

Oil Production and Consumption Strategies for the UAE

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The Emirates Center for Strategic Studies and Research

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– 82 –

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Oil Production and Consumption: Strategies for the UAE

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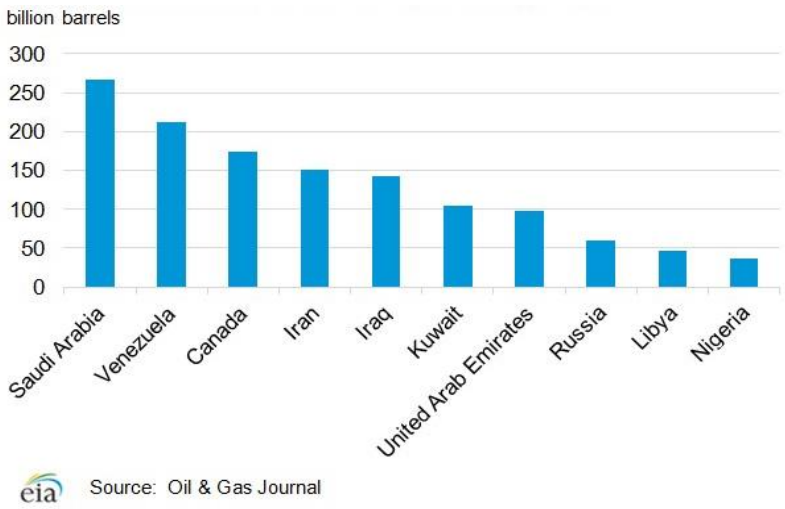
Introduction[1]

The Arabian Gulf region[2] has the most prodigious energy reserves in the world. As of 2012, it contained 489.4 billion barrels of proven oil reserves, approximately 36 percent of global supply.[3] The latest figures for 2012 indicate that the region collectively produced 17.3 million barrels per day (m/bpd).[4] With the advantage of enormous oil reserves and small, albeit growing, populations, the region exports the majority of its oil production. The region holds approximately 42 trillion cubic meters (tcm) of natural gas, about 23 percent of global natural gas reserves, but it only produces about 8 percent of the total global production.[5] With the exception of Qatar, most Gulf countries consume the majority of their natural gas production. It is estimated that at current production rates, the official oil reserves will last another 70 years and natural gas reserves another 118 years.[6]

In terms of the UAE, it has approximately the seventh largest proven oil reserves in the world, at 97.8 billion barrels (see Figure 1), which represents approximately 7 percent of the total global proven oil reserves.[7] The majority of the oil reserves are located in Abu Dhabi (approximately 94 percent), while the other six

emirates in aggregate contain just 6 percent of the UAE's oil reserves, with Dubai having the second largest reserves at 4 billion barrels.

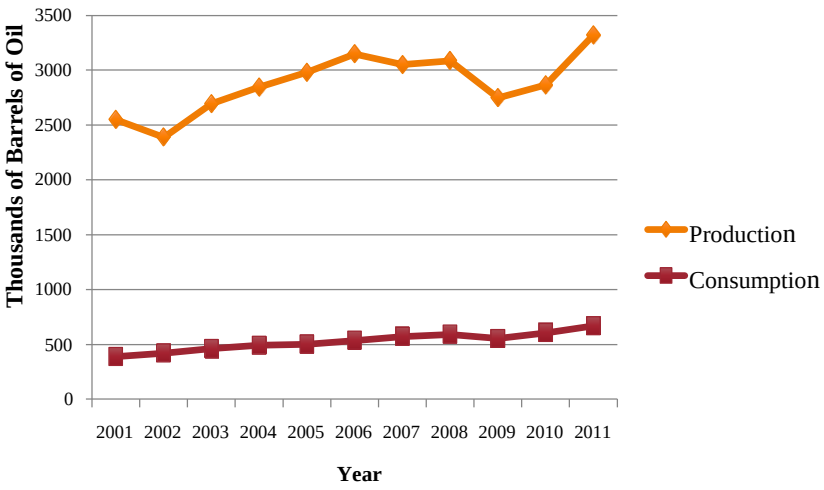
Figure 1
Proved Reserves of Crude Oil by Country, 2012



This monograph focuses on the most efficacious methods for the UAE to buttress its oil production while reducing its oil and natural gas consumption. It recommends that the UAE create a tiered strategy of increasing oil output by utilizing alternative methods of enhanced oil recovery (EOR) that would not depend upon natural gas, such as CO_2 EOR, nitrogen flooding and solar thermal EOR. These EOR methods would not only lower increasing Emirati natural gas consumption, but would also serve to promote the UAE's carbon and renewable energy goals. Additionally, this monograph discusses policies that would have a definitive impact on lowering the rising Emirati oil consumption. As the majority of Emirati oil consumption comes from the

transport sector, this paper posits some proposals that would increase the scope of technological innovation in this sector to reduce oil consumption.

Figure 2
UAE Daily Oil Production and Consumption



Source: BP and author's calculations (includes total oil liquids).

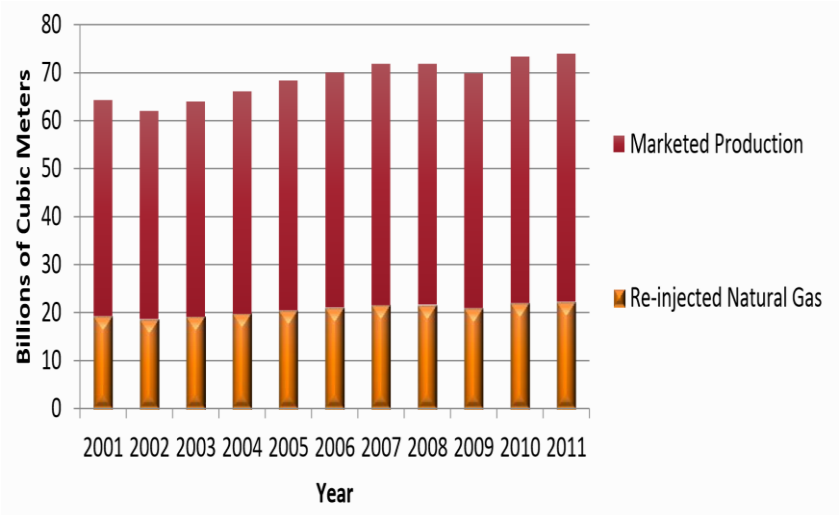
Most of the UAE's oil fields are mature, but with an innovative investment structure (based on a concessionary framework) and EOR, the UAE is more than likely to meet its goal of increasing oil production to 3.5 million barrels per day (m/bpd) by 2018. However, as illustrated by Figure 2, while Emirati production has been increasing for the past couple of years, from an average of 2.5 m/bpd in 2011 to 2.65 m/bpd in 2012, it did not meet its production target of 3 m/bpd by the fourth quarter 2012.

Nonetheless, the UAE still increased production in the first quarter of 2013 to 2.8 m/bpd,[8] and is still on schedule to meet

production of 3 m/bpd by early 2014. The IEA estimates that the UAE will increase its oil production to 3.06 m/bpd by 2014.[9] However, as the Arabian Peninsula is one of the most extensively surveyed areas in the world, the Abu Dhabi National Oil Company's (ADNOC) production increases will require more efficient production of known fields through infrastructure upgrades and use of EOR techniques. In furtherance of that goal, ADNOC is investing $40 billion on crude, natural gas, petrochemical, and refinery projects through 2014.[10]

However, increasing the recovery rate from mature fields has its own array of challenges. In addition to managing aging oil field infrastructure and increasing investments in mature fields, boosting the recovery rate must be considered with careful assessment of field profitability before determining the most optimal EOR method to be deployed.

Figure 3
UAE Gross Natural Gas Production with Re-injected Natural Gas

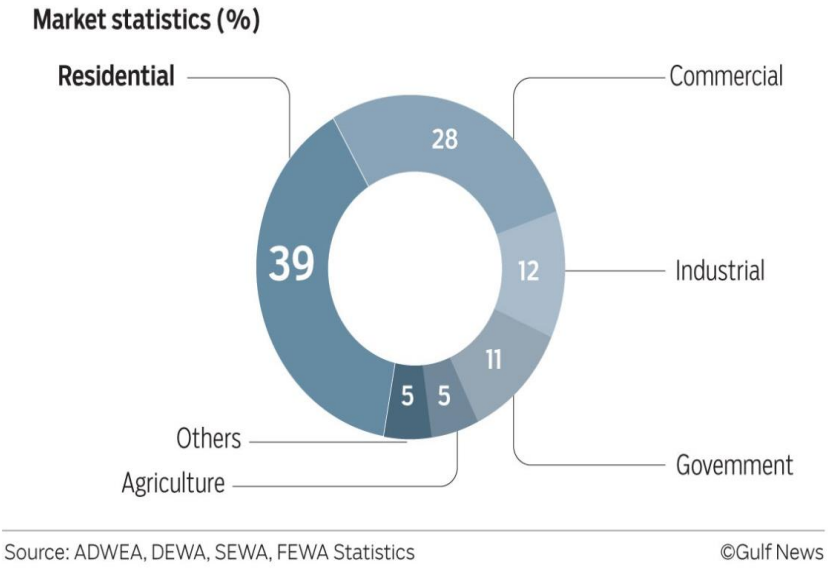


Source: BP, EIA figures and author's calculations (Re-injected Natural Gas estimated at 30 percent of gross production).

Furthermore, the UAE needs to transition away from its dependence on natural gas EOR. As seen from Figure 3, natural gas EOR consumes approximately 22.16 billion cubic meters (bcm) of natural gas per year (2011 figures). Furthermore, as Figure 4 illustrates, in terms of per sector consumption of power (nearly of all which is produced by natural gas, i.e., 98 percent), the residential and commercial sectors consumes the lion's share of the energy mix. Therefore, strategies to lower residential power consumption are critical for the formation of a sustainable energy policy.

Figure 4

UAE Electricity Consumption 2011



Over the past decade, natural gas utilized for re-injection has been on an upward trend since 2001 (See Figure 3). As the UAE plans to strategically increase its oil output to 3.5 m/bpd by 2018, this dependence on natural gas for re-injection would only increase. However, at the same time, the UAE is facing significant natural gas deficits. At the end of 2011, the UAE produced 51.7 bcm of marketable natural gas (excluding gas used for reinjection). It also consumed 62.9 bcm at the end of 2011. Therefore, the shortfall of 11.2 bcm caused the UAE to import LNG at international market rates to make up the difference.[11] If the UAE does not create a comprehensive strategy to lower its natural gas consumption, then its economic competitiveness in the mid- to long-term could be harmed.

Overview of Emirati Natural Gas Demand

Natural Gas Consumption

The abundance of hydrocarbon resources in the UAE brought enormous wealth to the country. GDP has doubled in the past decade as average growth approached 5.8 percent per annum.[12] Most of the economic development has come in the wake of an increase in oil and gas output. For instance, in 2010, the energy sector comprised 32 percent of the total GDP and 76 percent of all the fiscal revenue.[13] Yet rising GDP has been coupled with expanding domestic natural gas consumption, which has not only produced widespread gas shortages, especially in the energy-poor northern emirates, but also negatively impacted the ability to sustain gas exports and collect the associated foreign revenue. More specifically, natural gas demand has been rising by 6.8 percent per annum for the past ten years reaching 62.9 bcm in 2011.[14] In 2008 alone, gas consumption rose by more than 20 percent, which was a stark example of the reoccurring phenomenon of consumption exceeding domestic production.

There are multiple reasons for the rapid increase in domestic natural gas demand. Firstly, along with the growth in GDP, the UAE experienced a population boom in the last decade coinciding with a youth bulge that compounded already high consumption rates. Since 2001, the UAE's population more than doubled and is expected to continue to grow by 3 percent per annum for the next five years to reach 9.4 million people by 2017.[15] Other major factors driving domestic gas demand are the extended utilization of EOR techniques and increased electricity consumption. Sixty-five

percent (or 56.6 Mtoe) of the country's total energy needs are supplied by natural gas, a share that will continue to rise unless current proposals to diversify the energy supply away from oil and gas and into renewable and nuclear energy come to fruition. EOR consumed approximately 18 bcm of the total gas production in the UAE in 2009, while the power generation sector was by far the largest consumer of natural gas, outside of the resource-extracting industry, with 28.3 bcm in 2009.[16] Another 10–12 bcm is consumed by the industrial sector, which has been growing by an annualized average of 7 percent in the last decade.

Supply and Demand Projections

After a slight decrease in the wake of the global financial crisis (0.7 percent in 2009), natural gas demand rose again in 2010 and 2011 by 2.9 percent and 3.5 percent, respectively.[17] With International Monetary Fund (IMF) economic growth projections of 3 percent over most of the next decade, Emirati gas demand will likely continue to grow.[18] However, the ultimate gas growth rates will depend upon the ability of the Emirati government to implement its *2030 Economic Vision* program, which aims to diversify the Emirate's economy by raising the share of non-oil output from around 50 percent to 64 percent of GDP. Abu Dhabi plans to invest approximately $160 billion until 2014 on development projects, including constructing airports, energy terminals, new industrial cities to host more than 130,000 residents, and the expansion of electricity generation capacity.[19] Additionally, the UAE is committed to job creation for its nationals, which will require further industrial expansion. The federal government, hence, aims to boost industrial investment to an annual average of 25 percent by 2025.[20] Moreover, the UAE

focused on the expansion of its petrochemical sector by striving to expand the output of its flagship company, Borouge, to 4.5 million tons by mid to late 2013.[21]

All of the above mentioned factors will likely further boost natural gas demand in the next decade, independent from the general economic growth projections. In a business-as-usual scenario, gas demand will likely continue to grow by approximately 7 percent per annum until 2020 as major governmental investment in infrastructure project and industrial development begins.[22] The foregoing means that gas demand could reach 115 bcm per year in 2020, almost doubling current annual consumption (See Table 1).[23]

Table 1
Supply/Demand Projections – 2020

Year	Production (bcm/y)	Consumption (bcm/y)
2000	38.4	31.4
2011	51.7	62.9
2015 (est.)	64.6	82.5
2020 (est.)	78.1	115.7

Meanwhile, unless there is a significant increase in production, gas supply is forecast to grow at slower rates, thereby expanding the gas deficit (See Table 1). Nonetheless, associated gas production is expected to increase as the UAE implements its oil

production expansion plans to ramp up production up from 2.8 m/bpd to 3.5 m/bpd by 2018. However, while associated gas demand will increase, EOR demands will likely increase as well in order to coax additional oil from maturing fields.

There will be an increased associated gas production from the Integrated Gas Development (IGD) and Hail Gas Development Projects that are designed to process approximately 27 bcm (830 bcf) from the Umm Shaif and Habshan oil fields by 2014. Moreover, there is an expected 12.9 bcm increase in non-associated natural gas production as several fields come online by 2014/2015, including the giant Shah sour gas field and smaller gas developments in the northern emirates.

The Power Sector

Being extremely dependent on natural gas (98 percent) the power generation sector is facing expansion and peak demand challenges. According to the EIA, the UAE consumed an estimated 79.3 billion kwh in 2010, while power generation, despite growing by 9.7 percent annually on average for more than a decade, is having difficulty in meeting current demand levels.[24] The difficulty in meeting peak demand could hamper Emirati economic competitiveness, especially with its diversification and modernization plans. In the summer of 2007, rolling blackouts spread to a number of cities (principally in the northern emirates) in the UAE, exacerbated by a 10.25 bcm (362 bcf) gas shortfall that year. This had to be compensated for by using oil and coal to keep power plants running and the cement industry functioning. In addition, in the period 2006–2008, peak gas demand often outstripped the supply to power plants by 40

percent.[25] In response, the UAE diverted a portion of the gas used for EOR to the electricity generation. This policy had implications for foreign revenue as a decrease in EOR re-injection led to a decrease in oil production as well as associated natural gas output. Based on current demand trends, gas consumption is forecast to reach to 115.7 bcm by 2020. [26]

The global financial crisis in 2009 dampened the effect of the gas shortages, principally due to lower industrial and residential consumption, as well as the implementation of strict OPEC quotas, but they still remain an issue as demand continues to grow. However, the potential for nuclear power and renewable energy development for power generation may mitigate some of the power demand challenges. Moreover, on a regional level, a GCC power grid inaugurated in November 2012 would increase regional power capacity by 1.2 GW between the UAE and the rest of the Gulf.[27]

A further demand solution would be to decrease the utilization of natural gas for EOR re-injection. Over the past several years, UAE natural gas utilized for EOR has hovered between 18 to 20 bcm per annum.[28] Replacing gas with nitrogen or carbon for EOR processes would liberate large quantities of gas for power generation. However, costs have been an issue for a more extended use of the gas substitutes. Until recently, the UAE had been using water for re-injection, but this is somewhat counterproductive in a region characterized by water shortages and highly energy-intensive water desalination programs.[29]

Technological Advances in Production: EOR Techniques

As a field matures, substantial amounts of oil, often as much as 60 percent, may remain in place even after secondary recovery. EOR techniques target this remaining oil in order to increase field viability. Any growth in Emirati oil production must come from existing acreage, which has the potential to significantly contribute to future oil production if recovery rates are optimized. This section considers the three different EOR techniques of gas injection, thermal recovery, and chemical injection, to analyze their impact on oil production.

As the majority of the UAE's oil fields are mature, well-managed EOR will be essential to increase the recovery factors and will therefore be crucial to meet growing global energy demand. EOR techniques have been implemented in the UAE with success and have underpinned the country's strong oil production. Furthermore, EOR's importance will only increase in the future as Abu Dhabi expands its oil production and as field pressure continues to decline. As UAE Oil Minister Mohammed Bin Dhaen al-Hamli stated, "[T]he days of easy oil are coming to an end."[30]

However, the UAE has been especially reliant upon natural gas re-injection as its primary EOR method. But this technique has placed strains on the country's ability to continue to supply natural gas to its burgeoning industrial and power sectors. As an example, it is forecast that in the UAE gas re-injection will grow from the current 22.16 bcm per annum to approximately 45 bcm

by 2020.[12] Most of this gas will be needed because of the increased focus on expanding oil production to 3.5 m/bpd by 2018. Yet, gas is essential to the UAE's future because of growing electricity consumption, demand from the petrochemical, aluminum and steel industries, and LNG export commitments. The majority of Emirati power generation is fueled by natural gas (98 percent gas vs. 2 percent liquid fuels), and has a much better energy mix position than its neighbors in terms of power generation.[31] Nonetheless, gas shortages have also caused the UAE to increase the amount of oil it burns in power stations to meet peak demand, albeit incrementally.

Therefore, transitioning away from natural gas for EOR will have significant positive implications for the UAE's economic competitiveness and will conserve more natural gas for the power and industrial sectors. There are several notable non-natural gas reliant EOR techniques that could be successful in the UAE. These EOR methods would assist the UAE in expanding oil production, in line with its strategic goals, while at the same time allowing it to reduce the domestic consumption of natural gas for reinjection purposes.

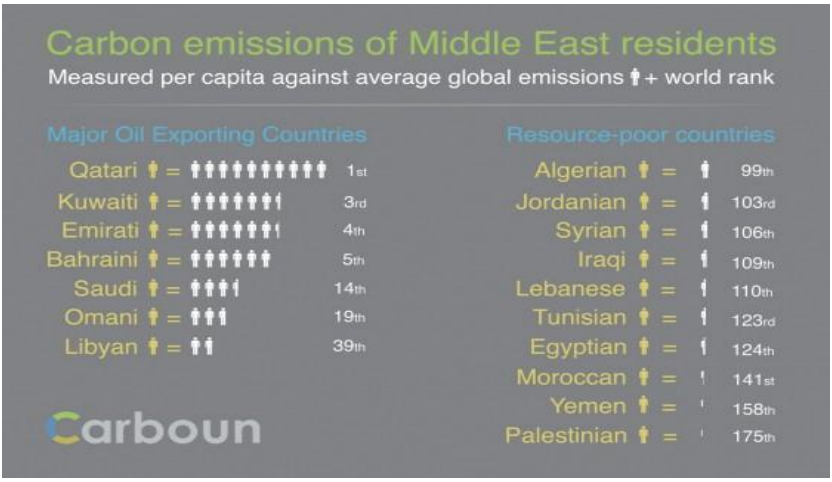
Policy Option One: Incorporation of CO_2 EOR

Carbon dioxide flooding (CO_2 EOR) is of particular interest to the UAE because it has the potential to not only increase the yield of depleted or high viscosity fields, but can also store carbon dioxide that would normally be emitted into the atmosphere. CO_2 EOR has a long history; it has been used for about 40 years in the energy sector.[32] In the United States, CO_2 EOR comprises nearly 40 percent of all current EOR projects. Worldwide it consumes approximately 50 million metric tons of CO_2 for EOR.[33] The

principal benefits of carbon capture storage (CCS) for CO_2 EOR are an increase in oil production and a reduction in gas consumed in re-injection, as well as generation of carbon credits.

CO_2 EOR would be quite beneficial for the UAE for several reasons. Firstly, as long as the reservoir integrity is preserved, the reservoirs that contained the oil and natural gas deposits should also be able to sequester CO_2 for the long term. As there have been in-depth seismic studies on Emirati reservoirs, their geological robustness is understood very well. The afore-mentioned, combined with the extensive experience of the Emirati oil and gas industry along with the dynamics of gas reinjection, provide a starting point to develop a conceptual model on how well the UAE reservoirs could sequester CO_2.

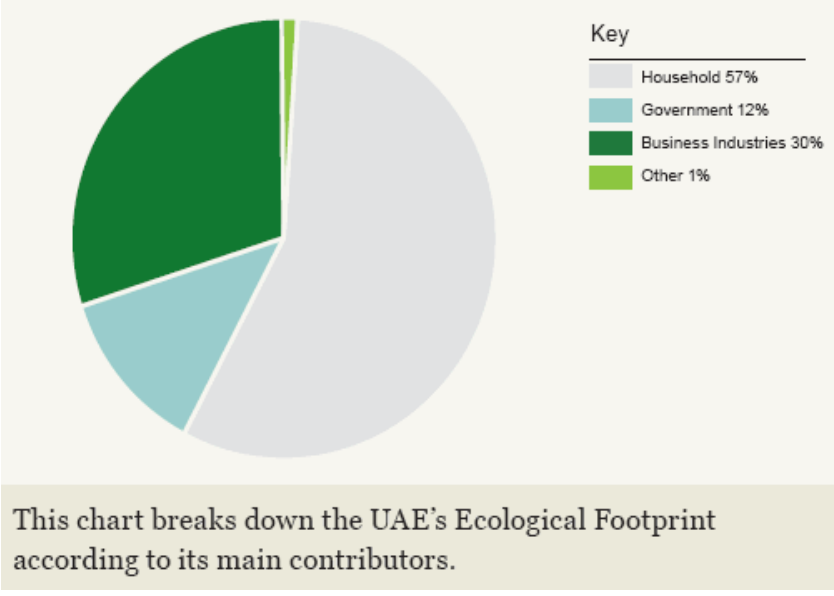
Figure 5



Secondly, as oil and gas fields are fairly well spread out in Abu Dhabi, it would not be difficult to deposit the CO_2 in a nearby field. Additionally, for emission points that are not located nearby,

it is possible to build a pipeline from those points to the reservoir. Thirdly, CCS from CO_2 EOR projects can also be monetized for one of the emerging carbon markets. For example, it is estimated that the typical Gulf oil and natural gas project has the potential to generate at least one million certified emissions reductions (CER) annually.[34] Therefore, not only would CO_2 EOR benefit the UAE by reducing its dependence on gas reinjection, but it also has the potential to create another revenue stream. Lastly, the UAE has one of the largest per capita carbon emissions rates in the world, with strong year-on-year growth. As seen in Figure 5, the UAE has the fourth largest per capita carbon emissions in the world.

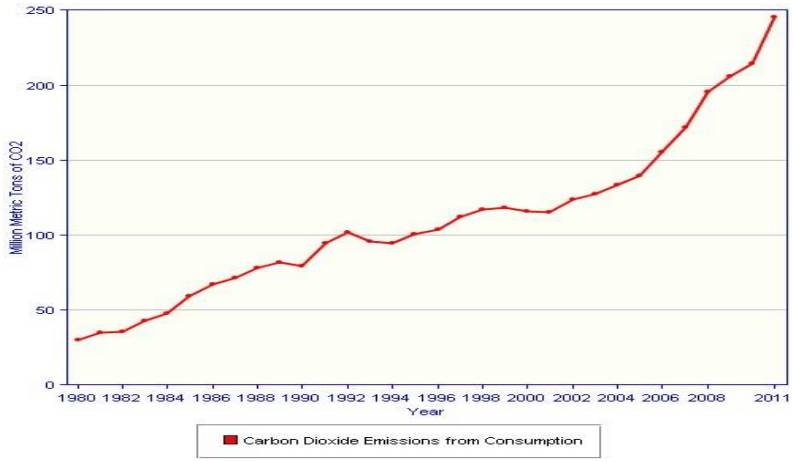
Figure 6
The UAE's Ecological Footprint



Source: The UAE Ecological Footprint Initiative.

Development of a comprehensive carbon management system linking CO_2 EOR with CCS would help reduce the high per capita carbon emissions rates in the UAE (245.38 million metric tons at the end of 2011; see Figure 7). Additionally, as a major step forward, CCS has been formally included during the climate change negotiations held in Durban in December 2011 (COP 17) under the UN's Clean Development Mechanism (CDM) of the Kyoto Protocol. With the agreement of a set of procedures and modalities for CCS projects, the ability of CCS projects to earn CER credits on the international carbon market is now a reality.

Figure 7
UAE Carbon Emissions, EIA Figures



Nonetheless, it still must be understood that it is not necessarily an 'easy process' to initiate CCS as CDM; there are costs associated with the process (see Table 2). It requires significant project funding to build the pipeline infrastructure. As the IEA announced in a detailed study on the technological and economic

viability of CCS, it would require firm policy support from the government to stimulate the rapid scaling up of the necessary infrastructure.[35]

Table 2
Economic Costs of CCS

1)	CO_2 commodity cost
2)	Infrastructure and transport costs
3)	Surface and sub-surface infrastructure costs
4)	Monitoring, measuring and verification for sequestration
5)	Regulatory compliance for sequestration and EOR
6)	The still relatively high cost of capturing carbon and storing it.

Furthermore, a notable study by Carnegie Mellon University argued that when the entire lifecycle emissions are taken into account, that "without displacement of a carbon intensive energy source, CO_2–EOR systems will result in net carbon emissions."[36] The crux of the study's thesis was that as CO_2–EOR would be used to produce more oil, the produced oil would emit more carbon emissions into the atmosphere when consumed resulting in a net carbon increase. As a result, environmentalists still consider CO_2–EOR a controversial (and somewhat suspect) EOR method.

Nonetheless, significant research and development is being applied to CO_2–EOR to develop the next generation of CO_2–EOR techniques that comprise injection of significantly larger amounts of CO_2, improvements in mobility control of injected CO_2, and flood design to send CO_2 to un-swept areas of the reservoir.[37] Overall, CO_2–EOR has the potential to displace significant amounts of natural gas used for re-injection, and can therefore assist the UAE to decarbonize its economy.

Policy Option Two: The Role of Nitrogen

Gaseous nitrogen (N_2) has been successfully utilized in EOR in various jurisdictions. The limitations associated with natural gas (due to supply shortages in the Gulf) and the costs associated with CO_2 have made nitrogen a viable economic alternative for EOR programs. Depending upon the quantities, location and pressure, nitrogen may cost less than one quarter to one half of the cost of natural gas. With nitrogen, the majority of the cost is associated with the cost of production, whether it is inert gas separation or cryogenic air separation. For nitrogen production, the higher the percentage of nitrogen that is needed, the larger the system that is required to obtain a given flow rate. As more compressed air is required, then it is necessary for more electricity to be consumed.[38]

The cost of electricity is the largest single operating cost for air separation plants. Electricity typically assumes between one-third to two-thirds of the operating costs. Relatively small gaseous product plants often consume hundreds of kilowatts (kW), while large liquid plants have electricity requirements between several thousand to tens of thousands of kilowatts. Production of one ton

of nitrogen from an air separation plant requires approximately 243 kWh of electricity consumption.[39]

Furthermore, approximately 28 cubic meters of natural gas is required to produce 125 kWh of electricity. Using the aforementioned as a basis, a midsized nitrogen plant could consume upwards of 100 cubic meters of natural gas for operations. These figures must be viewed in comparison to the 20 bcm of natural gas used annually for natural gas EOR. Therefore, while natural gas, through electricity provision, is indeed utilized to run an air separation plant, in the last instance, the displacement of natural gas used in EOR through nitrogen EOR is much greater than the amount of natural gas required to produce said nitrogen for EOR purposes.

In the Gulf countries, the cost of natural gas considered should not be the administrative pricing framework, averaging approximately $1.30 throughout the region, but rather the opportunity cost of using natural gas for re-injection as opposed to other industrial uses that may support economic development (petrochemicals, fertilizer, and energy-intensive industries). Furthermore, in addition to the opportunity cost, the cost of imported LNG (at international market rates) and the cost of production from non-associated gas fields, such as the Shah and Bab fields, should be weighed as well.

Nitrogen has some advantages over CO_2 as it is typically less expensive and non-corrosive.[41] Furthermore, on a per unit cost basis, it may be manufactured on site less expensively than other EOR alternatives. Additionally, due to cryogenic separation, it may be extracted from the air, and therefore is unlimited in supply. Because nitrogen is immiscible with oil and water, an EOR program which utilizes it can be used to displace missed areas of oil from an injection point to the production well. Moreover, nitrogen has a higher reservoir displacement volume per standard volume of nitrogen than any other gas. In short, it has the lowest volume requirement needed to maintain reservoir pressure.[42] When it comes to high pressure and deep reservoirs with light oil, nitrogen may be the preferred EOR method, rather than CO_2 or solar EOR.

Nitrogen can be utilized in the UAE with great success as it has been proven to reverse field decline in several oil fields across the world. Furthermore, the UAE is already undertaking steps to implement nitrogen EOR in its mature fields by constructing an onsite generation plant in Mirfa. Typically, because significant amounts of nitrogen are needed for major fields, it is much more economically feasible to produce nitrogen onsite, as opposed to purchasing bulk shipments. On February 2, 2012, Samsung Engineering signed a contract with Gasco for construction of a nitrogen gas plant, named Elixir II, worth around $160 million in Mirfa. Elixer II will comprise two large air separation units (with a combined production capacity of 670,000 standard cubic meters per hour) and is expected that the plant will come online in August

2014 for injection into the onshore condensate fields at Habshan.[43]

Nonetheless, despite its clear benefits, nitrogen EOR does have some disadvantages. For instance, while utilizing nitrogen injection, the oil produced will eventually become contaminated with nitrogen (see Table 3 for the optimum field characteristics). This issue may be overcome by additional investment in separation units, which add to the overall cost structure. These additional costs depend upon the available technology, as well as the separator and plant size.[44] Overall, nitrogen EOR has been used with success for many decades and provides a cost-effective alternative to maintain reservoir pressure in mature oil fields.

Table 3
Viability of Nitrogen Flooding

Nitrogen flooding can be an economically feasible EOR method if the following conditions exist in the candidate reservoir:

1. The reservoir oil must be rich in ethane through hexane (C2-C6) or lighter hydrocarbons. These crudes are characterized as "light oils" having an API gravity higher than 35 degrees.
2. The oil should have a high formation-volume factor – the capability of absorbing added gas under reservoir conditions.
3. The oil should be under saturated or low in methane (C1).
4. The reservoir should be at least 5,000 feet deep to withstand the high injection pressure (in excess of 5,000 psi) necessary for the oil to attain miscibility with nitrogen without fracturing the producing formation.

Source: National Energy Technology Laboratory.

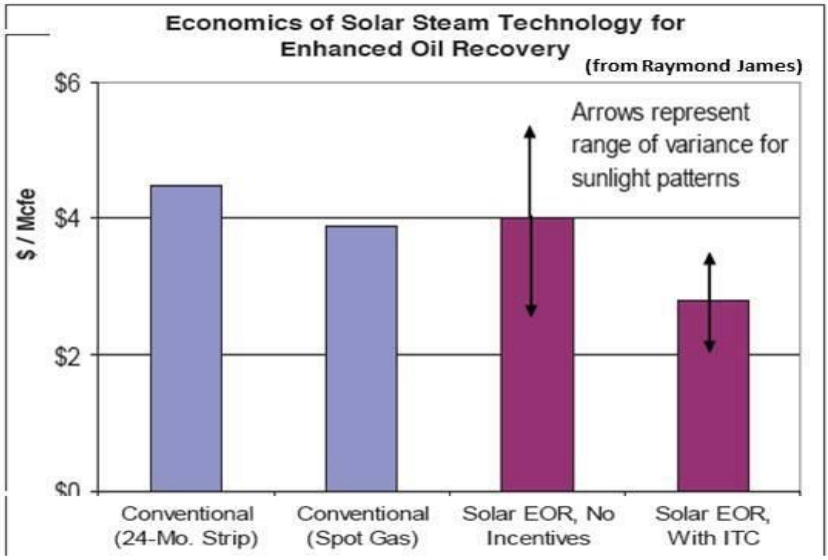
Policy Option Three: Solar Thermal EOR

Steam-enhanced oil recovery (thermal EOR) is an effective and widely utilized method to increase heavy oil production and production from tight reservoirs. The oil industry has been utilizing steam injection for decades to much success.

While the basic process of injecting steam to increase reservoir temperature and pressure has not changed, certain technological advances have made the process much more viable for utilization

in the Gulf region. The advent of cost-effective solar steam equipment has been able to reduce the industry's dependence on fossil fuels to increase oil production and instead replace it with a renewable resource, i.e., the sun's energy. Furthermore, technical advancements with solar EOR has made the process technically feasible, such as the pilot solar tower pioneered by ARCO in the 1980s, as well as Shell's parabolic trough system in Oman, and Chevron's solar tower steam project in California.

Figure 8
Economics of Solar Steam Technology for Enhanced Oil Recovery



Source: Greentech Solar.

Yet, despite it being technically feasible, capital costs still remained fairly high, which has limited deployment. However, the newly created solar collector system by Glasspoint

significantly lowered costs over the lifetime of a field. The solar collector system is now considered to be the most cost effective means for solar EOR projects.

With this aforementioned process, solar EOR's cost of production is approximately half the cost per barrel of steam produced by burning natural gas in most countries. Depending on sunshine patterns, solar EOR systems can operate at an average cost of approximately $2.25 per thousand cubic feet (mcf) (see Figure 8). In the Gulf region, the average cost of production is likely to be approximately $2 per mcf.[45] Additional technological advances could drive the cost of production even lower in the mid-term.

While this production cost is higher than the current administrative prices for natural gas in the UAE and across the Gulf region, when compared against the cost of producing from non-associated gas fields, which contain significant amounts of hydrogen sulfide, such as the Bab and Shah gas fields (estimated at between $5–7 per million British thermal units (MMBTU)), it is much lower. It is also lower than the opportunity cost of consuming natural gas for re-injection. Therefore, solar EOR manages well with the Emirati strategic focus of reducing domestic consumption of natural gas and promoting solar energy.[46]

When the advantages of solar EOR are considered, one of the most important is that it has no associated fuel costs, as well as extremely low maintenance costs. Its operating costs are essentially fixed over the lifespan of the project. Therefore, solar EOR has an operating lifespan much longer than the average gas-

fired unit, averaging about 30 years. The long lifespan can reduce overall capital costs and maximize oil production. Additionally, solar EOR units can be aligned with gas-fired steam generation systems that allow for steam generation 24 hours a day, under various weather conditions. Yet, one of the primary disadvantages of solar EOR is that it depends on sunshine patterns. However, the Gulf region has one of the highest areas of solar irradiance in the world. Furthermore, if aligned with concentrated solar power (CSP) storage, the ability to store thermal energy, such as in molten salt, operating times can be lengthened.[47]

Even though the 100 MW Shams 1 solar plant does not currently have thermal storage, if additional miniature CSP plants with thermal storage capability are built near heavy oil fields, then 100 percent solar EOR scenarios are not only achievable, but economically competitive (see Table 4). Further technological advances will lead to a decline in upfront capital costs. Currently, Oman has the first solar EOR project to develop heavy oil in the south of the country.[48] This 7 MW solar EOR installation will reduce the natural gas utilized for tertiary EOR and thereby help stave off Oman's natural gas deficits. Similar benefits would accrue to the UAE.

Nonetheless, it is of critical importance to understand the limitations of solar EOR. Detailed feasibility studies need to be undertaken in order to understand the rates of direct normal irradiance (the amount of sun that falls on an area), which can result in fairly significant efficiency loses (up to 15 percent). However, as light crude oil production in the Gulf region is declining, with a concurrent transition to heavier oil and natural

gas deficits present in nearly all Gulf countries, there are substantial benefits to be had with the utilization of solar EOR. Moreover, as the UAE begins to manage its carbon emissions, and makes substantial investments in solar energy technology, such as the Masdar project and Shams 1, solar EOR has the potential to considerably add to the UAE's goals of economic sustainability.

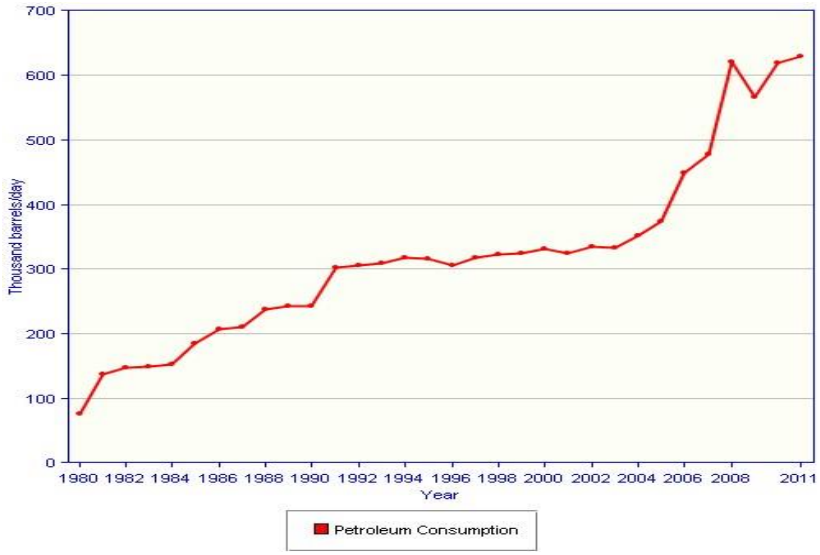
Table 4
Scenarios for Solar EOR Implementation

1) **Integrate Solar EOR alongside gas-fired steam generation:** Without modifying the amount of steam generated, field operators are able to displace about 20 percent of their yearly fuel costs with a solar-gas hybrid model. 20 percent solar steam generation can increase oil production by 5–7 percent, while at the same time reducing operating costs.
2) **Solar-Gas Hybrid Model with Steaming Rate Variations:** Variations in the steam rate during a 24-hour period can occur without disruption to the daily oil production cycles. If the solar collectors undertake a higher proportion of steam generation, such as 50 percent or more, then both production and recovery rates improve.
3) **100 Percent Solar EOR:** Field development plans that base steaming rates on available sunshine patterns (a daily cyclical steam injection schedule) that are capable of the same production rates as those that occur with the continuous-injection system. In the Gulf region, this is likely the most economical method as it avoids carbon emissions and natural gas consumption.

Reducing Domestic Oil Consumption

While the UAE is not a major oil consuming country, it is still forecast to experience a sharp growth in oil consumption until 2020, where it is estimated that Emirati oil consumption will rise by 27.5 percent from current levels.[49] As may be seen in Figure 9, since 1980 the UAE has experienced very strong upward pressure on oil consumption. At the end of 2011, it stood at 671,000 barrels per day (b/d).

Figure 9



Growth of UAE Petroleum Consumption

Strong Emirati oil demand growth is driven by several interrelated factors, such as demographic growth and rising GDP. The rapid economic and industrial development of the UAE led

to the creation of low-density public infrastructure connected to a robust highway system, which combined with low fuel costs, led to increasing consumption of oil for urban transport. UAE energy demand recorded an annual growth of 9 percent since 2007, and caused the UAE to maintain its position as the second largest Arab energy consumer, after Saudi Arabia, in barrels of energy equivalent (oil and natural gas).[50]

The UAE, which has the second largest economy in the region after Saudi Arabia, registered energy demand growth of 48 percent from 1.057 barrels of oil equivalent per day (boe/d) in 2006 to 1.56 in 2011.[51] This rate increase was much higher than the total Arab energy consumption of approximately 27.2 percent during the same period.[52] Additionally, even though the UAE principally uses natural gas in its domestic power generation mix (98 percent), using fuel oil to meet peak demand is growing across the country at about 3.2 million barrels of oil and 2.7 million barrels of gasoil per annum.[53]

Because of the growing oil consumption, strategies need to be pursued that decisively reduce oil consumption. As the majority of power generation is produced from natural gas, the transportation sector plays a dominant role in Emirati oil consumption. As the UAE seeks to reduce its oil consumption, it must support the development, distribution and adoption of new technologies in the transportation sector. This is best undertaken with a mix of policies that include regulatory promulgation and incentives for energy efficiency technology adoption. Additionally, as discussed earlier, as most of the peak power demand in the UAE occurs during the hot afternoons when people

rely upon their air conditioners, solar energy could be a viable alternative to meeting peak demand rather than relying upon fuel oil. Also, as a region, the Gulf region needs to reassess its relationship with fuel consumption in the transportation sector. Urban transport demand is a major source of oil consumption in the world. Globally, approximately 60 percent of the 87 million barrels consumed per day is from urban transport demand.[54]

While the Gulf region has some of the highest rates of CO_2 emissions per capita, public transport in the region only accounts for approximately 5–10 percent of all transport. However, urban transport demand in the region is forecast to double by 2025.[55] Therefore, through the development of fuel efficiency standards, renewable fuels, efficient public transport systems and the promotion of alternative fuel cars (hydrogen, diesel) the UAE will be able to significantly reduce its oil consumption in the sector.

Recently, in light of the oil consumption trends the UAE has taken steps to attempt to mitigate dependence on private transportation vehicles through the development of Mass Rapid Transit (MRT) systems that carry large amounts of passengers relatively quickly.[56] [57] The UAE has been focusing on MRT development in order to reduce congestion, oil consumption and air pollution. In 2009, Dubai inaugurated its metro system with overwhelming success. It is supported by three park-and-ride stations, a network of feeder buses and the Salik toll system. Since its opening in the first half of 2012, the Dubai Metro has carried over 207 million passengers and often operates close to capacity during peak hours.[36]

Furthermore, the first stage of the Al Sufouh Tram will arrive in Dubai in December 2013.[58] This tramway will have 19 stations serving businesses and residential districts to meet the growing transport demand from population growth. Al Sufouh is part of a master plan to create a comprehensive MRT system by 2020 that will include metros, trams, bus and marine lines. This MRT system will be instrumental in alleviating traffic congestion and transport demand.

Additionally, in Abu Dhabi, preliminary development is being conducted on 40 kilometers of light rail transport lines, 18 kilometers of Metro and the construction of a Bus Rapid Transit loop. In addition, in 2011 Abu Dhabi conducted trials of the 'superbus,' an electric vehicle that can carry up to 23 passengers and is capable of traveling at speeds of up to 250 kilometers per hour for travel between Abu Dhabi and Dubai.[59] Overall, the UAE needs to promote the use of buses as the backbone of a transition to a mass transit society.

As stated earlier, under a business as usual framework, urban transport demand (typically met by private vehicles) is expected to double across the Gulf region, which would therefore increase oil consumption. The increase in oil consumption would serve to reduce the amount of oil available for export, resulting in a significant opportunity cost for the region's economies. That is in addition to the increased amount of air pollution and carbon emissions that result as a consequence of urban transport demand. To decisively reduce oil demand, policymakers should focus upon the following:

1. Expansion of public transport, such as investment in metros, trams, bus and marine lines.
2. Increasing the use of diesel and hydrogen power in private transportation.
3. Implementation of third and fourth generation biofuels and fuel efficiency requirements, such as corporate average fuel economy (CAFE) standards, to further reduce oil consumption in the transportation sector.

Development of a comprehensive MRT system, as well as incremental energy efficiency measures in the transportation sector and existing alternative fuels, will result in significant reductions in oil consumption in the short to medium term.

Conclusion: Policy Recommendations

The UAE has developed significantly since its independence in 1971. As a result of the farsighted policies of the Emirati leadership, the country boasts one of the highest standards of living in the world and has the second largest Arab economy, with a GDP of approximately $375 billion.[60] The Institute for International Finance forecast that the Emirati economy would continue its upward climb reaching a GDP of $395 billion in 2013 and $410 billion in 2014.[61]

However, the high annual economic growth has placed certain constraints in effective management of energy demand growth. The UAE desires a resilient and competitive economy. The UAE desires an economy that enhances living standards by creating wealth and employment opportunities for its citizens, as well as

encouraging the development of new technology in the energy sector. In order to remain economically competitive, the UAE should develop a multipronged strategy to concurrently meet its goals of increasing oil production, while at the same time driving down oil domestic consumption. To meet these goals, the UAE should adopt a comprehensive policy package that meets the following objectives:

1. Reduction of natural gas consumption in EOR.
2. Reduction in national carbon emissions.
3. Forge technological innovation (third and fourth generation biofuels, CAFE standards, diesel fuel, hydrogen cars) in the transportation sector to reduce the growing domestic oil consumption.
4. Promotion of mass transit systems.
5. Implementation of price signals to reduce gasoline consumption.

However, what would be the crux of the development of a sustainable energy policy in the UAE is that the 'true cost' of energy be incorporated into any economic policy development. The true cost would encompass the opportunity cost of utilizing a particular energy source in a certain sector. The recommendations in this section will discuss steps that Emirati policymakers could introduce in order to meet the UAE's strategic development goals.

An Integrated EOR Strategy: Increasing Oil Production

As discussed earlier, the UAE consumes a significant amount of natural gas for its EOR program. While EOR is essential to maintain reservoir pressure, the consumption of significant

amounts of natural gas complicates the ability of the country to adequately source natural gas to its essential industries. It is suggested that the UAE develop an integrated strategy that utilizes carbon, nitrogen and solar EOR to maintain reservoir pressure instead of natural gas EOR. There is not a 'one size fits all' EOR process. The economics of field development must be well understood and therefore evaluated to make an adequate determination as to which EOR process would be best suited for particular reservoirs. This is conducted through reservoir modeling, simulation, screening and characterization.

Also, there can be some disadvantages in utilizing alternative EOR methods. There are often relatively long lead times, prohibitive upfront capital costs, a dearth of local technical expertise, and if CO_2 is utilized, difficulties in sourcing adequate amounts. Moreover, depending upon the EOR method, there are certain cost factors with the aforementioned EOR methods that should be considered. In terms of CO_2 EOR, location is quite important. Proximity to CO_2 in significant amounts and of superior quality is essential. Furthermore, pricing is of particular importance to make certain that field development is economical. Constructing a long pipeline for the transportation of CO_2 can be a costly undertaking. In terms of nitrogen, even while it is cost competitive, there are significant upfront capital costs such as the construction of large compressors to inject nitrogen directly into the reservoir. For solar EOR dust and sunshine patterns can be complicating factors.

It is suggested that for heavy oil fields, solar EOR be implemented because firstly it is one of the most successful methods to produce

from heavy oil fields without the CO_2 emissions associated with combustion-based steam generation, and secondly it does not increase natural gas consumption. This will thereby extend the economic life of mature heavy oil fields. Additionally, solar EOR is able to be implemented fairly rapidly. For instance, the solar EOR project in Kern County, California, was constructed in less than six weeks.[62] Furthermore, the entire lifecycle costs are fixed with minimal variable costs, as most of the costs are construction related.

Solar EOR would not just benefit development of Emirati heavy oil, but benefit the Gulf region as a whole. For instance, Mubadala is lending its heavy oil expertise in developing fields in neighboring countries, such as in Bahrain's Alwali field.[63] With incorporation of solar EOR as part of the UAE's strategic expertise, the UAE could become a technological innovation leader in solar EOR across the region. Solar EOR also aligns itself with Abu Dhabi's commitment to renewable energy deployment, especially that of solar. Abu Dhabi's official target is to generate 7 percent of its energy requirements by 2020 from renewable energy sources. The promotion of solar EOR alongside that of CSP plants will reinforce each step for solar power technology transfer and development in the UAE. Of immense importance is the fact that solar EOR is supported by global energy investors and the supermajors. The Omani solar EOR project was funded by Shell, Rockport Capital, Nth Power and Chrysalix Energy Venture Capital.[64] As the UAE is a global financial hub and the leading economy of the Arab world, it is almost certain that the supermajors and the leading financial firms would back any development of solar EOR in the UAE.

Nitrogen EOR is also a viable method as it is extremely cost competitive. It can be manufactured on site and can be recovered nearly anywhere from the air via an air separation plant. In comparison with CO_2, nitrogen requires less compression, which signifies that the cost structure of CO_2 is higher as greater amounts are needed to create adequate reservoir pressure. In terms of power consumption, even though natural gas is required in the first instance to generate the electricity for nitrogen production, when compared to the amount of natural gas utilized in EOR processes, it is quite minimal.

Additionally, nitrogen is non-injurious to the environment, completely inert, and continues to remain inert in the presence of water. Policymakers should also determine which method of nitrogen production is the most viable for which reservoir, and whether to use cryogenic or non-cryogenic methods. Cryogenic processes are the most cost-effective method when a large amount of nitrogen is required. Additionally, cryogenic processes can produce at a high level of purity. Non-cryogenic nitrogen plants are not as energy efficient as their cryogenic counterparts when based on comparable product purity. However, they are typically less expensive to construct, especially when the required production rate is not large. Furthermore, non-cryogenic plants can be constructed relatively quickly and easily. This is beneficial when nitrogen is not required on a full-time basis. Depending on the production method chosen, additional cost savings can be had. Overall, it is recommended that while solar EOR is utilized for heavy oil fields, nitrogen EOR be utilized for light oil fields as it is much more effective in reservoirs with an API greater than 35 degrees.

Meanwhile, CO_2 EOR has significant benefits as well for the UAE. CO_2 EOR is a proven technology that has been used for many decades in the oil sector and can allow for an additional recovery of 4–15 percent of a reservoir's oil over primary and secondary recovery.[65] These recovery rates may be increased as new pilot projects have reported incremental recovery rates of as much as 22 percent.[66] Recent research also suggests that certain technological innovations may boost the recovery rates to more than 60 percent.[67]

As the UAE is attempting to reduce its carbon footprint, an integrated strategy could be developed to align CO_2 EOR with CCS. An integrated CO_2 EOR and CCS initiative would overcome one of the principal problems in this sector, i.e., obtaining an adequate supply of reasonably priced CO_2. Regulatory incentives should be created to promote CCS, which would then allow the oil sector to obtain sufficient amounts of CO_2 for EOR.

This approach will enable various industry sectors to market new sources of CO_2 to the oil industry. It would also allow various advanced technology sectors to develop technological and operational expertise that will be a driver of innovation and further reduce costs in CO_2 capture, compression, and transport in the mid-term.[68] In addition to increasing CO_2 supply for the oil industry, these projects would also benefit the industrial sector by assisting them in the reduction of their carbon footprint in response to expected global carbon regulations (by 2020) in light of the COP 17 and COP 18 climate negotiations. This would

therefore make Emirati industry much more competitive in a decarbonizing global economy.

Lastly, the construction and deployment of CO_2 capture and pipelines for utilization for EOR will establish a national infrastructure across the UAE that could eventually be used by other industries for more long-term CCS in non-oil and gas geologic formations.[69] By promoting CO_2 EOR aligned with CCS, a virtuous cycle can be created that would expand the CO_2 supply at a cost competitive basis for the oil industry, increase domestic oil production and employment opportunities, forge technology transfer in the emergent market of CCS technology, gain revenue through the sale of carbon credits through the UN's Clean Development Mechanism (CDM) and reduce the UAE's expanding carbon footprint. An integrated EOR strategy that carefully incorporates solar, CO_2 and nitrogen EOR based on a reservoir's characteristics and cost competitiveness would enable the UAE to reduce its dependence on natural gas for EOR, and allow the previously allocated gas to be used in other economic sectors.

Reducing Oil Consumption: A Comprehensive Transportation Sector Strategy

As discussed previously, the Emirati transportation sector is the main driver behind domestic oil consumption. Emirati domestic oil demand is increasing annually, primarily due to demographic growth, relatively low gasoline prices and increasing GDP. In order to reduce domestic oil consumption, policymakers should consider focusing on several issues:

1. Promotion and development of a mass transit system.

2. Energy efficiency standards in automobiles.
3. Increasing the use of third and fourth generation biofuels in the domestic transportation fuel mix.
4. Increase gasoline prices to send price signals.

Overall, a broad multi-tiered policy should be adopted for promulgation of renewable energy standards, establishment of basic fuel efficiency standards for the market to be met by the most cost competitive technological choice, and through an increase in gasoline prices in order to send price signals to the market.

Advanced Biofuel Promotion

The UAE should collaborate with the global biofuels industry to support technology development and commercial deployment within the UAE. For instance, it could give subsidies such as grants, low-interest loans, and loan and performance guarantees to promote domestic production. Furthermore, the creation of a type of renewable fuel standard that requires fuel suppliers to incorporate a certain amount of renewable fuels (including biodiesel) in the transportation fuel mix would be advantageous.[70] These renewable fuel targets can be adjusted and increased on a scheduled basis, e.g., 2015, 2018, 2021, etc. As there have been concerns about the amount of food crops utilized in biofuel production, renewable fuel standards should promote the incorporation of advanced biofuels, i.e., fuels produced from non-corn feed stocks. Also, policymakers should develop specific quotas for cellulosic biofuels and for biomass-based diesel fuel.

Fuel Economy Targets

To promote the adoption of energy efficiency technologies in the transportation sector, policymakers should develop fuel economy targets for automobiles. In the United States, the corporate average fuel economy (CAFE) standards have been quite successful in increasing overall fuel economy in automobiles.[71] Additionally, policymakers should develop fiscal incentives for the importation and sale of flexible fuel vehicles able to utilize advanced biofuels.

Mass Transit Systems

The UAE should develop public transportation on several grounds. The main strategies for increasing the reach of the transportation sector are demand management, pricing policies, operations management, integrated land-use and transportation planning.

Although the UAE has already begun to expand its mass transit system, this expansion should be coupled with additional policies to increase usage and consumer adoption. In furtherance of that goal, carpooling should be rewarded and specialized lanes should be created for carpoolers. The Salik system should be expanded and a congestion tax added for entry into traffic prone areas. Additionally, subsidized petroleum for consumer use should be gradually removed to increase the total cost of using a private automobile. By creating incentives for consumers to use the mass transit system and increasing transportation costs for those who do not use it, the UAE will increase the likelihood that the system will be effectively utilized.

Additionally, engaging in urban planning to design infrastructure conducive to pedestrian traffic would assist in encouraging commuters to use public transportation. Many cities around the world have developed high-density commercial areas centered on public transportation or pedestrian only arterials, which greatly contributes to the usage of public transportation systems. As the population of the UAE continues to grow, designing cities, neighborhoods and areas with the purpose of increasing public transportation usage should be central planning, such as was done with great success in the Netherlands and Denmark. Moreover, transportation demand management can create efficient use of the existing transportation system by influencing travel behavior in terms of the schedule, transport mode selected and the travel routes of the transit systems.

Subsidy Reform: Increasing Gasoline Prices

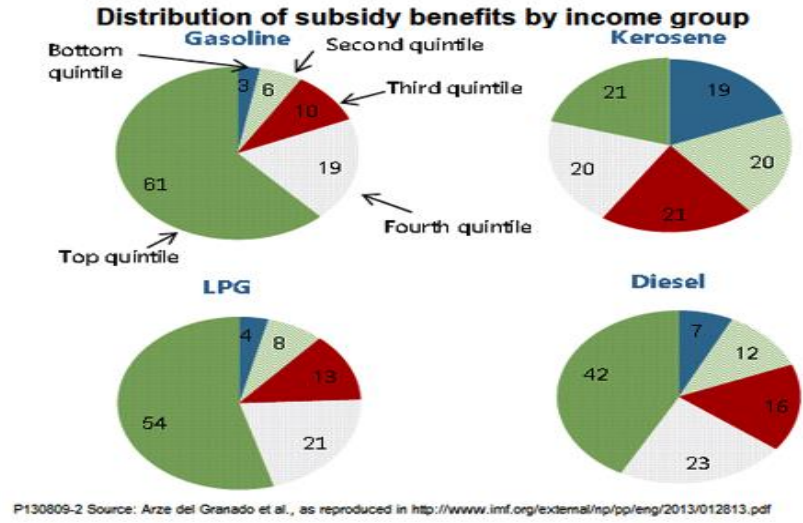
Out of all of the policy suggestions to reduce oil consumption, one of the most effective is gasoline subsidy reformation. It has the potential to reduce carbon emissions, encourage the use of UAE mass transit systems and stimulate adoption of alternative fuel vehicles. The UAE heavily subsidizes domestic gasoline, which allows residents to purchase gasoline at well below the prevailing global market price, this in turn encourages market inefficiency and overconsumption.[72] In the UAE both citizens and expatriates pay only $0.47 for a liter of gasoline.[73]

Due to the generous subsidization, a 2013 report by the International Renewable Energy Agency (IRENA) discovered that the UAE had the highest levels of energy (natural gas, gasoline and other fossil fuels) subsidization in the Middle East.[74]

When all of the Emirati energy subsidies are calculated, it equals $4,172 paid to every man, woman and child in the country to keep energy prices low.[75]

These fuel subsidies have a detrimental impact on the overall economy for several reasons, and they often do not work as they were originally intended. Inherently, fuel subsidies tend to be regressive, as opposed to progressive. Therefore, the ones who benefit the most from such policies are the wealthiest cohort of the population. An IMF study illustrated that the wealthiest 20 percent of the population obtain as much as six times the benefit from a subsidy as the poorest 20 percent (See Figure 10).[76]

Figure 10



As the study illustrated, fuel subsidies injure both poor and rich households. Fuel subsidies harm the poor because they burden the governmental budget and siphon money away from other social

programs that would have a much more beneficial impact. And, in the case of the UAE, expatriates, who make up approximately 89 percent of the population, are the biggest beneficiaries of gasoline subsidies.[77]

Additionally, fuel subsidies have externalities that impact the quality of life for citizens of all income levels. Fuel subsidies tend to increase traffic congestion and air pollution. Subsidized gasoline encourages citizens to purchase additional vehicles that they may not require, and the increased number of cars on the roads directly increases the amount of air pollution. Elimination of gasoline subsidies would not only encourage motorists to ride public transport, but it would also liberate significant amounts of money that could be directed toward investment in modern transportation infrastructure.

Due to gasoline subsidies in the UAE, the four UAE state-owned gasoline retailers – Dubai government-owned Emirates National Oil Co (ENOC); Emirates Petroleum Products Co (EPPCO); federally owned Emarat; and Abu Dhabi's National Oil Co. (ADNOC) – experienced financial losses of approximately $3 billion in 2012 and 2013.[78] While elimination of any subsidization program is not an easy prospect, and often engenders strong opposition, the abolition of gasoline subsidies in the UAE would benefit the overall economy and place significant downward pressure on rising oil demand and carbon emissions.

Notes

1. The author would like to acknowledge the unflagging efforts of his research assistant, Arthur DeLong.

2. In this brief, the Gulf region is used to designate the countries of the Gulf Cooperation Council, i.e., Saudi Arabia, the UAE, Oman, Kuwait, Bahrain and Qatar.

3. *BP Annual Statistical Review of World Energy* (June 2011), pp.6–18; (http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report _2011.pdf).

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6. Ibid.

7. Ibid.

8. Florian Neuhof, "Abu Dhabi's Oil Output at 2.8m Barrels Per Day," *The National*, January 10, 2013.

9. "UAE's Crude Production Capacity Could Increase," Qatar News Agency January 5, 2010.

10. Hemendra Mohan Kumar, "UAE 2012 Oil Output Averages 2.65m bpd-IEA," *Gulf News* January 23, 2013.

11. The UAE also imports natural gas (.056 BCM per day) through the Dolphin natural gas pipeline from Qatar.

12. Author's calculations based on IMF country statistics.

13. Hakim Darbouche, "Issues in the pricing of domestic and internationally traded gas in MENA and sub-Saharan Africa," Oxford Institute for Energy Studies, June 2012.

14. Databases from the *BP Statistical Review of World Energy,* 2012.

15. Author's calculations based on IMF and World Bank country statistics.

16. EOR consumption is calculated as the difference between total gross natural gas production and the marketed output, which is utilized in the power generation and power sectors of the economy, Justin Dargin, "The UAE Gas Sector: Challenges and Conclusions for the 21st Century" in (ed) Bassem Fattouh and Jonathan Stern, *Natural Gas Markets in the Middle East and North Africa* (Oxford: OIES Press, 2011), 454.

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31. For instance, Saudi Arabia has 49 percent of its gas consumption for power generation and Kuwait has 29 percent.

32. CO_2 EOR was first used in 1972 in Scurry County, Texas. Afterwards, it has been successfully used in throughout the Permian Basin of West Texas and eastern New Mexico. Additionally, it is now being utilized in in Wyoming, Oklahoma, Colorado, Kansas, Mississippi, Utah, Montana, Alaska, and Pennsylvania.

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39. This is based on the best achievable energy consumption as energy consumption can vary depending upon ambient air conditions or elevation, plant scale operating modes and coproduction of oxygen and nitrogen.

40. Source: Offshore Technology.

41. The fact that it is non-corrosive means that the injection equipment does not require any special metallurgy.

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