TIGHT NATURAL GAS AS A BRIDGE FUEL TOWARD RENEWABLES

By Magdi Ragheb

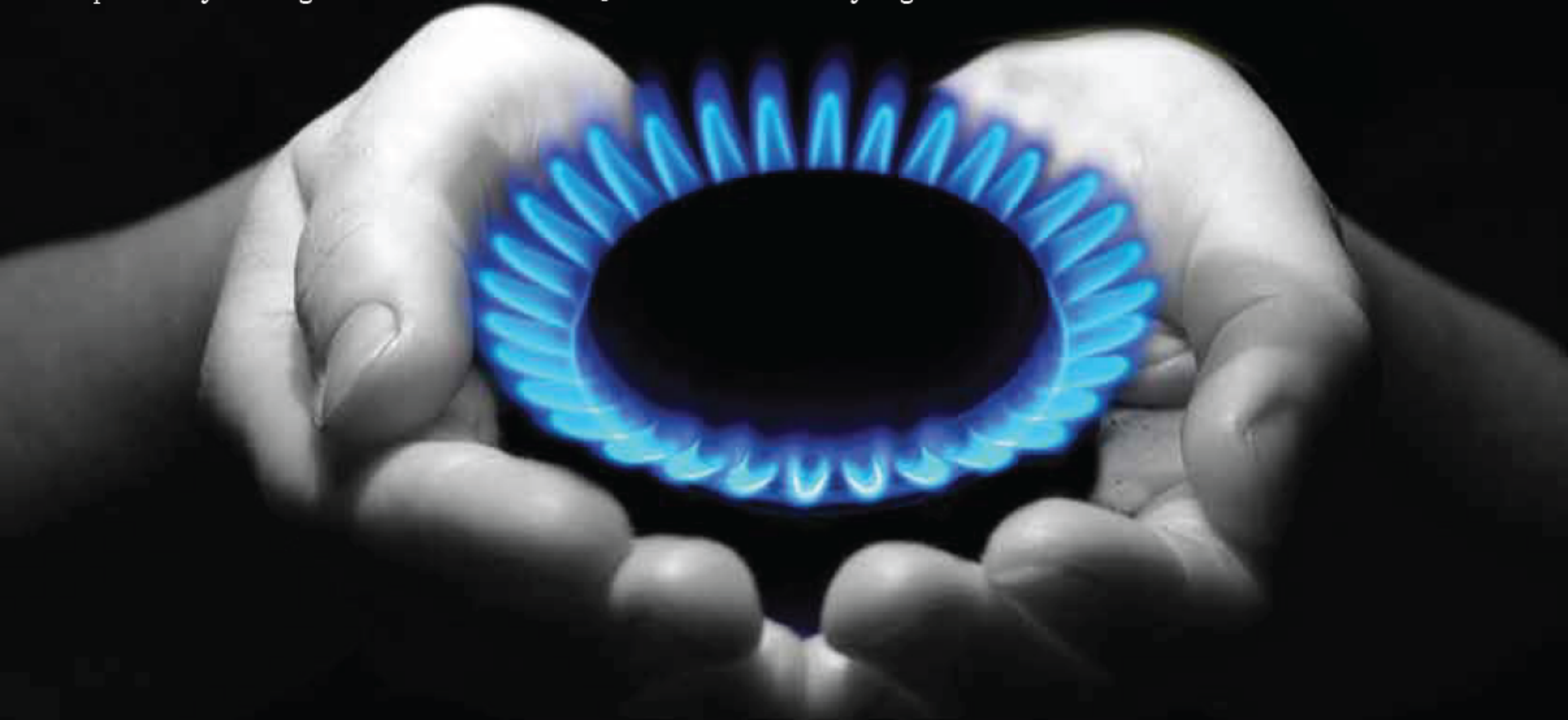
Tight natural gas as a product of Hydraulic Frac turing or Fracking is asserting a role in North America and Asia as a bridge fuel towards the eventual adoption of renewable and carbon free sources of energy. Tight natural gas is trapped in rock formations that are about one thousand times less permeable than conventional gas reservoirs and requires the use of fracturing for its release.

The decades old secondary recovery technique of hydraulic fracturing is undergoing a dramatic revival and a wide adoption since the introduction of horizontal well drilling in shale formations, but has generated environ mental concerns about water contamination because of the chemicals used in the process.

Natural gas is filling a role as a bridge fuel along the road of the implementation of renewable energy sources and an energy economy where hydrogen is used as an energy carrier with fuel cells replacing the Internal Combustion Engine (ICE). Natural gas could be used in the steam reforming process to produce synthetic gas which is a mixture of H_2 and CO. Instead of Carbon Separation and Storage (CCS), the process of carbon dioxide reforming would use natural gas to turn CO_2 into useful products such as green diesel fuel. To over come the intermittence property of thermal solar energy, the Combined Cycle Concentrated Solar (CCCS) alternative uses natural gas in hybrid plants under construction to provide power during the night period and on cloudy days.

NATURAL GAS COMPARISON TO OTHER FUELS

Natural gas prominently has a high specific energy among existing fuel choices, only exceeded in the energy con tent per unit weight by nuclear fuel (Table 1). In the last 200 years there has been an evolution toward burning less carbon in favor of burning more hydrogen in different fuels as shown by the atomic ratio of hydrogen to carbon (H / C) in Table 2 for different fuels from wood to natural gas or methane CH_4, as well as its liquid form as methanol or methyl alcohol CH_3OH. The increased per capita energy consumption as estimated by Ausubel is leading to a trend toward using fuels with more hydrogen content as shown in Table 3.



SPECIAL REPORT!

However, hurdles have to be overcome along the road. Based on environmental concerns, the province of Québec in Canada, the state of New York in the USA, and France do not authorize the use of the technique of hydraulic fracturing for the extraction of tight natural gas from shale rock formations. Improper application of the technique generated claims that the hydraulic fracturing of tight shale natural gas formations may lead to more environmental concerns than the mining and burning of coal.

VERTICAL VERSUS HORIZONTAL DRILLING

In conventional natural gas reservoirs a few vertical wells are usually drilled every 2.5 km^2 and are sufficient to extract the existing natural gas. Tight natural gas formations are porous and have a permeability that is three orders of magnitude lower than the conventional gas reservoirs. Tight gas does not diffuse easily in the low permeability formation rock and is often spread over a larger area.

This necessitates an approach where wells are drilled in different directions from a central location that penetrate the gas reservoir both vertically and horizontally. This poses a limitation on the number of available drilling locations or wells pads on the surface.

An extensive network of wells is generated, stretching underground for lengths of up to 2 kms or 1.2 miles. This increases the potential production to 10 times more than is achieved through conventional methods. Mobile drilling units are moved between the well pads, avoiding the dismantling and reassembling of the drilling equipment for each pad.

HYDRAULIC FRACTURING, FRACKING

Hydraulic fracturing of tight natural gas shale formations is a secondary recovery drilling technique that involves pumping a mixture of water, sand and chemicals into deep shale deposits to fracture the rock, increase its permeability, and free the oil or gas. The technique has been used since the 1950s, but in the last decade the development of the horizontal drilling technique has made hydraulic fracturing a useful technique. It has allowed the extraction of natural gas from oil shale rock deposits, which are usually around a mile in depth. The tight natural gas that used to be inaccessible is leading to a substantial increase in natural gas production in the lower 48 USA states.

In hydraulic fracturing, fluids are pumped into a well whose casing has been perforated by projectiles shot from a special gun to create fractures in the rock, increasing its permeability. The sand keeps the cracks open after withdrawal of the fracturing fluid and allows the gas to flow into the perforated casing. This takes place deep underground below the shallow fresh water aquifers at pressures sufficient to create fractures in the host rock.

The hydraulic fracturing fluids consist mainly of water mixed with small amounts of chemical additives that help to cool and lubricate the piping and drill bits and prevent scale formation. Sand or ceramic particles are mixed with the fracturing fluid to keep the fractures open and allow natural gas to diffuse through them. Ceramic particles are preferred to sand for shale formations at the greater depths and pressures.

The wells are finished by lining them with steel pipes and are cemented in place down from the surface to below the level of the shallow fresh water aquifer that are the primary sources of the drinking water supplies. When properly installed, these barriers are effective in containing to the hydraulic fracturing fluid and prevent the fluid from mixing with the water in the shallow water aquifers.

INCREASED PRODUCTION AND RESERVES

As of 2011, tight shale natural gas deposits are reported to have provided 25 percent of the USA's natural gas production. They are expected to provide 45 percent by the year 2035. In 2010, the USA produced 4.87 trillion ft^3 of shale gas. This represents a 57 percent increase above the 2009 level.

Tight shale natural gas discoveries accounted for 90 percent of the increase in the USA's domestic natural gas reserves in 2009, when gas reserves grew by 11 percent, even as the prices fell by a factor of one third as a result of increased production and supply. Tight shale natural gas currently amounts to 21 percent of the USA's total natural gas reserves.

The increase in tight shale natural gas production was facilitated by the recent developments in the technique of horizontal drilling. The technology advanced to a level where drillers are able to perform the hydraulic fracturing process horizontally. Hydraulic fracturing has been used to extend the lives of vertical wells since 1949, but vertical fracturing cannot retrieve tight shale natural gas at economic levels.

As the global conventional gas fields are suffering depletion, an increase in the price of natural gas occurred and encouraged exploration

TABLE 1 Specific energy of different energy supplies.

Fuel	Specific energy [MJ/kg]
Enriched Uranium(3-5% U^{235})	3.7×10^6
Natural Uranium(0.72% U^{235})	5.7×10^5
Natural gas	55.6
Diesel fuel	45.8
Crude petroleum	41.9
Coal	32.5
Ethanol	26.8
Wood	10

TABLE 2 Hydrogen to Carbon ratio (H/C) for different fuels

Fuel	Hydrogen to Carbon ratio, (H/C)
Wood	0.1
Coal	0.5-1.0
Oil	0.8-2.0
Light sweet Crude, $(CH_{1.5})_n$	1.5
Heavy sour crude, $(CH_{0.8})_n$	0.8
Clean transport fuel, $(CH_2)_n$	2.0
Cetane, $C_{16}H_{34}$	2.125
Hexane, C_6H_{14}	2.333
Propane, C_3H_8	2.666
Methane, CH_4	4.0
Methanol, methyl alcohol, CH_3OH	4.0
Ethanol, ethyl alcohol, C_2H_5OH	3.0
Hydrogen	∞

TABLE 3 Per capita energy consumption trend for different fuels.

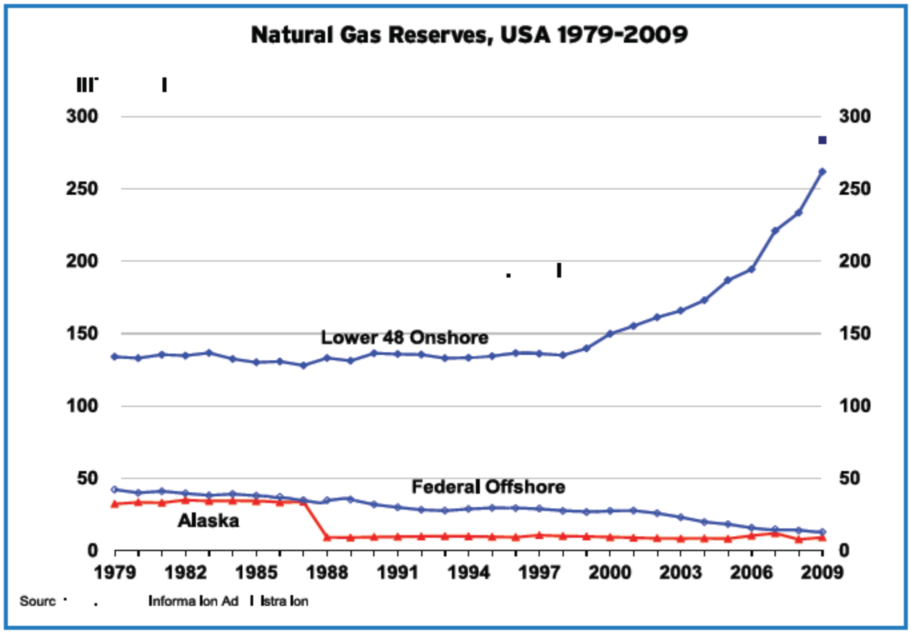
Timescale	Fuel	Per capita consumption in tons of coal equivalent (tce)
1850-1925	Coal	0.3-1.0
1925-2000	Oil	0.8-2.3
2000-2050	Gas	2.0-6.0
2050-...	Hydrogen	6 0-15 0

and capital investment. Hence tight shale natural gas is considered as the "bridge fuel" in the USA's energy plan as it transitions from the depleting hydrocarbons fuels to the renewable energy sources.

TIGHT NATURAL GAS PRODUCTION GOVERNMENT INCENTIVES

President Barack Obama's administration has promoted natural gas as part of its clean energy policy. Yet, earlier support for hydraulic fracturing originated from the time of President George W. Bush's tenure. In 2005, his administration passed the Energy Policy Act, a wide-ranging energy bill championed by his Vice President Dick Cheney.

The Energy Policy Act of 2005 explicitly exempted the hydraulic fracturing process from excessive regulation, specifically the provisions of the Safe Drinking Water Act, the Clean Air Act, and the Clean Water Act. This introduced a loophole that is known as the "Halliburton Loophole," in reference to the previous involvement



of Vice President Dick Cheney with the Halliburton Company. It allows the tight gas extraction companies to pump large volumes of hydraulic fracturing fluids into old wells and to store the used fluids in open pools.

About eight million gallons of water are usually needed to hydraulically fracture a tight natural gas well. A well may be repeatedly hydraulically fractured about 18 times. Each time, about half of the hydraulic fracturing fluid is pumped to the surface entraining the natural gas. The gas is collected at compressor stations, where it is separated from carbon dioxide and compressed for pipeline transport. The returned hydraulic fracturing fluid is either trucked to water treatment plants, injected into old wells, or stored in large, tarp-lined evaporation pools.

ENVIRONMENTAL CONSIDERATIONS

The rapid growth of hydraulic fracturing has generated opposition due to concerns about shallow fresh water aquifers contamination by the chemicals used in the process. Their leakage is associated with hasty improper or sloppy well finishing and casing procedures. The chemicals reportedly used in the process include organic solvents such as benzene and toluene, boric acid, xylene, diesel-range organics, methanol, formaldehyde and ammonium bisulfite. The use of carbon dioxide fracturing is under consideration as an alternative to water fracturing.

The wells, if improperly finished, are considered eyesores for some. The access roads, storage tanks and drill pads construction have affected pristine tracts of land. The real concern is water contamination. Incidents of fresh water supplies being contaminated by metals and volatile organic compounds as a result of improper hasty well finishing and casing have generated complaints about health problems for people, livestock and wildlife.

In the state of Pennsylvania, the Department of Environmental Protection reported an incident involving the contamination of the fresh water aquifer feeding rural household wells in Dimrock after more than 60 wells were drilled in a nine square-mile area. The hydraulic fracturing operations may have caused the water to turn brown in color and imbued it with methane (CH_4) gas, iron and aluminum. Hydraulic fracturing fluids leaked into water streams, affecting their colors and killing fish. The methane in a water well ignited and caused an explosion. A family evacuation was initiated because of hazardous methane levels at their home.

Tight shale natural gas formations are typically 5,000-8,000 feet in depth. This is below the fresh ground water aquifers that exist up to 1,000 feet in depth. Consequently, it is not plausible that the hydraulic fracturing gases and fluids diffuse all the way up to the aquifers through fractures. Contamination can more likely be attributable to hasty poor cementing and well casings that would cause the hydraulic fracturing fluids and methane gas to escape at the shallow fresh water aquifers level.

The so-called Halliburton Loophole exempts hydraulic fracturing from otherwise restraining regulations. The above-ground handling of return hydraulic fracturing water and the airborne pollution produced through processing are perceived as sources of health risks in the hydraulic fracturing process. The city of Fort Worth, Texas, sits atop a productive tight natural gas shale formation. The chemical emissions from the natural gas processing facilities at Fort Worth are reported as equal to the city's total emissions from automobiles and trucks.

The Cuadrilla Resources Company using hydraulic fracturing in drilling for natural gas from tight shale rock in the North-West UK near the Blackpool coastal resort reported that studies by independent experts concluded that some Earth tremors measuring 1.9 and 2.8 on the Richter magnitude scale in April and May of 2011 were due to an unusual combination of geology and operations and would be unlikely to reoccur again. Its operations were suspended on May 27, 2011 pending the studies. The resulting report suggests that a maximum magnitude could reach 3 on the Richter magnitude scale and would be barely felt at the surface.

SAFETY CONSIDERATIONS

GENERAL PROVISIONS

Safety procedures are applied in the hydraulic fracturing process according to the "as reasonably practicable" industry and regulatory principle. Professionally conducted hydraulic fracturing engineering operations incorporate electronic monitoring equipment measuring the wells parameters to ensure its safe operation. Pressure sensors are used to check that the wells are firmly sealed. The fractures and the fluids are also monitored.

Hydraulic fracturing technology

was developed in the 1940s and has been continuously improved. Advanced sensors record what happens when the shale formation rock is fractured. Imaging software using virtual reality methods and specialized computers is used to map the gas fields below the surface to better target the gas-bearing formations.

In the USA, about one million hydrocarbon wells have been hydraulically fractured since the process was first introduced. However, local communities are becoming concerned over the increase production activities and fracturing. Studies by the USA Environmental Protection Agency (EPA) and the Ground Water Protection Council have determined that the process can be safely conducted.

Before drilling a well, a set of practices, called a "safety case," is used to analyze the anticipated risks and to develop protective barriers over the operational lifetime of the well. Two or more barrier layers are built into all oil and gas wells and for the surface storage enclosures of the fluids produced from the wells. Steel casings and cement is used to protect and isolate the potable groundwater zone from the production stream, as well as from the hydraulic fracturing fluids, in the wellbore.

The use of open pit systems for the primary containment of the produced and drilling fluids is being phased out in several operating areas. The released information about the chemicals used in the hydraulic fracturing operations is still incomplete and sketchy and is considered as proprietary information by the suppliers.

Monthly safety reviews of the processes are conducted. Emergency response plans that take into account the local surroundings are put in place.

WATER USAGE ISSUES

The completion and production activities are designed in such a way so as to isolate them from the potable groundwater aquifers. Only air, water, or water-based drilling mud is used through and to at least 500 feet or 150 meters below the potable groundwater aquifers. This particular zone is carefully cemented and cased before drilling further or hydraulic fracturing is carried out at the lower levels of the wells.

In new potential development areas, the potable groundwater is tested before and after drilling to help determine whether changes have occurred as a result of the hydraulic fracturing activities. The use of potable water is minimized and non-potable water supplies are used whenever available. The hydraulic fracturing and completion fluids are pumped back to closed systems or tanks. The fracturing fluid and produced water that comes out of the well are recycled to the extent possible in the field. It is stored, treated and disposed of it in an environmentally responsible manner and in accordance with the prevailing regulatory requirements.

EMISSIONS CONTROLS

Emissions are minimized as much as reasonably practicable. The emissions are measured, catalogued and reported to the appropriate regulatory agencies. Fugitive emissions are detected by visual observation and infrared testing. Routine venting is eliminated if permitted; wherever venting is required by regulation. Vapor recovery units are usually used at the wellheads.

Steps to lower emissions from the operations include the use of natural gas engines. Catalyst technology used in diesel cars and power plants can be used on drilling rigs in harsh winter environments. The catalyst can reduce the local emissions from the drill rig engines by about 90 percent.

Natural gas is considered as a clean and green fuel because, on combustion, it emits roughly half the carbon dioxide of coal and about 30 percent that of oil. The problem is that its combustion is only one part of the natural gas life cycle. During other parts of the cycle, methane CH_4 could be released to the environment. Cornell University studies suggest that the rush to develop the USA's unconventional gas resources will likely increase the nation's carbon emissions rather than decrease them. The suggestion is that between 3.6 - 7.9 percent of the CH_4, a greenhouse gas, is lost from the time a well is plumbed to when the gas is used.

A study from the Goddard Institute for Space Studies at NASA suggests an interaction between CH_4 and certain aerosol particles significantly amplifies its already potent greenhouse gas effects.

A large fleet of trucks drive around to bring the hydraulic fracturing fluids to drills and to remove the waste water. When this is factored in, the greenhouse gas footprint of shale gas is likely 20 percent greater than coal per unit of energy content, and may be as much as twice as high. Such an impact needs to be minimized by judicious engineering, as well as the impact from the operations on wildlife and livestock, such as limiting the activities during specific time periods.

The landscape is to be restored once a drilling location is completed in collaboration with the Bureau of Land Management such as planting a mix of native species trees, brushes and grasses that are food staples to the local fauna.

ECONOMICAL ATTRACTIVENESS

Hydraulic fracturing enjoys wide ranging industry and landowners support in the USA. In the USA, landowners in most locations also own the mineral rights below their land, which is not generally the case in Europe. The royalties and lease fees that the drilling companies pay to the landowners are sufficient to turn them into ardent supporters. The price to lease an acre of the Marcellus Shale, the shale

Comparison of different sources of hydrogen as transportation fuel. Hydrogen production: 150 x 10^6 tons /year.

	Nuclear Fission	Wind Power	Solar Power	Natural as	Biomass	Coal
Total cost [$ trillion]	0.84	3.0	22.0	1.0	0.565	0.500
Price per gallon of gasoline equivalent [$ /gce]	2.5	3.0	9.5	3.0	1.9	1.0
CO_2 emissions [millions tons]	0	0	0	300	600*	600**

* Zero net emmissions. **With 90% Co_2 capture and underground storage.

formation stretching from West Virginia to New York, continues to climb. Twenty years ago around 1990, it was just $25 /(acre.year). Currently it averages $5,000 /(acre.year). The industry creates a large pool of local jobs and pumps lots of money into the local communities and state economies.

NATURAL GAS AND THE HYDROGEN ECONOMY

The USA uses some 10 x 10^6 tons /year of hydrogen for industrial purposes, such as making fertilizer and refining petroleum. If hydrogen-powered vehicles are to come into use the need would increase to 10 times the current usage.

STEAM METHANE REFORMING, SMR

Fossil fuels are also considered as "hydrocarbons" and hence contain hydrogen in addition to carbon. About 95 percent of the USA's hydrogen is produced from natural gas through a process called Steam Methane Reforming (SMR).

High temperature and pressure break the hydrocarbon into hydrogen and carbon oxides including carbon dioxide, which is released into the atmosphere as a greenhouse gas.

Over the next 10 - 20 years, fossil fuels are expected to continue to be the main feedstock for the hydrogen economy. Using fossil fuels energy to make clean energy does not solve the CO_2, SO_x and NO_x, mercury, arsenic, cadmium and even radioactive pollution problems associated with fossil fuels.

A partial remedy is Carbon Capture and Sequestration (CCS) which involves capturing that CO_2 and sequestering it underground to make the process more environmentally friendly. The General Electric Company (GE) and British Petroleum (BP) announced plans to develop as many as 15 power plants that will strip hydrogen from natural gas to generate electricity. The waste CO_2 would be pumped into depleted oil and gas fields.

The USA Department of Energy (USDOE) is considering funding a 10-year, $950 million project to build a coal-fed plant that will produce hydrogen to make electricity, and likewise lock away CO_2 to achieve what it bills as "the world's first zero-emissions fossil fuel plant."

Hydrogen gas can be produced in gas station-size facilities using natural gas steam reforming. There would be a need for 15.9 million ft^3 / year, which is a fraction of the current USA annual natural gas consumption. A number of 777,000 small distribution facilities would be needed with a number of large central production plants.

Uncertainties still exist about the CO_2 containment in large scale operations. Natural gas is a limited resource whose price fluctuation would affect the cost of the produced hydrogen.

The Steam Methane Reforming (SMR) process is the most widespread method to generate hydrogen-rich synthesis gas from light hydrocarbons. The feed material can be natural gas, liquid gas or naphtha. They are converted endothermically with steam into synthesis gas in catalytic tube reactors. Process heat as well as flue gases are used for the generation of steam.

The process consists of three main steps:

REFORMATION PROCESS

The first step of the SMR process involves a light hydrocarbon reacting with steam at 750-800 °C or 1,380-1,470 °F to produce a synthesis gas or syngas, which is a mixture primarily made up of hydrogen, H_2 and carbon monoxide, CO.

The desulfurized hydrocarbon feed is mixed with superheated process steam in accordance with the steam/carbon relationship necessary for the reforming process. This gas mixture is heated up and then distributed on the catalyst-filled reformer tubes. The gas mixture flows from top to bottom through tubes arranged in vertical rows. While flowing through the tubes heated from the outside, the hydrocarbon/steam mixture reacts, forming hydrogen and carbon monoxide according to:

$$CnHm + nH_2O \rightarrow nCO + \frac{(2n+m)}{2} H_2$$

SHIFT REACTION

The second step, known as a Water Gas Shift (WGS) reaction, the CO produced in the first reaction is reacted with steam over a catalyst to form H_2 and CO_2.

This process occurs in two stages, consisting of a High Temperature Shift (HTS) at 350 °C or 662 °F endothermic reaction:

$$CH_4 + H_2O \rightarrow CO + {}_3H_2$$

and a Low Temperature Shift (LTS) at 190-210 °C or 374-410 °F exothermic reaction:

$$CO + H_2O \rightarrow CO_2 + H_2$$

To minimize the CH_4 content in the synthesis gas while simultaneously maximizing the H_2 yield and preventing the formation of elemental carbon and keeping it from getting deposited on the catalyst, the reformer is operated with a higher steam/carbon relationship than theoretically necessary.

As the process is endothermic, the required heat must be produced by external firing. The burners for the firing are arranged on the ceiling of the firing area between the tube rows and fire vertically downward. The residual gas from the pressure swing adsorption unit as well as heating gas from battery limits is used as fuel gas. The flue gas is then cooled down in a convection zone, generating steam.

PURIFICATION PROCESS

High to ultra-high purity hydrogen is needed for the durable and efficient operation of fuel cells. Impurities are believed to cause various problems in the current state-of-the-art fuel cell designs, including catalyst poisoning and membrane failure. Additional process steps may be required to purify the hydrogen to meet industry quality standards.

Additional steps could also be needed if carbon capture and sequestration technologies are developed and utilized as part of this method of hydrogen production. Hydrogen produced from the SMR process includes small quantities of CO, CO_2, and HS as impurities and requires further purification. The primary steps for purification include:
1. Feedstock purification: This process removes toxic substances, including sulfur (S) and chloride (Cl), to increase the life of the downstream steam reforming and other catalysts. 2. Product purification: In a liquid absorption system, CO_2 is removed. The product gas undergoes a methanation step to remove residual traces of the carbon oxides. Recent SMR plants utilize a Pressure Swing Absorption (PSA) unit instead, producing 99.99 percent pure product hydrogen.

DRY CO_2 REFORMING PROCESS

Synthesis gas (syngas), is a mixture of H_2 and CO and is a building block for several important chemicals.

The CO_2 dry reforming of

natural gas produces syngas from the equation:

$$CO_2 + CH_4 \rightarrow 2CO + 2H_2$$

Syngas can be produced by reforming natural gas with CO_2 or steam. Partial oxidation of natural gas and heavier hydrocarbon feedstocks is another means of producing syngas.

Reforming of natural gas with CO_2 can produce syngas with a H_2/CO ratio of unity at 1,652-1,832°F (900-1,000°C) and 1-20 atmosphere pressure.

Group VIII metals such as nickel, Co, rhodium and ruthenium or Mo_2C are suitable as catalysts for natural gas CO_2 reforming. Nickel has a high tendency of coking under most reforming conditions, but is still a preferred option. Palladium and platinum offer a compromise between costs and good functionality.

Alumina, magnesia, silica, zirconia, and titania have been considered as support structures to the catalysts. Syngas can be produced with imported CO_2 or from captured and recycled CO_2. Syngas itself can then be converted into other products such as methanol, sulfur-free green diesel fuel and carbon.

HIGHER VALUE PRODUCTS

Synthesis gas is an equimolar mixture of CO and H_2. By adding H_2 to the reactant gas feed to establish the correct reactants ratio, it can be used to produce higher value products, most notably sulfur-free diesel using the Fischer-Tropsch process:

$$nCO + (2n+1)H_2 \rightarrow CnH_{2n+2} + nH_2O$$

It can also be used to produce methanol:

$$CO + 2H_2 \rightarrow CH_3OH$$

The required additional H_2 could be supplied by the steam reforming of CH_4 through the reaction:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

The dry reforming reaction is highly endothermic and so energy has to be supplied to drive it. Methanol is produced by the Synetix or ICI process in the temperature range 473-573 K, while reforming reactions are usually carried out in the temperature range 973-1,223 K.

Figure 9.
Integrated Solar Combined Cycle (ISCC) power diagram, Al Kuraymat, Egypt.

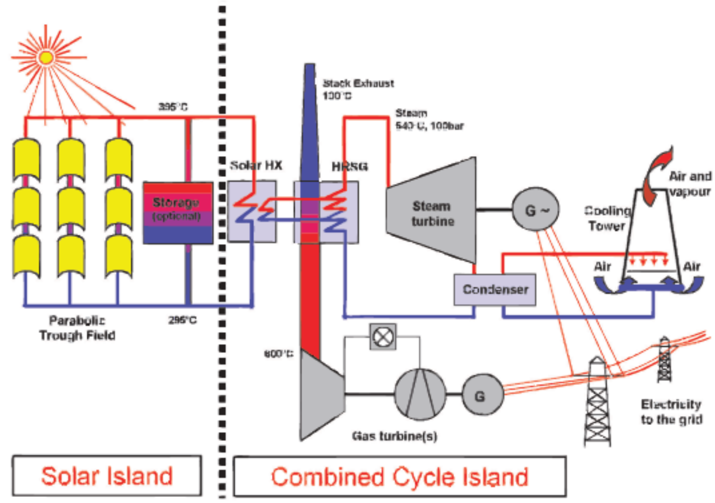
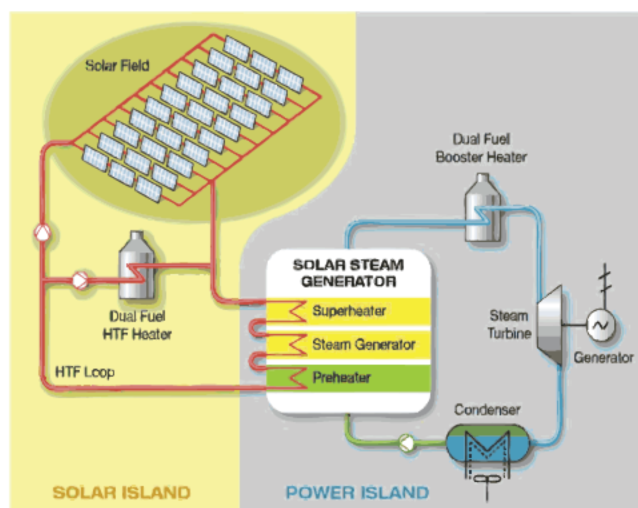


Figure 10.
Shams-1 (Sun-1) Integrated Solar Combined Cycle (ISCC) solar power plant project, United Arab Emirates (UAE) is supplemented with a natural gas heater unit. HTF: Heat Transfer Fluid.



INTEGRATED SOLAR COMBINED CYCLE (ISCC)

Conceptual plant designs with energy storage as well as supplemental heating to enhance the capacity factor as well as avoid the thermal cycling problem encountered in solar-only plants are under construction or in the design stage.

A world competition is ongoing on plans for the world's largest solar thermal power plant. The United Arab Emirates (UAE) is joining the fray with a massive concentrated solar energy project called Shams 1 or Sun 1 in Arabic.

The Masdar Company is teaming up with French oil company Total and Spanish solar company Abengoa Solar to build a 100 MW solar plant outside of Abu Dhabi in the UAE.

The plant is comprised of a solar field consisting of 768 parabolic trough collectors supplied by Abengoa Solar, plus a backup natural gas boiler to supply power when the sun is not shining. The plant will displace approximately 175,000 tonnes of CO_2 per year and directly contribute to the UAE's goal of seven percent renewable energy by 2020.

The new Integrated Solar Combined Cycle (ISCC) plant will be jointly owned by Masdar (60 percent), Total (20 percent) and Abengoa Solar (20 percent). Construction is expected to commence in the fall of 2010 and should take approximately two years to complete.

The project is located about 75 miles southwest of UAE capital Abu Dhabi and estimated to cost between $500 and $700 million and is expected to generate around 100 megawatts of power, and will be the world's largest Concentrating Solar Power plant (CSP) when completed by 2013.

Masdar currently operates a 10 MW Photo Voltaic (PV) power plant in Abu Dhabi. Unlike PV plants, which use solar panels that directly convert sunlight into electricity, ISCC reflect sunlight, usually with mirrors, heating liquids that produce steam to generate power and use natural gas to increase the capacity factor and overcome the intermittency problem.

THE ONGOING DEBATE

The USA Environmental Protection Agency (EPA) is studying hydraulic fracturing to determine whether it affects the fresh water supplies, and initial results are not expected until 2014.

Some jurisdictions are not waiting for official study results. New York City and the city of Syracuse, New York, have banned hydraulic fracturing in their watersheds, citing a study that concluded that hydraulic fracturing could pose "catastrophic" risks to the prized local water supply. New Jersey is considering a ban. The city of Pittsburgh has prohibited the practice within city limits. The Canadian province of Québec banned hydraulic fracturing completely, even though the province hosts a considerable shale gas potential. In Australia, hydraulic fracturing has been sweeping the Queensland countryside, and a furor is building among landowners. Shale exploration is similarly spreading quickly and causing strife across Europe.

Natural gas is blazing a trail as a bridge fuel along the road of the implementation of renewable energy sources and an energy economy where hydrogen is used as an energy carrier with fuel cells replacing the Internal Combustion Engine (ICE). Natural gas could be used in the steam reforming process to produce synthetic gas which is a mixture of H_2 and CO. Instead of Carbon Separation and Storage (CCS), the process of carbon dioxide reforming would use natural gas to turn CO_2 into a useful product such as green diesel fuel. To overcome the intermittence property of thermal solar energy, the Integrated Solar Combined Cycle (ISCC) alternative uses natural gas in hybrid plants under construction to provide power during the night period and on cloudy days.

Despite the remaining technological hurdles pertaining to environmental concerns, it must be admitted that the unconventional exploration for hydrocarbons, including hydraulic fracturing, is a phenomenon that will endure as a way to tap into the Earth's resources, even though it is coming under intense scrutiny. Natural gas is increasingly asserting its role as the bridge fuel of choice along the road of the implementation of renewable and carbon-free sources of energy. N

Dr. Magdi Ragheb is a professor of Nuclear, Plasma and Radiological Engineering at the University of Illinois at Urbana-Champaign, and has interest in energy systems in general. He has taught extensively since 1979, and is listed in Who's Who in America. *He has collaborated with numerous research institutions in the U.S., including Oak Ridge National Laboratory and Brookhaven National Laboratory.*