Space for Energy: The Role of Space-based Capabilities for Managing Energy Resources on Earth

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Abstract

In our search for a peaceful and feasible resolution to the energy problem, space-based capabilities can play an important role. This chapter discusses the nature of the energy problem as it stands today and examines some of the possible ways that space-based capabilities can be used to address the challenges and create new opportunities. The main focus of this chapter is on the role of space based capabilities for the management of terrestrial energy sources. The chapter also includes three case studies which focus on the use of EO data within the energy sector.

Keywords

Energy and environment, space-based capabilities, earth observation, solar energy, wind energy, fossil fuels, emissions trading, GEOSS.

1. Introduction

Throughout history, economic development has gone hand-in-hand with access to energy. Starting with solids such as wood and coal, moving to liquids such as plant oils and petroleum and then to gases such as natural gas, our species has mastered transforming the heritage of fossil fuels into increased living standards for the masses. Today, with the notable exceptions of nuclear energy and first-generation renewables such as biomass, our unquenchable thirst for energy is mostly met with seemingly abundant fossil fuels.

Energy statistics show that, as of 2005, fossil fuels constitute around 80% of the total primary energy supply[1] in the world (IEA, 2007). Even though new generation renewable energy systems, such as wind and solar energy, barely make a dent in today's global energy mix with under 1% of the total supply, their installed capacity has been increasing at a very steep rate during the last three decades. Between 1971 and 2004, the *annual* rates of increase for installed wind and solar energy capacity were 48% and 28%, respectively (IEA, 2007).

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[1] Total primary energy supply includes the energy used for all purposes, including transportation and electricity generation.

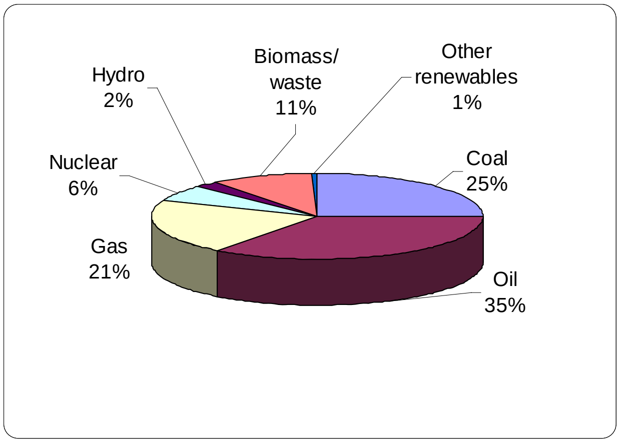

Figure 1: The global energy mix: total primary energy supply in the world for 2005 (Source: IEA, 2007)

Various projections regarding future energy scenarios provide a consistent outlook: fossil fuels will continue to dominate the energy mix for the next few decades. However, there is increasing evidence that this trend is not sustainable. Leaving all the debate of peak oil aside, the issue is not actually whether or not we will run out of fossil fuels soon. The current energy mix is not sustainable due to its huge strain on the environment. Furthermore, the distribution of fossil fuels around the world is a major source of political and military conflict. Access to clean, sustainable and uninterrupted sources of energy is increasingly becoming a challenge.

This trend forces us to develop innovative ways to use our fossil fuel resources more efficiently while reducing their impact on the environment. At the same time, a worldwide effort is underway to increase the efficiency and installed capacity of renewable energy systems. The ambitious “20 by 2020” objective (generating 20% of all energy consumed in Europe from renewable energy sources by 2020) of the European Union of is one of the leading examples of this trend.

1.1 Energy Policy Drivers

The three main policy drivers shaping tomorrow’s energy investments are energy security, environmental sustainability and industrial competitiveness[2]. A brief discussion of these policy drivers is necessary to illustrate the importance of space-based capabilities for the energy sector, and their impact along these three main axes.

Energy security simply means ensuring an uninterrupted, steady supply of energy. Given that most economies are not self sufficient and rely on energy imports, energy security is an important dimension of bilateral and international relations. However, it also relates to the management of domestic energy networks, maximizing national generation capacity and managing the transmission system in a safe and efficient manner.

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[2] One of the prominent sources which outline these three priorities is the European Commission’s Green Paper entitled “A European Strategy for Sustainable, Competitive and Secure Energy”, available at: http://ec.europa.eu/energy/green-paper-energy/index_en.htm

The second policy driver, environmental sustainability, is causing us to revisit some of our assumptions regarding the true cost of energy. As the Intergovernmental Panel on Climate Change report indicates (IPCC, 2007), our environment, including the climate, is under a rapid period of transformation. It is becoming increasingly clear that our current energy regime, relying mostly on fossil fuels with uncontrolled greenhouse gas (GHG) emissions is not sustainable and exacts a heavy toll on the environment. Furthermore, IPCC asserts that “Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations.” In other words, although there could be other factors contributing to Climate Change, human behavior is at the core of the problem.

Therefore there is an urgent need to develop technologies which can help us monitor and forecast the trajectory of these emissions, as well as technologies which can generate emission-free, low impact forms of energy.

Although our reliance on fossil fuel reserves is not likely to ease significantly in the near future, tomorrow’s energy rich nations may not necessarily be the ones who have been the lucky winners of the energy deposit lottery so far. Those who master next generation energy technologies will be in a position to address the first two policy drivers and, at the same time, achieve significant economic benefits by exporting these solutions to other parts of the world. The tremendous success of Germany in transforming nascent renewable energy industries into global export leaders is a case in point.

This competitive edge partially rests on developing technologies within a specialized area (such as more efficient solar cells), but it also requires system-based solutions and capabilities which will enable tomorrow’s energy networks to be designed and operated as efficiently as possible. This is precisely where space-based capabilities can add significant value and help develop such solutions and capabilities.

2. Energy from Space

During the first 50 years of the space age, amazingly creative, yet largely infeasible ideas (at least in the short-term) were proposed to generate energy from space. Solar power satellites and Helium-3 extraction from the lunar surface are just two of these proposed concepts.

One of the most consistent and plentiful sources of energy is solar radiation. In fact, as it will be discussed later, most renewable energy sources on Earth are a result of solar radiation. Proponents of solar power satellites argue that by constructing large collectors around Earth’s orbit and transmitting the generated energy in microwave form from Earth’s orbit to ground-based collectors, we can unlock an immense energy potential (see for example O’Neill, 1977). After many years of hiatus, there seems to be a renewed interest in this concept (see for example Macauley and Shih, 2007; NSSO, 2007; and Summerer et al., 2006).

Another space resource of interest is Helium-3, a light isotope of helium with two protons and one neutron, which can be used as fuel for future nuclear fusion reactors. Helium-3 is rare on Earth, but it can be found in significant quantities on other planetary bodies, including the Moon, where the pulverized surface material (the regolith) retains helium streaming from the Sun carried by solar wind (Schmitt and Kulcinski, 1993). In the future, it is conceivable that the upper layer of the lunar regolith can be mined to extract Helium-3, and then transported to Earth to fuel future nuclear power generation systems using fusion technology. It is important to note that, the other piece of the puzzle, nuclear fusion technology, is still in development and optimistic estimates point to mid-century for their commercial exploitation (New Scientist, 2006).

One of the main limiting factors of these space-based energy generation concepts is the cost of access to space. After decades of operations, only a modest decrease in launch costs was achieved. Today, launch costs to geostationary transfer orbit range from $10,000 to $50,000 per kilogram (Futron, 2002). This cost structure is a severe limitation for placing large masses on orbit, which are required for building solar power satellites or kick-starting large scale mining operations on the lunar surface. Therefore, commercial operations of solar power satellites and Helium-3 powered nuclear fusion require significant advances in these technology domains as well as strides in launch vehicle development and operations.

No doubt that, if there is continued interest in these concepts, human ingenuity will find a way to surmount these challenges and unlock the potential of these space-based resources in the long-run. In the meantime, however, there is a case to be made for concentrating on the use of our existing space-based capabilities for the service of the energy sector. There are plenty of ways in which space-based capabilities can help us manage our energy resources here on Earth.

3. Energy on Earth - Supported by Space

This line of analysis brings us to the premise of this chapter: in the coming decades, the benefit of space for the energy sector is very likely to aggregate over many different technologies and applications centered on Earth Observation (EO) and new generation exploration technologies instead of a single groundbreaking space technology. No doubt that satellite telecommunications and satellite navigation will also play an important supporting role in the energy sector, especially for day-to-day operations.

Many space agencies around the world are acting on the link between EO and the energy sector, and there are some international initiatives as well, most notably the Global Earth Observation System of Systems (GEOSS).

3.1 GEOSS

GEOSS is a worldwide effort which can pave the way for increased use of EO data and applications for various sectors of economic activity, including the energy industry. In February 2005, ministers from nearly 60 countries endorsed the 10-year implementation plan for this initiative. GEOSS is based on the concept of integrating data obtained from many different instruments including satellites, airborne and in-situ instruments. It is expected that EO will play a key role in this mix, and the majority of data will be provided by satellites (Lautenbacher, 2006).

Three of the nine societal benefit areas identified for GEOSS are directly related to the energy sector:

- Improving management of energy resources
- Understanding, assessing, predicting, mitigating, and adapting to climate variability and change
- Improving weather information, forecasting and warning

Within the GEOSS framework, in order to facilitate the use of EO for energy applications, an “Energy Community of Practice” (ECP) was formed. Areas covered under ECP are linked to many of the strategic and operational aspects within the energy sector. These areas include: siting of power plants and facilities taking into account environmental and sociological issues; optimized design of power systems and facilities; yield estimation and resource monitoring based on historic information; yield forecasts based on near real-time weather forecasting; operation and management of power plants, including automatic failure detection; and trading and monitoring of emissions credits[3]. Although an exhaustive discussion of these areas will not be provided within this chapter, some of them will be illustrated through the case studies.

3.2. Earth Observation Market Development Programme

The European Space Agency (ESA), started the “Earth Observation Market Development Programme” in 2000 for supporting the operational use of EO in different economic sectors. One of the main thrusts of this initiative is applications in the energy sector. Specifically, the EOMD programme supports demonstration projects which enable the partnership of smaller companies specialized in Earth Observation with larger downstream companies. A number of demonstration projects have targeted the needs of the energy sector with a particular focus on solar, wind and hydroelectricity (Mathieu, 2005).

4. Space and Renewable Energy

Space-based capabilities, especially EO, can help address some of the issues related to energy scarcity by helping us better manage the supply and demand of energy. On the supply side, EO helps us to conduct resource assessment and forecasting studies for developing new generation capacity, using both renewable and fossil-fuel based energy systems. On the demand side, EO can help with energy conservation efforts by helping us better understand the impact of various environmental parameters, such as temperature and humidity, on the use of energy (Gurtuna, 2006).

One of the possible ways of ensuring energy security is to use existing domestic energy resources more efficiently, and adopting new prospecting practices. Fossil fuel exploration efforts, by and large, aim to discover existing deposits. Renewable energy generation, on the other hand, is more about mapping the behavior of natural processes over time, and developing new technologies which can “harvest” the energy from these processes.

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[3] For more information, please see the GEOSS ECP website at http://www.geoss-ecp.org/

One of the major advantages of renewable energy sources is their global distribution: all countries around the globe have access to multiple sources of renewable energy. Therefore the issue is not having access to a particular energy source, but mastering the corresponding energy conversion process.

The Sun is the source of almost all renewable energy on Earth, with the exceptions of geothermal and tidal energy. Solar energy systems are based on converting solar irradiation into electricity or heat using photovoltaic and solar thermal principles. The uneven heating of Earth's surface by the Sun creates a pressure gradient in the atmosphere which in turn creates wind. The air above the equator is heated up by the Sun while the air around the poles is much cooler due to the angle of solar radiation reaching these regions. Since the density of air decreases with increasing temperature, the lighter air from the equator rises, causing a pressure drop around this region. This pressure drop attracts cooler air from the poles towards the equators, thus creating winds and eventually fueling wind power (Mathew, 2006). Solar heating and winds are two of the primary forces acting on the oceans and generating ocean currents and waves, major sources of marine renewable energy. Finally, hydroelectricity generation is dependent on the global water cycle and the atmospheric processes which trigger different forms of precipitation.

All of these natural processes, solar irradiance, wind, ocean currents and precipitation can be considered as the "fuels" of various energy conversion systems such as photovoltaics, wind turbines, wave/current turbines and hydro dams, respectively. One of the primary advantages of these systems is the cost of fuels: once the capital investment is made and the systems are operational, the operating costs are mainly based on maintenance requirements and are not affected by wide swings observed in the oil and natural gas prices.

However, relying on these natural processes also has its disadvantages. The energy output from renewable energy systems can fluctuate significantly over different time scales creating daily, seasonal and multi-year variations. Therefore, the ability to predict these fluctuations and to characterize the long-term behavior of these processes is critical to ensure overall system security and reliability.

There are numerous ways to achieve this objective, particularly where Earth Observation can play an important role. Two specific applications are resource assessment and forecasting.

4.1 Modern-day Prospecting: Resource Assessment and Forecasting

Resource assessment is performed to create an "inventory" of renewable energy at a given location by characterizing the resource using statistical methods and determining the potential for energy generation. Forecasting helps us understand the output fluctuations and develop tools for predicting these fluctuations.

Resource assessment is a very important prerequisite for making strategic decisions such as developing a policy framework for renewable energy and determining the optimal locations of renewable energy systems. These decisions are not only contingent on the availability of the resource, but also on many additional factors, such as the distance of the candidate site from existing transmission lines, roads and population centers.

Forecasting the expected energy output from renewable energy systems is also becoming increasingly important as the amount of installed renewable power increases in the electricity grids around the world. In order to manage the variations in renewable energy output efficiently and ensure grid safety, there are a number of issues that renewable energy generators as well as electricity system operators have to deal with.

One significant risk caused by intermittency is rapid loss of power which would normally be generated by renewables. Although the probability of all installed renewable energy systems in a given region to stop generation is very low, it is still conceivable. There are certain mitigation methods to control this risk: compensating for the loss by acquiring electricity from other generators connected to the grid and balancing the load by generating more power from other types of generation (especially natural gas, coal and hydro systems which can be ramped up quickly). These mitigation methods need to be supported by a well functioning forecasting system which can help foresee reductions in supply as well as changes in demand.

Case 1: Siting Decisions for Off-shore Wind Farms

In order to illustrate how EO can add value to strategic decisions in the energy sector, this section will examine the use of satellite data for off-shore wind resource assessment.

Global cumulative installed wind energy capacity reached 94 GW as of January 2008 (GWEC, 2008). Although this capacity is mostly supplied by onshore wind farms, off-shore wind farms are considered as one of the most promising renewable energy systems which can provide large amounts of clean energy. In fact, European Wind Energy Association has set a target of 300 GW wind energy capacity for Europe by 2030. Half of this amount, 150 GW, is expected to be supplied by offshore wind farms.

Currently, Europe is leading the off-shore market with operational wind farms along the coastlines of Denmark, Sweden, the UK and the Netherlands and many planned ones along the coastlines of Germany, Ireland and Spain (Knight, 2007). A number of factors are stimulating the interest in off-shore wind farms, including the scarcity of land which can be developed as wind farms, some very favorable wind conditions on the oceans and more reliable and powerful wind turbine designs.

Wind speed is a key input for resource assessment studies, since the energy output of a wind turbine is a function of wind speed. Both for onshore and off-shore wind resource estimation, historical wind speed data is crucial. The conventional way of acquiring this data is to install a meteorological mast (metmast) on location. These masts are equipped with various instruments to measure wind speed and direction, and they also have data loggers and data transmission systems (such as satellite uplink/downlink sets) for data storage and acquisition.

Due to the complexity of marine operations, the cost of installing and operating a single mast can be on the order of 750,000 euros a year (Mathieu and Hasager, 2007). Given that wind information from many different sites needs to be studied for a siting decision, the cost is prohibitive to install metmasts for each and every one of them.

The industry practice is to obtain at least one year's worth of data before a siting decision is made. Even though the metmast data can be very accurate for the year it was in operation, a one-year data set cannot necessarily capture the long-term variability characteristics of wind. In their comparative assessment of satellite derived wind speed data, Hasager et al. (2006) report that the annual wind speed averages can vary significantly, resulting multi-year variations of up to 14%. In other words, even though very accurate annual data may be acquired using a metmast alone, without use of other tools, such as meteorological models, the data for a given year may not be representative of the climatological averages. Therefore identifying multi-year trends is essential before a siting decision is made. Otherwise, investment decisions based on a single year's data can result in significant financial losses.

In order to capture longer-term variations, climatological adjustments are needed before metmast data can be used in decision-making (this requirement applies to other short-term data sources as well, regardless of their source). A relatively new technique for these adjustments is based on satellite data. For off-shore wind resource assessment, there are three sets of satellite instruments which can provide useful data: passsive microwave instruments (e.g., the Special Sensor Microwave/Imager - SSM/I), scatterometers (e.g., NASA's QuikSCAT satellite) and Synthetic Aperture Radar (e.g., RADARSAT series, ERS-2 and ENVISAT).

Although passive microwave instruments provide relatively low spatial resolution, they have been operational for a long time (in some cases providing data sets going back as early as 1987). Scatterometers and SAR are both active (radar) instruments and can provide all weather and night-time coverage capability as well as increased spatial resolution. Together, the complementary capabilities of these instruments can be very valuable for the feasibility analysis of an off-shore wind farm.

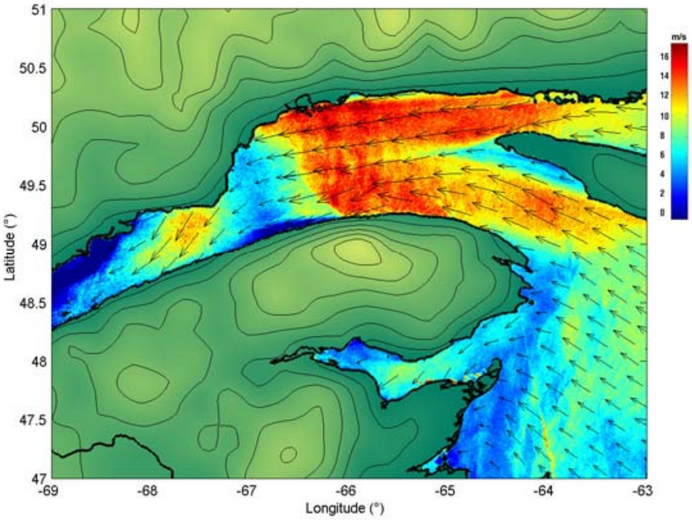

Figure 2: An off-shore wind speed map derived from Radarsat-1 data (depicting the Gaspe Peninsula in Quebec on April 24, 2003) Source: Philippe Beaucage, INRS, Canada, 2008

Research results in this area indicate that, from both reliability and data availability perspectives, satellite data can be used as a complementary source of information (see for example Hasager et al., 2006 and Beaucage et al., 2007). Satellite data obtained from multiple platforms show consistent wind speed values. Moreover, comparisons to meteorological mast observations are also encouraging, making satellite-based analysis a strong contender for pre-feasibility stage wind resource mapping activities.

Case 2: Solar Energy Resource Assessment

Solar energy is following the path of wind energy and rapidly becoming a viable form of renewable energy from both technical and financial perspectives. The installed capacity of both solar PV and solar thermal plants is rapidly increasing. During the last decade, Europe and Japan have invested heavily in solar energy systems and built significant capacity. Although other regions of the world have been lagging behind, momentum is building rapidly, especially in the U.S. and China.

Broadly speaking, there are two kinds of solar power systems: solar photovoltaic (PV) and concentrating solar power (CSP). Solar PV technology generates electricity by direct conversion of electromagnetic radiation into electrical current. CSP, on the other hand, relies on a thermal conversion principle, where the solar radiation is focused on a single point (or a small area) to heat a liquid which also stores the energy. This energy is then used to create steam to power a turbine. In addition to electricity generation, the same principle can also be used to heat water for residential or industrial use.

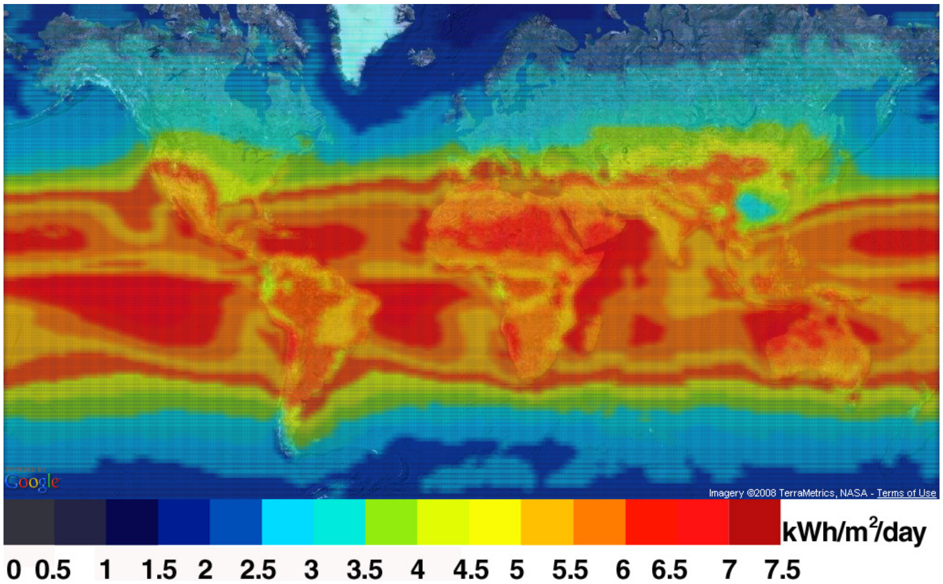

Figure 3: Global Horizontal Radiation (in kWh/m2/day) map based on 22 years of satellite observations (Source: Turquoise Technology Solutions Inc.; data source: NASA, TerraMetrics; map was produced using Google Maps API)

Understanding the variability of solar energy over time is an important step in increasing the share of solar energy in the overall energy mix. In Europe, especially in Germany, France and Spain, a number of R&D efforts are underway to use historical time series from satellite data to support solar energy projects, such as the ENVISOLAR project[4].

At the strategic decision-making level, a critical parameter for site selection of solar parks is solar irradiance, the “fuel” of such generation systems. For this purpose, meteorological satellite data for solar irradiance is used in combination with other earth observation capabilities such as Digital Elevation Models and cloud cover measurements (Schillings et al., 2004; Davison and Gurtuna, 2007). For site selection analysis, having access to long-term time series is highly desirable, since it can dramatically increase the accuracy of solar irradiance estimates for a given site (Mathieu, 2005). Therefore archived satellite data sets, such as the one used to produce the resource map in Figure 3, are particularly useful for pre-feasibility studies.

This capability can also be used to support operational decision-making: plant managers can compare the actual energy production with the estimates from satellites on a continual basis. A wide spread between these two values can help identify potential problems with the performance of solar plants (Schroedter-Homscheidt et al., 2007).

The data for solar energy resource assessment and forecasting studies come mainly from meteorological satellites at GEO, such as the European Meteosat series and the U.S. GOES satellites.

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[4] More information can be obtained at http://www.envisolar.com/

Once a solar energy generation plant is operational, companies generally install their own radiometric stations in order to acquire very precise, real-time radiation data. However, such instruments cannot be readily used for forecasts, since they are not forward-looking such as meteorological models based on satellite information.

Satellite-derived information has some obvious advantages over other methods for solar energy forecasts. Archived satellite data from Meteosat are available going back as far as 1985. This enables advanced statistical analyses which can provide the backbone of forecasting models. When used with cloudiness forecasts and other parameters which have an impact on solar irradiance (such as aerosols), these models can be very helpful in managing tomorrow’s large scale solar energy generation systems.

Recently, the interest in satellite-derived solar energy information has spread to many different sectors, including financial institutions. Today, such information is being used for strategic decisions such as site selection (e.g., map products), as well as site qualification (e.g., time-series products). ESA reports that time-series of at least 10 years are required by the banks in Spain as part of the due diligence for extending loans to solar energy investments (ESA, 2006). Given that the scale of such investments has reached the level of 200 million euros for a single project, the economic importance of these analyses becomes clear. ESA indicates that for most places in the world this due diligence process can only be achieved through the use of meteorological satellite data.

5. Space and Fossil Fuels

As discussed in Section 1, fossil fuels will continue to be the leading contributors to the global energy mix in the coming decades. Therefore it is imperative to explore possible ways in which space-based capabilities can help industries which are in the business of finding and extracting fossil fuels (i.e., oil & gas and coal industries) as well as industries which make heavy use of such fuels (e.g., aluminum and steel production, energy generation, etc).

Furthermore, in order to manage the impact of fossil fuels on the environment at a global scale, continuous monitoring of GHG emissions is required to model and forecast the evolution of atmospheric dynamics and the concentration of various gases and aerosols over time.

Oil and gas industry already makes extensive use of earth observation data from both passive (e.g., optical) and active (e.g., radar) instruments. In recent years, satellite-based hyperspectral systems have also been proposed. Currently, almost all of remote sensing satellites in orbit have either panchromatic or multispectral imagers, collecting data from a few spectral bands and with limited resolution. In contrast, hyperspectral imaging can enable data acquisition in contiguous narrow bands simultaneously (up to several hundred bands) in the electromagnetic spectrum (NRCan, 2005). The “Hyperion” instrument aboard NASA’s EO-1 satellite provided the first set of hyperspectral data from space in 2001.

Among the various users of hyperspectral maps are oil, gas and mining companies, and government authorities. Such maps can help define potential exploration targets. This application is of particular interest in areas where either no maps or generalized maps exist, such as arctic environments, and it can also assist in the detection of hydrocarbon micro-seepage.

Hyperspectral imaging can also be used to monitor oceanic and coastal zone regions for oil spills. Specifically, it can help us predict how oil spills disseminate in a body of water under current environmental conditions, and where it might affect sensitive sites. It can also be used to identify shoreline features and the severity of oil spills in environmentally sensitive areas such as coastal wetlands. It can even help us determine the pollutant type (e.g., crude or light oil). This information is useful for the cleanup crews to identify the best cleanup method, the environmental impact of burning oil, and to predict the flow path, dispersion rates, and the time before a slick hits the shoreline (Salem, 2001).

OECD reports that another space application for the oil & gas sector is the use of EO data to monitor pipelines and to assist in major energy infrastructure projects (OECD 2005). Finally, EO data can also be very helpful for day-to-day operations. For instance, Synthetic Aperture Radar data is routinely used to manage the risk posed by sea ice to offshore oil & gas platforms. A recent study (Davison and Gurtuna, 2007) has documented that satellite-derived sea ice information is an integral part of offshore oil & gas operations off the east coast of Canada.

Case Study 3: Emissions Credits

As discussed in Section 1.1, there is mounting scientific evidence demonstrating that our heavy reliance on fossil fuels is taking a toll on the environment. This impact, along with the continuing dominance of fossil fuels in our energy mix, forces us to explore new ways to curb GHG emissions.

Developing new energy systems with minimal emissions, as discussed in the previous two case studies, is part of the solution. However, in the short to medium term, given the modest amount of renewable energy output in our energy mix, it is clear that solutions targeting fossil fuels are also needed.

Proposed methods such as carbon capture and sequestration can help us operate fossil-fuel plants while decreasing their overall emission levels. In parallel to such technological innovations, there are also market-based mechanisms which can make a difference. These economic innovations function by putting a price on GHG emissions and creating incentives and/or penalties to change the behavior of emitters.

Cap-and-trade systems (also called emissions trading) is defined by IPCC as “a market-based approach to achieving environmental objectives that allows, those reducing greenhouse gas emissions below what is required, to use or trade the excess reductions to offset emissions at another source inside or outside the country” (IPCC, 2001).

In January 2005 the European Union launched Greenhouse Gas Emission Trading Scheme (EU ETS), with the primary aim of cutting industrial emissions within the EU. This multi-national system created interest worldwide and resulted in some very valuable lessons. The higher the price of permits that allow for extra emissions, the more incentive there will be for market participants to limit their GHG emissions. In April 2006, the price of permits dropped from 31 euros to around 12 euros (per tonne CO2), when it was revealed by national governments that power producers and other energy-intensive European industries were 44 million tonnes under the permitted limit for 2005, significantly below the expected level (Schiermeier, 2006). During subsequent trading sessions, the price of credits dropped even further. Critics argued that this was largely a result of overly generous emission caps set by the European governments.

As this experience demonstrates, the efficiency of any trading system in controlling GHG emissions is limited by political and regulatory risks to a certain extent. However, the success of these markets in reducing emissions is ultimately dependent on the market fundamentals. Currently, CO2 output constitutes the main price driver for permits, which in turn is a function of various parameters such as weather, fuel prices and economic growth (European Climate Exchange, 2007). Therefore, monitoring the level of CO2 output and incorporating this information into trading decisions can give a competitive edge to informed traders in this market while ensuring market efficiency.

Earth observation satellites can provide the required data to monitor the evolution of emissions. An international coordination entity, the Committee on Earth Observation Satellites (CEOS), has identified continuous monitoring of CO2 output and understanding the carbon cycle as priority areas. As indicated in the Earth Observation Handbook published by CEOS: "Since the dominant influence on future greenhouse gas trends is widely agreed to be the emission of CO2 from fossil fuel burning, an improved understanding of the global carbon cycle has become a policy imperative for the forthcoming decades, both globally and for individual countries." Although global observing systems for climate will involve multiple instruments, both terrestrial and space-based, CEOS expects that earth observation satellites will become the single most important contribution to global observations for climate (ESA, 2005). In the near future, coupled with more mature emission trading markets spanning both developed and developing economies, EO-based CO2 monitoring capability is likely to make a significant contribution to reducing GHG emissions.

6. Future Exploration Technologies

Some of the prominent energy technologies of today, such as photovoltaics and fuel cells, have a very distinct space heritage. At the beginning of the Space Race, in order to provide a steady supply of energy to their satellites, both the U.S. and the Soviet Union launched research projects to develop practical solar PV technologies. In 1958, the U.S. Vanguard I satellite was equipped with solar PV technology and solar panels become an integral part of spacecraft design (DoE, 2008).

As part of the U.S. Space Shuttle program, liquid hydrogen is used as fuel for rocket propulsion, and also as fuel for the fuel cells aboard the Shuttle fleet which provide electricity and water to the crew. Although NASA started using fuel cells in 1960s, it took almost three decades for this technology to diffuse to other sectors, such as automotive and energy generation (Gurtuna, 2005). The recent boom in the terrestrial solar market and the increasing use of fuel cells for industrial applications were, to some extent, enabled by the space investments made decades ago during the Apollo era.

Likewise, the renewed interested in space exploration, embodied by the Global Exploration Strategy (GES), may result in new space technologies which can be used for terrestrial applications in the coming decades.

The deliberations of 14 national/international space agencies resulted in the Global Exploration Strategy document which was published in May 2007[5]. GES emphasizes the importance of human exploration and outlines future strategies for international partnership in this endeavor. At least two of the priority technology areas identified within the GES are related to the energy sector: efficient power generation and energy storage, and planetary resource extraction and utilization. A sustained interest in human space exploration is likely to push the footprint of human presence from LEO to the lunar surface and other planetary bodies in due course. This expansion will no doubt trigger many innovative approaches for energy generation and storage, which may be one day be used for terrestrial purposes as well.

7. Conclusion

This chapter provided a broad overview of the role space technologies and applications play in the energy sector. Given the complexity of the energy problem and the limitations of our existing infrastructure, it is not realistic to expect a single breakthrough technology to emerge and meet all of the energy needs of the growing global economy. Although the dominance of fossil fuels will continue in the foreseeable future, it is clear that renewable energy sources have a lot of potential in addressing the environmental and energy security concerns. Therefore, a sensible approach is to develop a host of applications which will help us manage our existing fossil fuel resources more efficiently, and actively develop new-generation renewable energy sources in the meantime.

In this regard, the role of innovation cannot be overemphasized. By developing new technologies such as carbon capture, and new applications such as emissions trading, we can decrease the environmental impact of our energy mix, address energy security issues and create new industries. In this endeavor, space technologies and applications will also play an important role.

With all the promise of space exploration ahead of us and many space-based resources waiting to be explored, perhaps the single most important contribution of space activities will prove to be the mastery of managing the energy and environment balance of our home planet.

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√ List of Acronyms

CSP concentrating solar power
DoE U.S. Department of Energy
ESA European Space Agency
EO Earth observation
GEOSS Global Earth Observation System of Systems
GES Global Exploration Strategy
GHG Greenhouse gas
GOES Geostationary Operations Environmental Satellite
IEA International Energy Agency
IPCC Intergovernmental Panel on Climate Change
NASA National Aeronautics and Space Administration
OECD Organisation for Economic Co-operation and Development
PV photovoltaic(s)
SAR Synthetic Aperture Radar

√ About the Author

Ozgur Gurtuna is the founder and president of Turquoise Technology Solutions Inc., a Canadian company providing services in the energy, environment and aerospace sectors. He is active in both professional and academic domains, and has a keen interest in developing innovative solutions by merging multiple technology areas. He obtained his Ph.D in Operations Research from the joint Ph.D. program in Montreal (this program is administered by four Canadian universities: Concordia, HEC, McGill and UQAM). His areas of expertise include space applications for the energy sector, emerging technology markets and quantitative analysis in decision making (covering areas such as optimization, simulation and mathematical modeling). He is also a part-time faculty member at the International Space University, lecturing on topics related to the business and management aspects of space activities.