technologies, KSA-specific customer data provided information about industry/building utilization, load factors, and peak coincidence factors. In addition, data about facility-specific fuel consumption characteristics and industrial production at the country informed the data development. For the industrial sector, the team used fuel consumption as a proxy for either waste heat or fuel requirements. This data was used 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, engineering judgment was applied to determine the appropriate CHP technology for each combination of industry and size segment. For the commercial/institutional sectors, building floorarea was estimated using the commercial survey results and general market knowledge as indicators. Then secondary data about energy intensities was adjusted to represent the conditions that are unique to the KSA (i.e., climate, building stock, etc.).

Technical Potential

For the industrial sector, various industrial processes were analyzed to find how CHP technologies could be integrated with the process and if the process was suited to a topping or bottoming CHP cycle. In a typical topping cycle system, fuel is consumed in a prime mover, such as a gas turbine or reciprocating engine to generate electricity. In a bottoming cycle system, also known as "waste heat recovery," fuel is combusted to provide thermal input to a furnace or other industrial process and heat rejected from the process is then used for electricity production. For the commercial/institutional sectors, cooling with absorption chillers and CHP is only feasible for facilities that have large cooling loads. As such, the analysis was limited to commercial market sectors that would require at least 1000 tons of cooling capacity.

The assessment resulted in a total of five CHP prime driver technologies for industrial and commercial applications in the KSA. These five technologies included:

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

While other CHP technologies, such as micro turbines, fuel cells, and solar were considered, they were ultimately deemed to not be sufficiently mature 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 technical assessment did 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. However, it should be noted that the CHP potential in these sectors is quite large and should be explored.

Figure 2 summarizes the CHP technology applicability across the various KSA market segments that were assessed as part of this study. Aside from heavy industry applications where bottoming cycles are most suitable, the bulk of applications are for topping cycles.

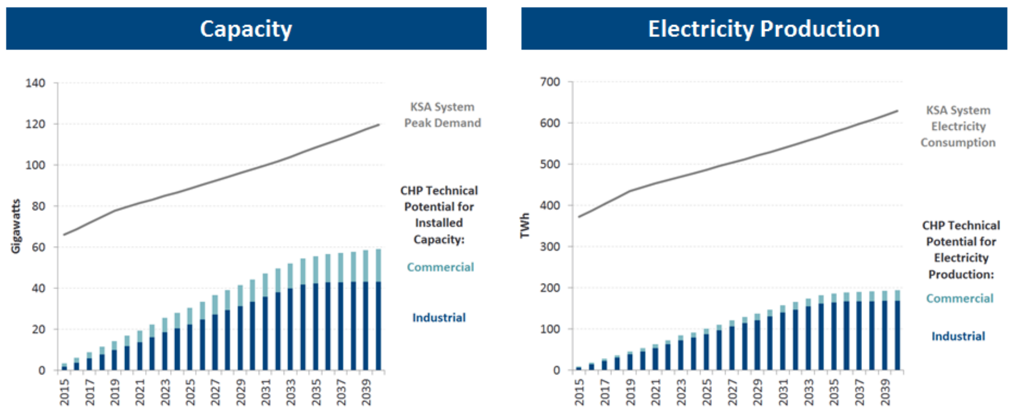
Figure 2. CHP Technology Applications by Market Sector

Industrial Sectors		Commercial Sectors	
Industry	CHP Type	Building Type	CHP Type
Aluminum	Bottoming	Airports	Topping
Ammonia	Bottoming	Colleges/Universities	Topping
Benzene	Bottoming	Government	Topping
Cement	Bottoming	Hospitals	Topping
Ethylene Dichloride	Bottoming	Hotels/Lodging	Topping
Ethylene Glycol	Topping	Military	Topping
Ethylene Oxide	Bottoming	Office Buildings	Topping
Ethylene/Propylene	Bottoming	Other - Commercial	Topping
Food	Topping	Refrigeration	Topping
Formaldehyde	Bottoming	Residential District Cooling	Topping
Glass	Bottoming	Retail	Topping
Iron/Steel	Bottoming	Schools	Topping
Methanol	Topping	Stadiums	Topping
MTBE/Isopbutylene	Topping		
Other - Industrial	Topping		
Paper	Topping		
Phosphoric Acid	Bottoming		
Polyethylene	Topping		
Polypropylene	Topping		
Propylene	Bottoming		
PVC	Topping		
Soda Ash	Topping		
Styrene	Topping		
Urea	Topping		
Vinyl Chloride	Bottoming		

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.[3] 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. Technical potential by year is summarized in Figure 3. To put the figure in context, it is compared to system wide peak demand and electricity consumption forecasts.

Figure 3. Technical Potential for CHP



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 curve). 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.

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***

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[3] 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.

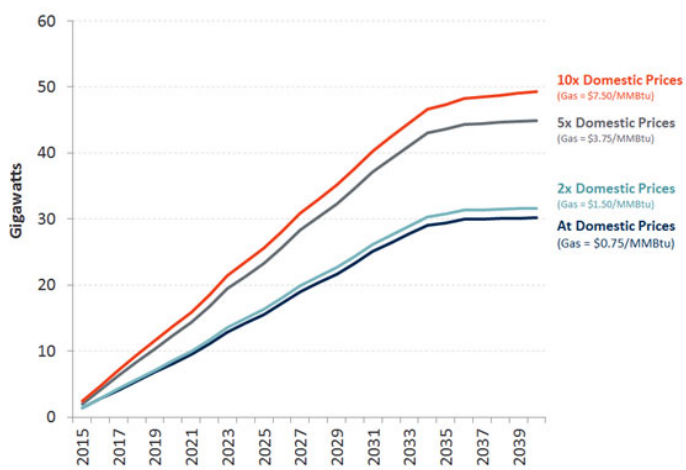
account for practical considerations that limit the number of customers who will choose to adopt a cost-effective CHP technology. These considerations, for example, could include limited access to capital, perceived operational risk associated with self-generation, or uncertainty around access to fuel for the CHP plant. A comprehensive discussion of barriers to adoption is provided later in this paper. 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.

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.[4] Figure 4 below summarizes the annual economic potential for CHP capacity at these price multiples.

Figure 4. Economic Potential for CHP

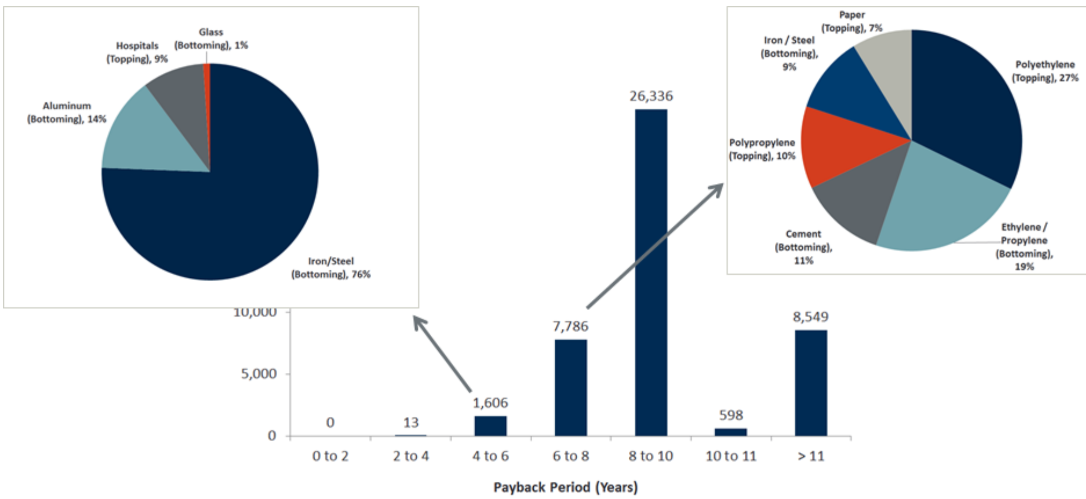


Economic potential is defined as the amount of CHP that would be beneficial to the KSA as a whole rather than to individual customers or CHP participants. Because payback periods are an important determinant of market adoption, Figure 5 shows the distribution of payback periods of

4 This highlights that the relationship between price and CHP potential is non-linear.

the economic potential for CHP assuming a value of fuels equal to five times current domestic prices.

Figure 5. 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.[5] 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).

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,[6]

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5 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.

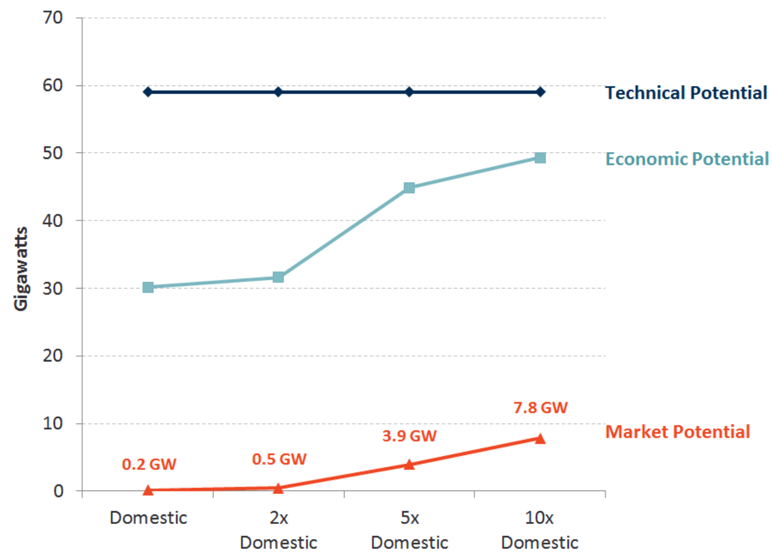
6 ICF, "Combined Heat and Power: Policy Analysis and Market Assessment: 2011-2030," February 2012 and Primen, "2003 Distributed Energy Market Survey," May 2004. A number of customer adoption curves have been developed for different purposes, including for the adoption of electric heat pumps and distributed 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,

and is further supported indirectly by several studies on customer adoption of energy efficiency measures.

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 6, alongside the previously reported estimates of technical and economic potential.

Figure 6. CHP Capacity Potential (2040)



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

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.

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 the remainder of this paper.

Barriers Assessment

An assessment of the various barriers to CHP deployment in the KSA was carried out by the project team. A total of five KSA-specific barriers were identified based on the primary data collection efforts (i.e., through end-user interviews carried out by Eco Solutions) and through insights offered by experts from the National Team. These barriers are:

- Subsidized electricity rate. Because of electricity retail rate subsidies, end-users do not have the sufficient economic incentives to make investments in CHP. This likely represents the single most important barrier to CHP development in the KSA.
- No market exists to sell excess power to the grid. In the absence of a functioning wholesale market and no established standard for compensating electricity injected into the grid by third parties, this uncertainty is likely a major barrier to the development of topping cycle CHP applications, which tend to be sized in ways that result significant excess power production relative to electricity demand by the CHP host.
- Fuel allocation uncertainty. 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. Once a fuel allocation is granted, the allocation requires regular reauthorization, which creates ongoing risk for CHP plants.
- Cross-subsidies between rate classes. 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 the electric utility (SEC) not having the ability to cover its costs. For this reason, the regulatory agency is reluctant to grant cogeneration licenses, in particular to commercial applicants.

- Availability of CHP replacement parts. There is significant uncertainty related to the availability and cost of important CHP replacement parts, many of which would typically need to be imported.

The barriers assessment suggests that CHP faces a number of barriers in 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 that was found. Additional important barriers to CHP deployment in the KSA, which could further reduce market adoption, are uncertainties about fuel allocation and the price received for exporting power 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.

Policy Approaches

To ensure that the identified market potential is realized and the barriers to CHP are overcome, the following policy recommendations were identified.

- Reform fuel allocation approaches. Since essentially all industrial customers with high CHP potential as shown above 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. However, reforms to the existing fuel allocation regulatory scheme will need to be made to ensure that the uncertainty barriers are overcome.
- Create interim strategies to bridge 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 far lower than the benefits to society overall. Rather than impose regulatory mandates for customers to install CHP systems, an interim strategy might involve limited financial incentives to could be used to close the gap between domestic fuel prices and national fuel values. Three potential avenues 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.
- Align infrastructure to accommodate CHP development. As discussed earlier, 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. Both existing and planned future gas pipeline infrastructure should be used to support the development of CHP.
- Allow 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 that inside their own organizations there

may be important skill gaps relative to being able to plan, build and operate CHP facilities. One obvious solution is to allow third parties to build, own and operate customer-sited CHP plant.

- 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. Furthermore, 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.

Conclusions

While the market potential for CHP appears to be substantial when compared to overall installed electric capacity in the KSA, several important conditions must likely be met to achieve this potential. 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, the economic potential for CHP in the KSA resides within 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, 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).

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