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Energy Efficiency: The Overlooked Energy Resource

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Abstract

The objective of this chapter is to draw the attention of government policy makers internationally to a strategy for alleviating global warming through proven cost-effective energy efficiency measures. The Saudi Arabian government has embraced the approach with demonstrable success over the past 20 years, with rates of return on investments averaging more than 25%. Even though Saudi Aramco is the National Oil and Gas company, the company takes the threat of climate change to the world's economies very seriously and initiated programs for, systematically and responsibly, transition to less-polluting energy sources. Primarily, the chapter will define the supply chain components of Saudi Arabia's energy sector and explain the existing conditions and efficiencies of each of its components. It analyzes the existing energy management framework and its achievements, as well as its current and forthcoming commitments, status, and updates. It will also explain the vital equipment, systems, and processes in the supply chain, with possible energy efficiency improvement gaps based on existing literature/Energy Assessment Reports conducted by Saudi Aramco professionals in numerous industrial facilities. The chapter will pinpoint the highest achievable efficiencies areas in major systems, processes, or equipment and discusses its impact on the primary energy fuels and green house gas (GHG) emission reduction.

Keywords: energy efficiency, industrial energy power generation, energy transmission, energy oil and gas

1. Introduction

Oil and gas are the world's most used energy sources based on the share of each source of global energy consumption. More than half of the global energy demand is fulfilled by oil and gas, as shown in **Figure 1** [1]. The production of these primary energy fuels (oil and gas) involves them going through various stages of processing before it is used directly in the vehicle or converted to electricity in the power plant for other end-users. It can be characterized as a typical supply chain, which is defined as a complex structure of supply facilities linked together in order to serve end customers, collectively called the "supply chain" network. In the present context, it can be referred to as the energy supply chain. The main objective of the energy supply chain is to deliver crude oil, natural gas, and refined products safely and economically to customers. These energy supply chain networks are subject to various losses in primary energy (oil & gas) as well as secondary energy (electricity), some of which are unavoidable while some are not. Improvements in the

overall efficiency of the energy supply chain certainly result in enhanced profit margins and mitigated environmental impacts. Consequently, a comprehensive strategy to develop efficient energy supply chain network is inevitable.

The Kingdom of Saudi Arabia (KSA) is among the top crude oil producing and exporting countries in the world as well as one of the major producers of natural gas. KSA has invested heavily to improve the overall efficiency of its energy supply chain and demonstrated an approach that is driving the business towards excellence with a noticeable improvement in the preservation of the livable environment. To identify the most significant opportunities for increasing energy efficiency and reducing energy losses, it is vital to determine where and how energy is used—how much is used, where are the losses—how much is lost, where energy losses could potentially be recovered or reduced, and to what extent. **Figure 2** shows an overall picture of KSA’s Energy flow, as a Sankey diagram, represents KSA’s total production, consumption, and exports [2]. It will aid the understanding of overall energy usage that occurs from source to end-user in KSA’s energy supply chain and consequently provides insights to identify areas of improvement and overall efficiency enhancement. **Figure 2** [2] clearly establishes KSA as the leading oil exporter,

however, the main emphasis here is about understanding the energy flow and the overall efficiency of the energy supply chains. There are certainly energy consumptions as the energy flows from sources to end-users, but a reduction in the amount of energy used to process and deliver it to the final users have greater implications as it will improve the performance as well as save the product i.e., energy, which will eventually be added to the product. Even though some losses occur at every stage in the energy supply chain, it is evident from **Figure 3** that a significant energy loss occurs at power generating stations.

From an overall efficiency improvement standpoint, primary energy is the best place to look at for energy use as well as for losses. As illustrated in **Figure 3**, a typical industrial pumping system utilizes only 10% of the primary energy resources, if pumping is considered to be the end-use of the energy from the primary energy sources and typical losses for all components in the supply chain is considered. Energy “footprints” could be created for all users, illustrating energy flows along the utility supply chain from energy sources to an industrial end-user based on which energy use, loss, and opportunities analysis shall be conducted to prioritize efforts to improve the overall efficiency of the energy supply chain.

To establish the effectiveness of the policy framework of overall efficiency enhancements for the energy supply chain, it is essential to evaluate macroeconomic benefits from such an approach. It is a very common and well-established causality relationship between energy consumption and gross domestic product (GDP). The ratio of energy use to GDP indicator is referred to here as “aggregate energy intensity” or “economy-wide energy intensity”. Economic-wide energy intensity is measured by dividing the cumulative energy consumption requirement of a particular region by its GDP. Its trend indicates the general relationship of energy consumption to economic development and provides a rough basis for projecting energy consumption and its environmental impacts on economic growth. It estimates the absolute amount of energy needed to generate a single unit of gross domestic product. GDP is represented at a consistent exchange rate and an increasing parity of power to exclude inflation, which influences and indicates the diversity of energy consumption and general energy price levels in the real economic scenario. The economic-wide energy intensity and GDP of some major countries are shown in **Figures 4** and **5** respectively [3, 4]. The trend for the USA shows that even though the GDP is growing, energy consumption is declining. Most of this is due to a shift away from low-margin energy-intensive manufacturing to more profitable financial and IT services, not due to better energy efficiency. A similar profile can be observed for Germany. In KSA however, it appears that energy consumption is rising faster than GDP till the year 2010 which reflects energy inefficiency in the energy supply chain including end-users inefficiency.

Figure 3.
A typical industrial pumping system.

Figure 4. Economic-wide energy intensity of countries [3].

Figure 5. World Bank provided GDP of countries [4].

It is important to have a look at the energy consumption in different sectors to improve the energy scenario and provide recommendations to meet the country's goal of rational energy consumption patterns. According to the Saudi Energy Efficiency Center (SEEC), 90% of domestic energy consumption in Saudi Arabia is consumed by the construction, transport, and industry sectors [5]. The industrial sector consumed 47%, the construction sector consumed 29%, while the transportation sector's consumption was about 14% of the country's primary energy in 2017 [5, 6].

Figure 6 shows trends of energy consumption in different sectors from the year 1990 to 2014 [7], indicating a sharp rise in industrial and building sectors. The trends with inference from GDP (Figure 7) movement suggest that energy consumption is increasing as a result of economic activity without any improvement in the consumption patterns. Consequently, energy efficiency policies need to be developed with an emphasis on the three most energy-intensive sectors i.e., industrial, transport, and building sectors.

Figure 6.
Total energy consumption in different sectors for the Kingdom of Saudi Arabia [6].

Figure 7.
GDP of the Kingdom of Saudi Arabia [4].

The best way to improve energy productivity as a way forward for the Kingdom's strategy would build on the competitive advantages by enabling a strong and energy-efficient industrial sector. As for the other two sectors i.e., transport and building sectors, they need more regulatory and behavioral improvements. For example, given the low energy prices in the Kingdom, it is difficult to invest in energy-efficient home appliances (AC units, refrigerators, or efficient lightings) to improve buildings' energy performance. Similarly, for transport, fuel-efficient vehicles will not be preferred by the masses if the gasoline prices are very low. It is obvious that there will be very little to no incentive for owners to invest in energy efficiency. Consequently, this will likely remain an issue, till the energy price regulation/reforms are fully implemented. However, when we see the supply side of these sectors, it is part of the energy supply chain i.e., part of the industrial sector, thus these sectors have a unique feature, where its boundaries are not completely dictated by its sector but by other sectors too. If the benefits from avoided energy consumption or improved efficiency in the supply side (power plant) which resulted in the avoidance of the new electricity generation facility, are considered, energy efficiency investments seem highly cost-effective.

In common with other parts of the energy sector transformation, it is important for actions to be based on an integrated strategy with clear goals. Energy efficiency and other demand-reduction measures will need to be analyzed together with supply expansions to find the best balance in terms of both service delivery and costs. It is critical to ensure that the opportunities offered by new digital technologies are fully utilized to enhance the efficient interaction of ever-more integrated energy system supply and demand elements. The system is first modified to use energy in a more effective manner, more energy efficiency opportunities are readily available to meet the emissions targets, within the given time frame. Moreover, it will have positive effects on energy transition as it will minimize demand and result in a lesser number of needed renewable/green energy installations. However, energy efficiency measures often need policy support to be implemented and strategies must address the main barriers to the adoption of energy efficiency measures and promote structural and behavioral changes. Furthermore, they must be considered across different sectors and areas, for instance, buildings, transport, and industrial sectors.

To address the global agenda of enhancing energy productivity, KSA's vision 2030 program has identified and addressed many areas in which energy efficiency can be improved significantly and cost-effectively. One of the outcomes of KSA's vision 2030 program is the Saudi Energy Efficiency Center (SEEC), which has taken wider initiatives to address national energy efficiency improvement and carbon emissions. It is functional from the inception of the year 2010. In 2012, SEEC launched a national program to raise energy efficiency in the Kingdom, using initiatives designed according to local market potential, by involving all stakeholders (government, companies, and the public). The program focuses on three key sectors (buildings, transport, and industry), which consume about 90% of the total energy in the Kingdom [6]. The program developed the factors and possible supporting mechanisms to boost its activities.

The program was launched as a dedicated system for energy efficiency improvements, to ensure the implementation and enforcement, including a mechanism to update when necessary, with an executive committee that holds all the power necessary to manage the program through an organizational structure. Since its formation to date, the impact of the programs on the overall national-level energy efficiency index is visible as shown in **Figure 4** (from the year 2012 onwards). It is important to note that other agencies and their initiatives contributed to this energy productivity improvement.

The Kingdom is implementing many other initiatives as well, including renewable energy (wind, solar), safe nuclear power, cost-effective energy efficiency, and minimization of needless fuel emissions through flare management. Best of all, these technologies are mostly well-established and proven for all commercial applications. It has been clearly observed that from 2012 to 2018 the overall supply chain energy efficiency improved significantly because of major efficiency improvement in utility plants, one of the most significant components of the supply chain. Overall national level utility plants efficiency has improved from 31.8–38% and is targeted to reach 45% by 2030 [8] through the incorporation of combined cycles and integration between power generation and seawater desalination at the same site. Towards this end, the formerly separate Ministries of Water and Electricity were merged by a Royal Decree into a single entity—MOWE. The combination of such strategic decisions justifies the reasons for such significant efficiency improvement in Saudi Arabia's Industrial and Public Utility sectors.

Energy efficiency in Saudi Arabia has included the establishment of a framework for an energy efficiency market involving energy service companies and a range of regulatory measures to drive the market. These were focused on the building,

transport, and industry sectors which covered around 90% of energy consumption in the Kingdom [5, 6]. The approach adapted is to develop a baseline for setting policies, establish performance relative to international benchmarks, prioritize initiatives based on potential impact, achieve consensus and coordination among implementation agencies, and establish execution teams and empowering policy environment. Then, finally, to monitor and evaluate progress, with a view of registering feedback into the design of the overall approach.

Energy supply chain is an essential part of the kingdom, as it fulfills energy requirements for all sectors and also provides products to export. As the Kingdom is one of the largest exporters of crude oil, the industry sector, which is the largest energy consumer in the kingdom, is predominant with the components of the energy supply chain. Accordingly, any improvement in the energy supply chain will result in a greater effect on the energy productivity of the whole kingdom. There are two key drivers to improve the energy productivity of the Kingdom, firstly, structural change in the economy by moving away from energy-intensive to a high margin value manufacturing and, secondly, energy efficiency in energy-intensive manufacturing. Both aspects of energy productivity are important for the Kingdom but the energy efficiency improvements provide a quick win for the kingdom. Moreover, the solutions to improve the energy efficiency of the energy supply chains are applicable to other sub-sectors of the industrial sector and could be leveraged across all industrial sectors. Improvements in the energy supply chain will have great implications on the abundant natural resources of the Kingdom i.e., the counts of barrels saved in the processing will be added to the export/usage.

2. Energy supply chain networks

Energy efficiency of the energy supply chain network is aligned with the Kingdom's Vision 2030 which is aimed at delivering more sustainable, socially inclusive, and prosperous economic development. The energy supply chain in KSA mainly constitutes of Hydrocarbon Supply Chain (HCSC) i.e., crude oil and natural gas supply chains, along with utility plants. HCSC chain is wholly owned by the state-owned oil giant Saudi Aramco while utility plants which are mainly for power generation plants are owned by Saudi Electric Company (SEC). Although SEC owned power generation plants and distribution of electricity, Saudi Aramco also has power generation capacity through cogeneration and generates power which is excess of its total consumption and supplied to SEC for distribution. **Figure 8**, provides an overview of the energy supply chain network in KSA which constitutes of different stages/components and could be defined in many ways but usually constitute of the following main components:

- 1. Reservoir and facility management:** This term in the present context refers to the exploration and production of oil and natural gas. Geologic surveys and any information gathering used to locate specific areas where oil and gas are likely to be found, commonly called "exploration". The term also includes the steps involved in the actual drilling and bringing oil and natural gas resources to the surface, referred to as "production". In short, from an operation perspective, it is associated with the extraction of hydrocarbons from the "wells" that bring the crude oil or/and natural gas to the surface as well as the reinjection of produced water.
- 2. Upstream facilities:** It is referred here to include all facilities which do the separation of wellhead fluids into constituent vapor (gas) and liquid (oil and

Figure 8.
Energy supply chain losses diagram.

produced water) components. It includes Gas and Oil Separation Plants (GOSPs), crude stabilization facilities, and gas compression plants along with utilities to supply energy to these plants.

3. Downstream facilities: These are the facilities involved in the processes of converting oil and gas into the finished product. These include refining crude oil into gasoline, natural gas liquids, diesel, and a variety of other energy sources. The closer an oil and gas company is to the process of providing consumers with finished petroleum products, the more it adds value to the hydrocarbons and generally results in higher energy intensity.

4. Terminals & distribution: These facilities deliver gas, crude oil, and refined hydrocarbon products in a safe, reliable, cost-effective, and environmentally friendly manner to the customers. It includes a network of pipelines and storage facilities to deliver the wellhead fluids to upstream facilities, upstream products i.e., oil and gas to downstream facilities i.e., refineries, fractionation plants, and also finished products from downstream facilities for other consumers including end-users.

5. Utilities plants: It is referred to all facilities that provide energy to the end-users in the form that can be directly usable by them and mainly, transform primary energy in the final form to be used by end-users. It supports energy requirement for both upstream and downstream activities and also includes power plants (one of the major contributors to energy inefficiency) that supplies electricity to end-users.

6. End-users: Transportation, building, industry, agriculture, etc. are the end-users. All the energy produced is consumed by end-users. It is the energy that reaches the final consumer's door and excludes that which is used by the energy sector itself. Final energy consumption excludes energy used by the energy sector, including for deliveries, and transformation. Final energy consumption in "households, services, etc." covers quantities consumed by private households, commerce, public administration, services, agriculture, fisheries etc.

Although, there are not very sharp and distinct boundaries among all components of the energy supply chain but it is needed to unify efforts to improve energy efficiency. The KSA’s energy supply chain, which is mainly HCSC consisted of two parallel supply chains of crude oil and natural gas, which are divided into three echelons: production areas (starting at the well head), processing plants, and distribution terminals. An overlap exists between the two networks because crude oil is strictly a two-phase fluid that contains both oil and dissolved associated gas.

Figure 9 [9] depicts a schematic representation of the HCSC network, it clearly indicates that Echelon 1 is mainly a reservoir facility management component, Echelon 2 covers upstream, downstream, distribution as well as utilities facilities while Echelon 3 belongs to end-users.

The reservoir facility management is very different from the above surface facilities. It includes sub-surfaces, highly dependent on the reservoir characteristic, and emphasis on reliability and not conversed in the chapter. Most of the equipment and systems, such as steam, compressors, furnaces and boilers, rotary equipment (air compressors, pump, and fan motors), combined heat and power, cogeneration is common for Echelon 2. The discussed solutions might be applicable to different components of the energy chain but considering the frequent applicability, they could be leveraged across an Echelon or beyond.

2.1 General strategies for energy efficiency improvement

There are several well-established and proven strategies for improving energy efficiency in industrial processes. Some of them pertain to equipment, and others to systems. For example, a heat exchanger is an item of equipment, but a Heat Exchanger Network (HEN) that preheats the feed to a distillation column is a system. Both categories must be addressed, keeping in mind that improving system efficiencies has multiple potentials for savings than component/equipment efficiency upgrades.

This chapter will list some of the more important techniques generally applicable to all processes, without attempting to describe any of them in detail. It highlights some of the findings of the energy assessments conducted by Saudi Aramco and based on the case studies;

Figure 9.
Details of upstream hydrocarbon supply chain network [9].

- Heat recovery optimization using pinch analysis.
- Variable speed drives—VFDs for motors, steam turbines—for pumps and compressors.
- Load management of series/parallel networks of boilers, furnaces, pumps, compressors, etc.
- Integrated optimization of utilities (combined heat, power, and cooling systems) with the process needs.

Rather, we will give examples of the application of these methods for specific projects under-taken or under consideration at Aramco facilities.

The following subsections will explain each energy supply chain network component. The energy consumption and production in upstream, downstream, utilities including power plants and end-users—is very complex and linked.

3. Upstream facilities

Several processing steps are required to separate the underground well fluids—a multiphase mixture of gas, oil, water, and solids (both dissolved and suspended) as shown in **Figures 10** and **11**. These separation processes not only include the separation of “produced water” from the oil/gas mixture, but also removal of dissolved gases, acid gases and extraction of light-end distilled products from the crude oil, and the separation of acid gases, water, condensate, and NGL from the associated gases.

The hydrocarbons from wells are transported to gas-oil separation plants (GOSPs) which is generally equipped with a three-phase separator and separate the associated gas and water from oil. The hydrocarbon stream from the three-phase separator might undergo water removal in desalters depending on the crude oil’s characteristics. The dry crude is stabilized in the stabilizer column and transferred to terminals either for exports or further processing in downstream facilities.

Figure 10.
GOSP process block diagram.

Figure 11.
 Typical oil & gas separation process.

Natural gas from dry-gas reservoirs (i.e., non-associated gas) and associated gas from GOSPs are collected at the gas gathering centers and fed to gas processing plants.

At Saudi Aramco, the gas processing plants are classified as part of the “Upstream” sector, whereas in most other parts of the world they are classified as midstream. At our gas processing plants, H_2S (used for sulfur production) and CO_2 (vented to atmosphere) are removed by *absorption and stripping* processes, while methane and NGL are produced as separate products by low-temperature fractional distillation. After that, NGL is fractionated further in a separate plant into its components (viz., ethane, propane, butane, and natural gasoline (C5+)). Finally, sweetened crude oil and gas are distributed to different storage terminals (local, industrial, and international) for shipment to customers. All of the above processes involve several levels of heating, cooling, pumping, compression, expansion, refrigeration, and other supporting operations.

In **Figures 12 and 13** [9], reservoir and natural gas networks in Saudi Arabia are shown.

3.1 Applications in upstream

The first process after the well-head typically involves a high-pressure test trap, a low-pressure degassing tank, electrostatic dehydrator, electrostatic de-salter, water-oil separator, several types of pumps (booster, shipping, disposal, condensate, wash, stabilizer bottom, transfer, and chemical injection), air compressors, gas compressors, refrigeration compressors, shell and tube heat exchangers, air coolers, a crude stabilizer column, etc. All this equipment and instruments involve multiple utility systems: process water, fire water, instrument/plant air, flare, gravity and pressure sewer, chemical injection, power generation, hot oil, boiler, and steam, etc.

Imbalance and inefficiencies in these systems and equipment have a significant impact on the GOSP, and thus on the overall energy supply chain, so must be carefully assessed and optimized. Typically, in GOSP configuration, essential energy consumers are water injection pumps (39%); gas compressors (44%); and pumps or internal liquids transport and deliver the crude oil via pipeline from the GOSP to the oil terminal or refinery (17%).

Figure 12.
The upstream crude oil supply chain network in Saudi Arabia [9].

Figure 13.
The natural gas supply chain network in Saudi Arabia [9].

Reliability is the main focus in the crude extraction process especially from the underground well to the GOSP. So, while working to improve the efficiency of that stage of the cycle, it is very important to improve other stages from the GOSP to transportation. The following few common measures are widely discussed in the upstream process energy improvement.

3.1.1 Compressors load management and process optimization

Overall energy efficiency of a compressor is the ratio of absorbed energy by the process gas to the energy consumed by the driver. Compressor load management means ideally turning only the minimum number of units in the network, and optimizing the load on each one according to the demand. This needs to be controlled and monitored with enough time delay function to reduce frequent

Figure 14.
 Performance curve and system resistance curve for a typical compressor system.

activation/inactivation. The use of variable speed drives may or may not be the best option, since it is difficult to control flow rates under turn-down conditions where the system curve may be nearly parallel to the compressor curve (see **Figure 12**). Properly controlled compressor load management can bring 3–5% savings from total compression.

The methodology for estimating savings potential from load management of compressors is similar to that for pumps, except that the fluid is gas instead of liquid in the pump. In general, the head vs. capacity curve (also called the “performance” curve, **Figure 14**) for a centrifugal compressor operating at a fixed speed is relatively flat, with the total head at the minimum throughput (the surge point) typically being only 105–115% of the head at design throughput. The system curve is also relatively flat because the static head usually dominates the frictional (dynamic) head. The operating point occurs at the intersection of the compressor performance curve and the system curve.

3.1.2 Reduction and recycling through VFD and impeller trimming

The compressor operation can be controlled, within limits, by installing a variable frequency drive (VFD). For extreme cases where the machine was grossly oversized for the duty and if the desired flow reduction is permanent, impeller trimming may be preferable compared to a VFD. The savings can be in the order of 5–10% of existing power and energy.

3.1.3 Fired heater efficiency improvement by controlling the excess O_2

The main operating parameters affecting combustion process efficiency are the flue gas temperature and the excess air ratio. The target FG exhaust temp should be about 50 F above the dew point, and the % of O_2 in the flue gas should be 2–3%. Approximately 3–5% savings in fuel consumption can be expected.

3.1.4 Design modification on the fired heater convective/economizers

Fired heaters transfer the combustion heat from the fuel to process streams. Most of the heat transfer occurs by radiation in the radiant zone, while some of the

Figure 15.
Fired heater zones.

heat in the flue gas is absorbed by convection in the convective section (common) and the economizer (not as common) zones (**Figure 15**). The remaining heat in the flue gas leaves the fired heaters through the stack and is lost.

The heater efficiency is defined as the ratio of heat absorbed by the process and the total heat released by the combustion of fuel. Even small efficiency improvements in fired heaters can yield considerable energy savings and green house gas (GHG) emissions reduction due to their large energy consumption. Usually, the fluid being vaporized is preheated in the convective section, while the economizer is used to recover heat into colder process or utility stream such as Boiler Feed Water (BFW). Since most furnaces come with a built-in convective section, to start with, the only remaining heat recovery retrofit opportunity is usually to add an Economizer. Unfortunately, for piping layout and structural support reasons, this is often not economically feasible but could be feasible with a separate economizer at the surface (i.e., not mounted on the top of convection section) connected through the duct.

3.1.5 Well-head to GOSP gas turbo expander generator

A turboexpander (**Figure 16**), also referred to as an expansion turbine, is a centrifugal or axial-flow turbine, through which high-pressure gas is expanded to produce work, and can often be used to directly drive a compressor or generator. Most gas from the wells is produced at high pressure, and after the first knock-out drum in a gas processing plant is usually let down to lower pressures across a valve. Instead of destroying the pressure energy, it could be let down through a turboexpander to recover and could be utilized energy is utilize as shaft power or to generate electricity in a generator.

3.1.6 Hydraulic turbine (liquid)

Similar in concept to a turbo expander, the hydraulic turbine can be used to recover some power from high-pressure liquids being let down to lower pressure. They are effective pumps operating in reverse but are not commonly used in oil and gas plants.

Figure 16.
Turboexpander schematic.

There are many other energy efficiency techniques available that can be applied in GOSPs, gas plants, stabilization units, and related supporting facilities, which have the potential for significant energy savings. It is estimated that 5–10% of total supply chain energy is used in upstream activities, out of which 15–20% energy savings are possible.

4. Downstream facilities

The oil refining sector is vast and diverse with multiple processes that are tailored to the type of crude oil feed (light, medium, heavy, etc.). Everything starts with the CDU (crude distillation unit) which fractionates the desalted feed into various cuts—light-end gases, naphtha (gasoline), kerosene (jet fuel), diesel, Light Gas Oil (LGO), Heavy Gas Oil (HGO), and tower Bottoms. The bottoms stream may or may not send to a vacuum distillation unit (VDU) for further fractionalization into more valuable cuts, depending upon the flow rate and composition. Other process units typically include hydro-treaters for sulfur removal, catalytic reformers for raising the octane value, hydro-crackers, delayed cokers, vis-breakers, alkylation units, hydrogen production, sulfur recovery units, etc. An oil refinery requires a multitude of supporting facilities and utilities, such as fuel storage and distribution, steam generation and distribution, power distribution, on-site power generation (whether as mechanical shaft work or electricity), compressed air, cooling water, refrigeration, freshwater supply, wastewater treatment and disposal, chemicals storage and distribution (e.g., caustic soda, nitrogen, etc.), firewater system, chillers, boilers, steam turbines, and gas turbines. Although all are important for the smooth operation of the processes, they are not equally important from an energy consumption perspective. The seven main ones—steam, fuel gas, fuel oil, electric power, air cooling, water cooling, and refrigeration are energy-intensive and important from the energy conservation point of view. All of these systems could involve significant energy losses.

4.1 Applications in the downstream

To identify the gaps, it is important to consider the energy assessment of the entire unit instead of just equipment by equipment. It starts with drawing the

boundary around the processing unit, calculating energy losses, and comparing them by equipment component first, followed by comparing with the unit's "target" energy consumption to identify the efficiency gaps for the whole integrated unit and subsequently for the whole facility.

The CDU + VDU system is generally the largest single energy-consuming unit in a refinery, the majority of them utilize fuel for the fired heaters to provide heat for reboiler in the columns, followed by steam used in the feed preheat train, for side strippers, and for vacuum jets. The goal of the preheat trains is to deliver the feed streams to the fired heater at the highest achievable inlet temperature on a sustained basis. The efficiency of the preheat train (PHT) can be easily measured as the actual heat recovery divided by the target heat recovery.

PHT efficiency is governed by two principal factors: (a) design the heat exchanger network (HEN) so as to follow the temperature profile of the hot and cold streams (using Pinch Analysis), and (b) the rate of asphaltene fouling in critical heat exchangers, generally at crude temperatures above 200°C (390°F). Fouling, especially in the processing of heavier high-boiling crudes, is a major problem. It can shorten the run length between maintenance shutdowns by as much as 1 year, with a significant negative impact on profitability. So, fouling control is a critically important energy efficiency improvement measure. However, it is not easy to manage.

Ebert and Panchal (1995) first identified and modeled the fouling rate as a competition between deposition and removal mechanisms. Deposition rate depends mostly on the surface temperature while removal depends on the mechanical shear rate (flow velocity). Fouling will be negligible if the removal rate surpasses the formation rate. Significant progress has been made in the 25 years since 1995, and there is commercial software available that is able to predict fouling rates throughout the PHT, and therefrom the optimum HX cleaning strategy (**Figure 17**), while the refinery is running, which can extend run times back to near non-fouled conditions [10].

An important perspective is that there is no such thing as waste heat; there is only WASTED Heat, whether deliberate (due to reluctance to invest in recovery) or accidental wasted due to ignorance). Because of historical anti-investment bias in the industry, there will almost always be opportunities to recover such wasted heat

Figure 17.

Furnace coil inlet temp was maintained within target range via optimized HX cleaning strategy.

at a payback that far exceeds what one can hope to get by other legally permitted investments.

One major area of opportunity is where systems are oversized/overdesigned. These are the consequence of engineers habitually putting extra safety margins into the original design. So, by clever modifications, the excess equipment capacity can be converted into better energy efficiency.

Traditional refinery energy efficiency “optimization” initiatives normally focus only on the obvious equipment performance improvements: furnace stack temperature, furnace excess air, adding extra HX surface to the PHT in an effort to raise column feed temperature, steam usage for stripping, and process heating, recovering obviously wasted heat, reducing flow rates recycle streams, cleaning of poorly-performing heat exchanger, power recovery, rotating equipment and motors/ machinery efficiency improvements, adding insulation, reducing steam leaks and improving condensate return. While these all are good things to do, but the benefits of optimal system integration are far greater, yet they are seldom addressed.

4.1.1 Optimum energy retrofit of a catalytic reformer

A project was undertaken to convert an existing Platformer unit to a Continuous Catalytic Reformer (CCR). The newly established Energy Systems unit of the company (Saudi Aramco) was tasked to assess the energy efficiency of the licensor’s heat recovery design (**Figure 18**).

An optimized HEN (**Figure 19**) for the process was developed by Aramco, with estimated utility cost savings of 16%. A patent was applied for the same and deemed

Figure 18.
Licensor’s proposed design and costs.

Figure 19.
Optimized HEN design.

to be qualified by the patent attorneys, but later with-drawn by the company for certain commercial and legal considerations, it was never implemented.

4.1.2 Power savings via pump load management at a refinery product loading terminal

The example refinery had multiple storage tanks for its various liquid products which had to be loaded onto ships at the dock about 5 km away. A schematic diagram is shown in **Figure 20**. All pumps were equal-sized with 3550 rpm fixed-speed motors and no flow control valves.

The original design basis assumptions were:

- All ships want to load up at the fastest possible rate, to minimize time at the dock.
- The maximum loading rate is determined by pumping capacity.

Figure 20.
Flowsheet for product loading station at a refinery.

- The operating policy was to run each pump at its maximum flow capacity (the “run-out” point).
- No flow control valve needed.

During the optimization study, the reality was found to be quite different. Each ship has its own max loading rate (to prevent capsizing), significantly less than the pump run-out flow rate (a case of oversizing). The system curve had low ΔP , which meant that the valve at the loading dock had to be severely throttled. The configuration resulted in a system which has an opportunity for significant power saving. The best solution turned out to be replacement of the existing 3550 rpm motors on 4 of the 5 pumps with dual-speed 3550/1770 rpm motors, and then apply load management techniques to match the pump network flowrate to the required ship loading rate. Total savings for a typical year worked out to be 76 kWh/1000 bbl of product shipped, about 68% savings compared to the previous operating policy. Until the 2-speed motor replacement project was approved, the no-cost savings from load management of the high full speed motors was estimated to be 30 kWh/1000 bbl, or 26% savings compared to the base case.

4.1.3 Improved catalysts for better conversion and lower energy consumption

The use of newer catalysts for enhanced yield and higher selectivity will reduce the recycling and separation of undesired species/streams. This can provide up to 5% efficiency gain (Btu/lb of desired product) compared to older catalysts, in many refinery processes.

4.1.4 Process improvement for maximum product valuation

Aramco uses the PIMS linear programming (LP) software for planning refinery and olefins operations, enabling optimization of feedstock selection, product slate, plant design, and operational execution. It includes assay management, making it easier to add, modify, and re-cut assays, and helps refinery planners develop more accurate plans that deliver greater profitability. The estimated benefits from energy efficiency are in the range of 3–5% of total energy consumption.

4.1.5 New design standards for energy efficiency

It is always more cost-effective in the long term to build energy efficiency and operating reliability into the original design of a new plant than to retrofit a poorly designed facility. Yet there appears an ingrained bias among corporate decision-makers towards the latter approach, following short-term policies such as minimizing construction time at the cost of lower safety, reliability, and efficiency.

Recognizing this reality, Saudi Aramco revised its published corporate standards and procedures in the mid-2000s to include an energy efficiency study between the preliminary process design stage and the detail engineering stage. In order to provide flexibility, however, these standards were made “advisory” not “mandatory”, to be followed at the discretion of the Project Manager. It is not hard to imagine the outcome.

To be effective, such standards must necessarily be mandatory, but with the flexibility to waive them by a senior corporate executive, and not at the sole discretion of the Project Manager.

Furthermore, the energy efficiency audit of the preliminary process design must be done by a qualified independent company reporting to the operating company,

not to the engineering contractor that produced the preliminary design in the first place. Without such terms, the standards will be toothless and ineffective in achieving the stated corporate goals.

Additionally, the incentive bonuses paid to the company's Project Manager and to the EPC contractor should be based not on beating the construction schedule, but on (a) trouble-free startup and commissioning and (b) meeting long term (e.g., 2–3 years) performance metrics for the facility.

An optimized new design will improve all performance metrics—yields, production rates, energy efficiency, reduced maintenance cost, etc. Even though the initial investment may be slightly higher by about 5% the long-term operating cost savings can be expected to be in the range of 15–20%.

Aramco, like most oil and gas companies worldwide, purchases process technology from international licensors. The scope of supply subject to the performance guarantee typically includes not only the reactors and catalysts but also the separations (distillation columns) and the heat exchange network. There are two issues that must be addressed. The first issue is that most licensors typically guarantee the performance of their units only if their design is followed exactly in all respects, with no deviations unless approved. Now it makes sense to purchase the guarantee for reactors and separations but makes no sense to accept voiding the guarantee if the operator modifies the HEN, or the pumping and compression network, or the utilities mix. Since 2001, the Energy Systems Unit (now a Division with over 50 staff) of Aramco has developed considerable expertise in optimizing HEN design as well as pumping, compression, and process-utility integration. All we need is to license the reactor/separator technology, and absolve the licensor for the performance of the HEN, pumps, and utilities. This is the direction in which the rest of the industry also needs to move to remain competitive.

The second issue is that as a matter of policy Aramco usually prefers to enter into joint venture agreements with international oil, gas, and petrochemical companies for new facilities. Usually, we have to compromise on which company's standards to follow and are often forced to sacrifice energy efficiency in return for some other concession.

5. Terminals and distribution facilities

These facilities are spread across all components and connect all components together by supplying either as feed to one sector which is the finished product of the other or the final product to the end-users. It includes a network of pipelines and storage facilities to deliver the wellhead fluids to upstream facilities, upstream products i.e., oil and gas to downstream facilities i.e., refineries, fractionation plants, and also finished products from downstream facilities for other consumers including end-users. As it includes mainly a network of pipelines, pumping systems, compression systems with various pressure requirements, consequently, energy losses are resulted mainly due to friction, pressure let-downs, types of drivers, etc.

5.1 Applications in terminals and distribution

Swing/transfer pipelines are the principal way of providing flexibility in transferring oil and gas to allow optimum dispatching of production among existing facilities in the most efficient manner. Aramco uses a Dammam-7, a new super-computer among the top 10 most powerful in the world, to manage its facilities. These swing line connections are utilized to effectively optimize the value chain from GOSP to product shipment, and save energy whenever the opportunity arises.

This requires close coordination between operations foremen for various facilities. For lower production, fewer gas compressors are needed to handle the associated gas. Similarly, for higher loads, the gas compressor and pump operation need attention.

The corporate energy conservation team helped develop such operating practices and incorporated them into the company's Standards and Procedures manuals. In addition, the team undertook a company-wide communications initiative to make sure production engineers, operations, and shift coordinators in the field were made aware of these revised documents.

5.1.1 Turboexpanders in high-pressure pipelines

Turbo-expanders are well-proven technologies for pressure-energy recovery (discussed previously under Upstream Sector applications) and are widely used in the processing industry to produce work or generate electricity. In distribution, high pressure (700–100 psig) pipelines are typically used to transport “wet gas” from upstream gas processing plants to centralized fractionation plants where high-value C2–C5 components are separated from methane by cryogenic distillation. Instead of letting down the inlet pressure across throttling valves, they can be passed through a turboexpander for power recovery. This is essentially free power that easily justifies capital investment. Up to 20–25% additional power can be generated by preheating the inlet gas prior to expansion using low-grade heat that has no other beneficial use (e.g., necessary cooling of HP steam condensate return, if available nearby, to avoid water hammer).

5.1.2 Pump load management

One of the biggest sources of essentially free power savings is to minimize the number of pump trains being operated in parallel. Two important considerations must be kept in mind: net positive suction head (NPSH), which generally becomes an issue when the flow falls below 60% of flow at the best efficiency point, and the flow achievable by using N pumps in parallel will be less than N times the flow through a single pump. The methodology used is to develop the composite performance curves for the pump network, and match them to the system pressure drop curve.

5.1.3 Drag reducing agents to reduce pipeline frictional losses

Pipeline drag reducing additives have proven to be an extremely powerful tool in fluid transportation. High molecular weight polymers are used to reduce the frictional pressure loss ratio in crude oil pipelines, refined fuel, and aqueous pipelines. The drag reducer used in the Mostorod to Tanta crude oil pipeline in Egypt reportedly achieved a 35.4% reduction in pressure drop and a 23.2% flow increase. The experimental application of DRA by Arab Petroleum Pipelines Company (SUMED) in a pipeline from Suez to Alexandria in Egypt achieved a flow increase ranging from 9 to 32% [11].

Aramco is using DRA technology (**Figure 21**) for the Riyadh-Qassim pipeline capacity expansion project and for future projects.

5.1.4 Proper piping networks design

For proper design of piping networks, the key optimization parameters that should be considered include pipe sizing and design code, materials, piping

Figure 21.
 ΔP reduction vs. DRA dosage.

connection, connection to the header, maintenance, etc. Saudi Aramco has engineering standards and best practices (SAES & SABP) which are continuously updated to improve the energy efficiency of the upcoming as well as existing facilities.

5.1.5 Utilization of high-temperature heat from exhaust of gas turbine-driven rotating machinery

While pumps and compressors are usually driven by electric motors, when the units are large enough and run mostly at a steady state, it can be advantageous to use gas turbine drives, with the hot exhaust (which must be above the process pinch temperature) being used for process thermal heating or even local steam generation linked to the site Utility System. Aramco has successfully implemented several such projects.

5.1.6 Let-down of imported HP fuel gas pressure using turbo-expander

Power recovery turbines (**Figure 22**) are one of the largest sources of clean power generation in many industrial facilities and high-pressure distribution pipelines in particular. The high-pressure fuels gas is let down to lower psig to supply the HP fuel gas header, and a part is further let down to supply the LP fuel gas header. An expander/generator can be installed between the HP sales gas and the HP fuel gas header to recover some power. Turbo-expander generators offer great promise from an energy efficiency perspective in that they have the potential to provide power at very high isentropic efficiencies over 90% and are extremely reliable, with availability factors approaching 99%. Furthermore, the inlet HP gas should be preheated if possible, using low-grade heat (defined as less than 350°F) such as steam condensate return from the refinery). Up to 20–25% additional power generation is possible at zero emission of CO₂.

Although the reported data so far are limited, potential energy efficiency improvement in the T&D sector is estimated to be 10–15% of baseline consumption.

Figure 22.
 Model of typical turbo-expander generator equipment.

6. Utilities and power plant

It is the components of the energy supply chain which generally provide energy in usable form to the end-users and also provide energy to the other components of the energy supply chain. Electricity is the most used secondary form of energy and power plants are the part of utilities that convert primary form of energy supplied by HCSC to electricity. Also, it is the component where high energy inefficiencies could have resulted. In 2017, the total power generation capacity of Saudi Arabia was 84 GW (100%), mainly from thermal sources (oil and gas). By 2030, it is projected to be 153–118 GW (65.5%) from fossil fuels, 58.7 GW (32.5%) from wind and solar, and 2.8 GW (2%) from nuclear [12]. This includes dedicated central power plants as well as industrial cogeneration. Other components of the energy supply chain need energy either as power or as heat, the conversion of primary energy to heat and power results in many configurations with differs a lot in terms of its efficiency.

6.1 Simple cycle power plant

The vast majority of fossil fuel power generation in the world is based on a simple Rankine cycle with steam as the working fluid. Water is heated to generate high-pressure steam, driving a steam turbine to either electric energy through a generator. The steam turbine cycle is highly versatile, adaptable to any fuel that provides enough energy by combustion to vaporize water. The main drawback is that the power generation efficiency is limited to 30 to 40%, versus overall energy efficiencies of 55–80% for modern alternative cycles.

6.2 Combined cycle power plant

The combined cycle for power generation offers efficiencies of about 58–60% (electricity only) in theory. It combines the gas-turbine (GT) based Brayton cycle (which has simple cycle efficiency of 18–27%) as the front end followed by a Rankine cycle at the back end. The GT fuel has to necessarily be in the vapor

phase—natural gas, synthesis gas from coal, vaporized diesel, etc. The hot GT exhaust containing about 15% O₂ issued as combustion air for a downstream heat recovery steam generator (HRSG) which uses the HP steam to make additional power by the Rankine cycle.

6.3 Power generation integrated with brackish water desalination

This concept applies to both simple Rankine cycle and combined cycle power plants. Instead of condensing the steam turbine exhaust against a cooling utility, the steam is exhausted at a back-pressure of about 15–25 psig, which is then used to drive a multiple-effect evaporator (MEE) desalination plant, increasing the overall site energy efficiency to about 75–80%. The MEE makes potable water from seawater or municipal and industrial wastewater treatment facilities effluent, thereby augmenting increasingly scarce freshwater sources. This is the direction KSA has taken.

To facilitate this transition, the formerly independent Ministries of Electricity and Water were merged at the direction of then King Abdullah. To the knowledge of the author, no other country in the world has taken such an enlightened policy initiative to promote national energy efficiency while simultaneously conserving the planet’s precious limited freshwater resources. It can serve as a model for the rest of the world.

The energy efficiency initiatives undertaken in the Kingdom’s Utility sector are estimated to improve the overall 2012 efficiency of 31.5% is to reach 45% by 2030 [8] as illustrated in **Figures 23 and 24**.

Concurrently, the power, fuel, and water utility supplies must be increased, and distribution infrastructure expanded to accommodate the rapidly growing population of the Kingdom.

6.4. Applications in utilities and power plant

Saudi Aramco plays a critical role in supporting the Kingdom’s evolving energy infrastructure. The overall average thermal efficiency of Aramco’s interconnected on-site power generation facilities (CHP and CC as well) is 71.9%, while the national power grid efficiency in 2018 was around 38.7%. The savings from the

Figure 23. Utilities map: 2012.

Figure 24.
Utilities map: 2020.

corporate energy program have reduced our CO₂ emissions footprint since 2001 by about 50% per unit of production compared to “Business as Usual” prior to the year 2000. No other company worldwide has been able to match this documented metric to our knowledge. It gives the lie to companies that claim energy efficiency is not economically viable in order to conceal their hidden agendas.

The optimal energy strategy from the Kingdom’s perspective would be for Aramco to operate its process-integrated cogeneration plants at full capacity, and to export any surplus power into the national electricity grid, to minimize fuel burning for electricity generation. As a result of the high thermal efficiency in 2018, Saudi Aramco saved approximately 263.8 MMSCFD of natural gas, compared to the average national energy efficiency. To improve power plant efficiencies, some best practices are as follow:

6.4.1 GT compressor inlet air cooling

The lower the inlet air temperature to the compressor of a GT, the higher the capacity as well as the energy efficiency. The air can be cooled in two ways by injection and evaporation of de-ionized water if the air is dry *(as in arid regions), or by indirect cooling using absorption chillers driven by low-grade heat from the process, or by LP steam. The overall efficiency of the GT increases 10–15% from capacity gain. Both systems have their pros and cons.

The direct injection approach, also known as a “fogging system” is simple and cheap, and became very popular worldwide. Aramco jumped on the bandwagon too. However, it was soon noticed that our facilities began to report erosion of the initial efficiency gains over time. A long-term 4-year study of their efficacy conducted with the help of SRI international (San Antonio, USA) found that dissolved salts and fine particulate deposits on the compressor blades were the cause. On balance, the fogging systems did not deliver a net benefit, at least in Aramco GT installations.

Absorption chiller cooling technology offers the advantage of not introducing water which tends to favor adhesion of solids to the compressor blades. However, it is much more capital intensive and incurs higher maintenance costs.

The verdict on these options seems theoretically attractive, is neutral when practical contemplations are considered.

6.4.2 Maximizing cogeneration units operation for power plants

Provided the high incentive for exporting power from a facility, it's always recommended to maximize the operation of cogeneration units. The overall efficiency improvement from a combined cycle with a cogeneration unit vs. a simple Rankine cycle is about 30–35%.

6.4.3 Conversion of simple cycle to combined cycle power plant with cogeneration

Energy efficiency in a simple cycle power plant is in the range of 30–35% and that in a combined cycle power plant is 50–55%, and a combined cycle with cogeneration option can go up to 75–80%. So, it is strongly recommended that the system moves from a simple cycle to a combined cycle with the cogeneration option.

6.4.4 Steam and water conservation by using steam traps and management

Industry data show that the average steam trap has a service life of 4 years. This means that on average 25% of traps will fail every year, usually in the leaking position. Therefore, it is imperative that every plant should have a permanent ongoing steam trap monitoring and maintenance program. This can give around 3–5% boiler fuel savings. A good steam system management program can improve plant efficiency significantly. It should include self-regulating electrical tracing, condensate recovery, piping insulation, minimizing or eliminating the use of steam-reducing stations and vents.

A simulation model of the Combined Heat and Power (CHP) system for the plant is the most effective tool to check the steam balance and to estimate losses. Although CHP simulation modeling is commercially available, they all lack an important feature which is data reconciliation. Aramco is currently developing in-house software to rectify this deficiency.

6.4.5 Supplementary firing

Supplementary firing may be used in combined cycles (in the HRSG) raising exhaust temperatures from 600°C (GT exhaust) to 800 or even 1000°C. Using supplemental firing will not raise the combined cycle efficiency but is used instead to increase peak power production of the unit, or to enable higher steam production in an emergency. Supplementary firing can raise the temperature of the GT exhaust gas from 800 to 900°C., enabling higher steam generation flows, pressures and temperatures.

6.4.6 Boiler load management

The performance curve for each boiler is basically a relation between fuel consumption and the steam production of the boiler. Boiler efficiencies can vary, even for nominally identical units, by 2–3%. By maximizing base load on the more efficient boilers in a set of parallel units and using the next lower efficiency boiler for swing production, overall steam gen efficiency can be increased 2–3%. Installing economizers in boilers, heat recovery from utility system blowdown, boiler minimum load reduction, minimum steam reserve reduction, and excess O₂ minimization to 2%, are a few other initiatives to improve the boiler system performance. Air preheating is usually not economic, with simple payback typically exceeding 10 years.

6.4.7 Minimize excess low-pressure steam

There should never be excess LP steam at any plant site which includes fuel-fired boilers. It is a symptom of gross steam system mismanagement and can be corrected using a CHP system model to pinpoint the causes of needless waste.

6.4.8 Minimize PRV letdown of high or medium pressure steam

Excess HP or MP steam is a symptom of CHP system mismatch between demand and supply. In such cases, the CHP system operating and control practices should be modified to generate less steam. It can be easily done at a near-zero capital cost, so there is no excuse for plant management to allow such a situation to fester.

6.4.9 Recovery of water from humid boiler or furnace flue gases (condensing economizers)

This approach was touted by academics without industrial experience back in the early 1970s in the wake of the first “energy crisis”. Many got US government funding for pilot plants to demonstrate the concept. In practice, operating below the acid dew point accelerates corrosion inside the condenser. Teflon-coated internals was tried, but the coating quickly peeled off, and this approach was largely abandoned.

7. Endusers

End-user in Saudi Arabia mainly belongs to two main energy sectors i.e., transportation and buildings, the transport sector is utilizing the majority of its usage from hydrocarbon (from refineries) while building sector depends mainly on electricity (from power plants).

7.1 Energy efficiency gap in end-user

The majority of demand from buildings is from HVAC, consequently, a closer look into the air conditioning is needed from an energy efficiency perspective. Data is not available on existing plant efficiencies in Saudi Arabia. But worldwide, it is common that without any efficiency improvement measure, air conditioning efficiency usually lies between 1 and 2 kW/ton. With that assumption, and based on the world's best efficiency practices, it is estimated that 40–70% efficiency improvement is possible across the air conditioning. Accordingly, more than 50% in energy savings is possible, by improving the existing old T8 and T12 lighting to LED lightings. A significant portion of the energy is lost in buildings, due to users' habits, and mainly results from a lack of knowledge about energy efficiency and improvement.

Energy efficiency in transport can be enhanced in three ways. First, by reducing transport demand through urban planning and information technology; then by shifting transport of passenger and goods away from more energy-intensive modes, such as road, to fewer intensive means, such as public transportation for passengers and rail and sea for goods; and finally, by improving the fuel economy of the vehicles used, be they road vehicles, aircraft, trains or ships.

8. Building components and their efficiency

According to the International Energy Agency (IEA) (2013), the residential sector accounted for more than a quarter of global electricity consumption in 2011.

Figure 25.
Existing energy supply from utilities plant to different sector [13].

In Saudi Arabia, this share is almost double at around 50%, largely because of very high average ambient temperatures, and the use of power-hungry air coolers for HVAC systems (**Figure 25**).

All buildings, including residential, in Saudi Arabia, use 40–70% (average 59.4%) of their energy for air conditioning. The combination of heating and ventilation consumption with air-conditioning systems i.e., HVAC, systems consumes about 70% of the total energy (**Figures 26 and 27**) [13]. In addition, lighting electrical energy represents around 15% of the total used electrical energy in buildings all over the Kingdom (19% globally). The remaining 11% of energy is consumed by other appliances/equipment items.

Figure 26.
Energy flow for residential buildings in Riyadh, source [13].

Figure 27.
Energy flow for residential buildings in Dhahran, source [13].

Figure 28.
Transport energy consumption per person [6].

To provide an indicative benchmark of energy efficiency in the sector, transport energy consumption per capita for road transport can be compared across a range of countries (**Figure 28**) [6]. It will be noted that while per capita transport energy consumption is relatively high in Saudi Arabia, it is still lower than in Canada and the U.S. However, the major difference is that per capita transport energy consumption is stable or declining in most OECD countries, whereas in Saudi Arabia it has been growing strongly.

8.1 Applications in end-users

There are several key areas, improvement of which can improve the end-user energy efficiency significantly. A few major energy savings opportunities are listed.

8.1.1 Holistic system design approach

Analysis revealed that changing the renovation design to a whole-systems approach could dramatically improve comfort, quadruple energy efficiency, and cost about the same as normal renovations. Super windows, deep daylighting, and efficient lights, and office equipment could reduce the cooling load (except that caused by the occupants) by 85%. This in turn could make the replacement cooling equipment three-fourths smaller than the original system, four times as efficient, and significantly cheaper to pay for the other improvements. The annual energy bill would then fall by 75%, which will result in a significant reduction in rent per square foot per year, and be at least 10 times the competitive rent difference in the local market. The fourfold energy efficiency improvement would cost essentially the same as the standard renovation that was about to be done anyway, with far better amenity, esthetics, and rentability.

8.1.2 Optimizing the design by providing wider piping and laying it first

Research shows that significant energy losses occur due to piping. In the study, it is found that the fatter pipes and cleaner layout yielded not only 92% lower pumping energy at a lower total capital cost, but also simpler and faster construction, less use of floor space, more reliable operation, easier maintenance, and better performance. As an added bonus, easier thermal insulation of the pipe.

8.1.3 Measurement of existing air conditioning plant efficiency

It is important that measurement of air conditioning plant efficiency including small residential split systems to large chiller plants should be conducted throughout the Saudi Arabian buildings and plants. Understanding the existing systems efficiency condition will help the building owner/operator to identify the savings potential and will raise interest to act. Proper understanding and retrofitting will make the system 15–25% more efficient.

8.1.4 Building data analytics

Buildings are loaded with a very large volume of data and information. Overall, there is a need for an automated solution to process this information. Building analytics can help turn data into action and savings. The overall building analytics services include: data monitoring and analyzing, automation and controlling, sustainability reporting and strategy development, metering and billing, asset management, measurement and verification, comfort management, carbon and waste reporting, energy and water reporting, demand analysis, etc. Utilizing the Advance Building Data Analytics can bring 5–10% savings from the existing operation.

8.1.5 Implementation of low hanging fruits (e.g., lighting replacement/refurbishment)

Buildings can easily save 5–10% of the consumption by installing easy solutions. There is technology, such as LED lighting that can be easily installed and bring more than 50% savings from its existing baseline. Simple set point adjustment will also help savings from air conditioning and other system operation savings.

In addition to that, as electric motors account for more than 30% of all electricity consumed in commercial buildings, more emphasis should be placed on motor efficiency. Finally, the system loss in the pumping and ducting, especially in all the throttling mechanisms, should be carefully reviewed. All of these are possible if the

user and the building owner/operator work sincerely towards a sustainable building, living and working environment.

8.1.6 Transportation sector improvements

In Saudi Arabia, all three transportation options are being pursued, with high-density urban areas being planned, a metro system being constructed in Riyadh, and nationwide railway infrastructure also under development. In terms of energy efficiency regulations, SEEC issued its fuel economy standard for passenger cars in November 2014, using the U.S. NHTSA CAFE standards as a reference, and has established a fuel economy testing lab for monitoring and evaluating actual performance against this standard. SEEC passenger car regulations also include a requirement for vehicle fuel efficiency labels and a low rolling resistance tire standard. In addition, fuel economy standards for heavy-duty vehicles and a “cash for clunkers” vehicle scrapping scheme are under development. For example, Egypt’s Greater Cairo Region Old Vehicles Scrapping and Recycling Program is one example that involved replacing old taxis with compressed natural gas (CNG) fueled vehicles.

8.2 Energy efficiency impact in end-user

The overall end-user loss in the supply cycle is about 10%. Based on current new technology and building upgrade along with transportation sector reforms, more than 20–30% of those losses can be recovered.

8.3 Impact of energy efficiency on primary energy and fuel

Energy supply chain efficiency is a global concern. It is a common misconception that the demand side primarily impacts the energy supply chain. With a detailed breakdown, as summarized in the chapter, it can be clearly observed that each component of the energy supply chain has a significant impact on the overall energy supply chain efficiency. It is also noted that the most critical two components that have significant losses and are impacted highly are the power plant and the end-user equipment/system. We propose to have an improvement in all components. A little improvement in the end-user system or in the utility power plant creates compounded impact throughout the overall chain.

9. Sensitivity analysis

Figure 29 shows the impact of end-user energy savings on overall primary fuel in 2030. With each portion of the improvement in end-user savings, the overall primary fuel will be saved significantly.

10. Overall summary and recommendation

Following section will summarize the overall losses, challenges, and recommendations for improvement.

10.1 Summary

The possible energy performance improvement percentage from existing conditions for different sectors is represented in **Figure 30** (GOSPs are shown as a sector

Figure 29.
Impact of 2030 primary energy fuel for different end-user efficiency improvement (Keeping all other parts of the network constant).

Figure 30.
Energy performance improvement (%) possibility.

as it is part of the industrial sector but due to its impact it is mentioned separately). Even buildings are segregated in commercial, residential, and government due to different ways to tackle energy efficiencies in these sub-sectors. On average, approximately 20–25% energy conservation and efficiency improvement are possible from all sectors. These figures are conservative and can go much higher in all three major sectors (i.e., industrial, transportation, and buildings).

There is a significant technological improvement for building sectors and there is huge hidden wastage due to consumer attitude. The sensitivity analysis represented earlier only considers up to 10% improvement from its existing wastage; however, the efficiency improvement can go up to 50% if holistic approaches are applied.

The analysis suggests that there is significant scope for energy efficiency improvement in the transportation sector. Improved urban planning, public

transport, and the implementation of energy efficiency vehicle regulations will play a key role. As awareness is a key factor to this sector, policies like incentives for carpooling, privilege parking for hybrid cars, have the popular social appeal that could have a significant impact in improving energy efficiency in this sector.

The industrial sector is the most energy-intensive sector in Saudi Arabia and it is principally made up of HCSC and the utility sector. The discussed improvements are predominantly covering the entire industrial sector and the energy enhancements are enormous creating opportunities for reducing GHG emissions along with monetary benefits. Improvements in the energy supply chain will have greater implications, the counts of barrels saved in the processing will be added to the export/usage, preserving natural resources and environment for the future generations. It is likely that by following the approach, manufacturing industry of the future will become energy efficient and fully embrace the best practices to optimize resources utilization while consuming less energy. All case studies are summarized to enrich and illustrate the subject and demonstrate the methodology appropriately to put them on track to achieve international climate and energy goals. The adoption of cogeneration technology, pressure energy recovery, heat integration, load management, etc. helps in promoting energy efficiency, lowering the energy intensity of operating plants, adding value to hydrocarbon resources, and protecting the environment. The analysis clearly indicates that there is an enormous potential for improvements in the complete energy supply chain and well-capitalized by the Kingdom's policy makers and can be leveraged to other countries.

10.2 Challenges

Improvement in energy efficiency has multi-dimensional challenges and needs some attention from the policy makers and strategists. Even though the technological knowledge gap could be minimized, yet there is a huge shortage of knowledgeable professionals in this specialty, (i.e., energy efficiency/energy conservation), worldwide. The unavailability of commercially available tools to conduct energy efficiency analysis is also an area of attention for the policy makers, to develop and promote the expertise and tools by providing investment for the required infrastructure. Technological development without strategies to realize the life-cycle basis where energy efficiency is an element to explore sustainability concepts along with the progression. End-users lack understanding/awareness about the significance of energy wastage, which in turn impacts global issues like global warming, making it very difficult to tackle. Upgrading from old inefficient systems and technologies to newer efficient ones demands a clear perspective on investment and a relative understanding of the impact of alternative investment.

10.3 Conclusions and recommendations

The outcome is that energy efficiency is essential for further and vigorous growth in all three major sectors. It is worth stating that using energy efficiency as a framework for environmental strategy and energy goals enabled the Kingdom to implement a plan that is feasible and robust. It provided the Kingdom a competitive advantage by enabling a strong and energy-efficient economy and reaping the benefits of selling avoided energy consumption. Other policymakers can leverage these findings and adapt a similar approach to alleviate global warming through proven cost-effective energy efficiency measures. Although, all sectors have similar savings potential percentage but the industrial sector is of greater importance as it is very energy-intensive and of larger magnitude. Kingdom's industrial sector is dominated by hydrocarbon supply chain, owned by Saudi Aramco, which is leading the

effort and playing a key role in positioning the strategy. Saudi Aramco has a vital role in the formulation of the strategy and also provided its support in deployment and further improvement.

Some of the key takeaways from the adapted approach of improving a livable environment through the implementation of energy efficiency measures are summarized below as quick wins;

- Implementation of more cogeneration systems for all simple cycle and combined cycle power plants.
- Emphasize process improvement through heat/process integration and evaluate each improvement based on life-cycle cost.
- Emphasize on innovation in utilities and other end-user technologies via providing incentives to the energy management professionals/institutions.
- Demonstrate key energy-efficient retrofit projects to share the experience and confidence to execute projects and adopt new technologies.
- Emphasize on energy efficiency monitoring by displaying a dashboard for end-user engagement.
- Promote green energy production utilizing turbo-expander, hydraulic turbine, etc.
- Improvement of refrigeration cycles (including air-conditioning) efficiency across all sectors (residential, commercial, industrial, utility plants, etc.).
- Implementation of building codes and advanced data analytics for end-user applications.

Nomenclature

BB	billion barrels
BBL	barrels
BCM	billion cubic meter
CHP	combined heat and power
CC	combined cycle
DRA	drag reducing agents
GOSP	gas oil separation process
GW	giga watts
HCSC	hydro carbon supply chain
HVAC	heating, ventilation and air-conditioning
IEA	International Energy Agency
kW/ton	the ratio of input electrical power to out thermal power. Ton of refrigeration is approximately 3.5 times higher than kW of thermal power.
LED	light emitting diode
MBD	millions barrel per day
OECD	Organization for Economic Co-operation and Development (36 countries)
ORC	organic Rankine cycle

SABP	Saudi Aramco best practice
SAES	Saudi Aramco engineering standards
SEEC	Saudi Energy Efficiency Centre
VFD	variable frequency drive

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