Available online at www.sciencedirect.com
SCIENCE DIRECT®
Space Policy 20 (2004) 17–24
Space Policy
www.elsevier.com/locate/spacepol

The benefits of remote sensing for energy policy

Avery Sen*

Master's candidate/Researcher, Space Policy Institute, Elliott School of International Affairs, George Washington University, Washington, DC 20052, USA

Abstract

A strong remote sensing regime is a necessary component of any contemporary national or international energy policy. Energy is essential to the functioning of modern industrial society, and as such it is the responsibility of governments to produce sound national energy policies in order to ensure stable economic growth, ecologically responsible use of energy resources and the health and safety of citizens. Comprehensive, accurate and timely remote sensing data can aid decision making on energy matters in several areas. This paper looks at the benefits that can be realized in resource exploration, weather forecasting and environmental monitoring. Improvements in the technology of remote sensing platforms would be of great value to buyers of energy, sellers of energy and the environment. Furthermore, the utility of such information could be enhanced by efforts of government agencies to communicate it more effectively to the end-user. National energy policies should thus include investments not only in satellite system hardware to collect data, but also in the services required to interpret and distribute the data.

1. Introduction

Public perception of human space activities is often focused on human space flight rather than on other areas of space science and technology. Human space missions are certainly more visible in popular culture because of their symbolic and inspirational character, which leads many to believe that the space program, at least the American space program, begins and ends with astronauts. For those who are not intimately connected to the space industry—everyday citizens, policy makers and industry leaders—questions may arise as to the utility of public funding of space programs. Should we be spending as much as we do on astronauts? Space may be a glorious endeavor, but is it useful? Indeed, one of the immediate reactions to the recent *Columbia* Shuttle tragedy was to question whether America should even have a space program at all.

Despite what many of the lay public may believe, ambition and achievement in space are not limited to human flight. Aside from the USA and Russia, all spacefaring nations are active without human transport systems. One can argue that robotic projects have progressed the most and have been the most successful since the dawn of the space era. Earth observation satellites in particular consistently yield enormous practical benefit to those here on Earth. Whether more or less government support should be given to human versus robotic projects is a topic of much debate, but not the immediate interest here. Rather, the subject of this paper will be to illustrate the value posed by spaced-based remote sensing technology to one particularly important domain of public and private concern: energy.

By analogy, one can easily see the benefits of space technology to the information technology industry—not to mention the economy and public at large—provided by the development of communication satellites. The development of this vital part of the telecommunications infrastructure could not have been achieved without government assistance and collaboration with industry at the outset with projects such as AT&T's Telstar, launched in 1962. An industrialized society's need for reliable, inexpensive and safe energy is at least as important as its need for services of communication. Energy is the single most important resource to industrial society simply because of its universal application. Besides economic impact, energy cost and availability also factor into quality of life issues that can directly affect the public through utility prices and power outages. The exploration for and transportation of energy resources, the production of energy and its transmission must all fit within the environmental

*3220 17th Street, NW, Apartment 109, Washington, DC 20010, USA. Tel.: +1-917-767-6815.

E-mail address: averysen@gwu.edu (A. Sen).

0265-9646/$ - see front matter
doi:10.1016/j.spacepol.2003.11.003

regulations set by local, national and international law. Many of these aspects of energy policy intersect with each other, but all fall under the responsibility of government. They are likewise all affected by, and can be improved with, remote sensing technology.

The voting public, its democratically elected representation, and leaders in energy industries should be aware of the role that remote sensing plays in energy production and consumption in order to judge whether or not to support the advancement of such technology in the future. Public space agencies around the world must remember where their support comes from, and that most people not affiliated with space are less concerned with human colonization of the planets than with Earthly applications and the bottom line. To this end, space agencies must actively demonstrate the benefits that remote sensing can provide to specific interests such as national and international energy policy. Information should be made clear enough for non-specialists to digest, and channels of communication should flow both ways so that these agencies can learn how to improve remote sensing products though suggestions from the public, policy makers and industry leaders.

This essay will hopefully serve as an extension of this process by providing examples of the utility of remote sensing to energy policy in three sections: economic, public welfare, and environmental benefits. The reader should be aware that such lines are drawn more for convenience than because of intrinsically determined categorical fact. As stated above, there is much crossover within these areas, often thanks to the multiple benefits, direct and indirect, of single remote sensing applications. The benefits to energy policy from remote sensing are realized through resource exploration, weather forecasting and environmental monitoring. Final thoughts and policy recommendations will follow in the conclusion.

2. Economic benefits

Publicly funded remote sensing systems can yield tremendous value to companies that produce fuels, generate electricity and transmit that electricity to consumers. Because we need energy in our homes, offices and manufacturing facilities, savings to energy industries translate to savings in energy costs across the entire economy. To begin to understand how much economic impact remote sensing has, we must measure the value of specific applications.

Satellite imaging is a convenient and cost effective method for resource producers to prospect for undersea hydrocarbon reserves. Petroleum deposits underneath the sea floor, if shallow enough, will seep up into the water. This seepage changes the reflective qualities of the water surface above, making it visibly different from the surrounding ocean. Scouting for these naturally occurring oil slicks is difficult and time consuming by boat. It is faster by airplane, but more expensive and may require fly over rights over other nations. The use of pictures from space can facilitate conducting these surveys by providing views of large areas, reducing the cost per unit area and avoiding international permitting procedures.

With this technique in mind, The Earth Satellite Corporation partnered with NASA through the Earth Observation for Commercial Applications Program (EOCAP) to create a seep detection product they could sell to the petroleum industry. The result of this collaboration was an advanced software package called the Seep Enhancement Algorithm (SEA), which is applied to images from Landsat, ERS-1 and SPOT satellites to highlight both the spectral and textural qualities of seepage in images of ocean water. Analysts can then visibly identify areas of ocean seep and can even distinguish it from pollution or phytoplankton blooms, which can create similar slicks on the surface of water. The cost of this enhanced imagery to EarthSat's customers is a modest $3/km^2, making it more cost effective than seismic, geochemical or low-altitude airplane surveys. The seep images can also be integrated with gravity and bathymetry data to create three-dimensional, comprehensive exploration maps of seepage location with the underwater terrain.[1]

Remote sensing products can also provide substantial value to energy suppliers and consumers simply through accurate weather forecasting. The petroleum industry conducts much of its business on open waters, making it particularly vulnerable to severe weather such as hurricanes. The development of offshore oil and gas reserves accounts for 22% and 27% of the United States' domestic production, respectively, and federal royalties and taxes on this production average $4 billion per year.[2] The crews of offshore oil drilling platforms must secure the rigs and evacuate in preparation for hurricanes. The drilling companies incur costs resulting from deferred production, crew transport, damage assessment and repairs. Companies regularly include 5–7 days of weather-related production losses in their business plans, but improved hurricane tracking could save them 3 days of unnecessary downtime at an estimated value of $15 million per day.[3]

[1] "Offshore Hydrocarbon Detection Using Seep Enhancement Algorithm (SEA)," Earth Satellite Corporation website, available at: http://www.earthsat.com/geo/oil&gas/hydrocarbon_SEA.html. Accessed 12 March 2003.

[2] "Economic Contributions," Pew Oceans Commission, available at: http://www.pewoceans.org/articles/2001/10/04/brief_19075.asp. Accessed 21 February 2003.

[3] Mary G. Altalo, Michael Mondshine, Jette Findsen, Julie Doherty, Christopher Mahoney, and William Keene, "Defining the Requirements of the US Energy Industry for Climate, Weather, and Ocean Information," Science Applications International Corporation, July 2000, p. 29.

Other sectors of the petroleum industry are also affected by extreme ocean weather. In response to official hurricane evacuation warnings, oil refineries located in coastal regions must undertake shutdown precautions similar to offshore rigs, with 4-day minimum downtime requirements and similar economic consequences. This is very important in the USA, which leads the world in refined petroleum products (at 23% of the world's total output) and where more than one third of the petroleum refineries are located on the Gulf Coast.[4] The transport of oil is also susceptible to the effects of extreme weather because so much of it is done via ocean-going vessels. The USA imports 3.3 billion barrels of oil every year, and interruptions to this supply could be very costly to both producers and consumers.[5] More accurate ship routing generally provides cost savings, but accurate forecasting of hurricanes and severe ocean storms is essential to the navigation and timing of maritime commerce.

A number of instruments on board NASA satellites are used for tracking hurricanes. The QuikSCAT satellite, launched in 1999, has the SeaWinds instrument for measuring ocean wind vectors and is particularly well suited to this task. The Earth Science Enterprise (ESE) at NASA expounds upon a suite of instrumentation available for hurricane monitoring:

> NASA and NOAA researchers have shown that remotely sensed wind speed and direction from QuikSCAT can help detect tropical depressions and hurricanes up to 46 hours earlier than current methods. Hurricane cloud monitoring and wind profile and prediction products from scatterometer (QuikSCAT), Special Sensor Microwave/Imager (SSM/I), Topex/Poseidon, Shuttle Radar Topography Mission (SRTM), Landsat, Atmospheric Laboratory for Applications and Science (ATLAS), and the Sea-viewing Wide Field-of-View Sensor (Sea WIFS) contribute to predicting candidate locations for hurricane landfall and surge, and provide assessments of damage and secondary impacts.[6]

The data from these satellites yield weather forecasts that are extremely valuable for the energy industry for reasons discussed above. The value obviously extends to other sectors of the economy as well as to public safety. These benefits will only increase in the future. Current technologies allow for the prediction of hurricane landfall within 400 km and two to three days. NASA/ESE goals for 2010 include improving this capability to within 100 km.[7]

In addition to accurate forecasts of extreme weather, better prediction of day-to-day weather can also be extremely valuable to the energy industry. Cold and hot weather will increase energy demand because of heating and air conditioning needs. Inaccuracies in temperature forecast will mean that utilities will generate either too much or too little energy; profits are lost in both cases. An error of 1°F in a prediction of tomorrow's temperature will not translate to a significant lack or glut of electricity if the temperature range is between 60° and 75° Fahrenheit (16°–24°C). However, for temperatures below 0°F and above 80°F (below −18°C and above 27°C) there can be 350 MW of excess or insufficient electricity generated for every 1°F error.[8] The exact cost of an imperfect forecast will depend on the market price of electricity, but on days like 24 January 2003 the price ran up to $135/MWh,[9] which could mean a cost of over $1 000 000[10] per degree day.

Advanced remote sensing technology could reduce these costs through more accurate prediction of day-to-day weather. NASA/ESE plans to use satellite data and powerful computing platforms to improve daily weather forecasts, including temperature. Today's forecasts are 93% accurate three days ahead and 62% accurate seven days ahead. NASA's goals for 2010 are to achieve a five-day forecast with >90% and a 7–10 day forecast with 75% accuracy.[11] These expectations imply that next-day temperature forecasts would likewise be statistically strengthened.

There are currently efforts at NASA to try to demonstrate the value of remote sensing data for energy needs. A NASA/ESE project called Prediction Of World Energy Resources (POWER) has been proposed to coordinate with other government agencies, energy industry associations and individual companies to make better use of NASA meteorology and solar radiation data. POWER would assist both the energy industry and government decision support systems. ESE makes several interesting predictions as to the benefit that POWER services could provide to the United States economy.

[4] Mary G. Altalo, Michael Mondshine, Jette Findsen, Julie Doherty, Christopher Mahoney, and William Keene, "Defining the Requirements of the US Energy Industry for Climate, Weather, and Ocean Information," Science Applications International Corporation, July 2000, pp. 31–32.

[5] "An Assessment of the US Marine Transportation System, A Report to Congress," US Department of Transportation, September 1999.

[6] "Science for Society: Benchmarking the use of Earth System Science Results for Decision Support," NASA Earth Science Enterprise, February 2003, available at: http://www.earth.nasa.gov/eseapps/natappin.htm. Accessed 3 March 2003.

[7] "Earth Science Enterprise Applications Strategy for 2002–2012," National Aeronautics and Space Administration, January 2002, p. 2.

[8] Patrick Walshe, Tennessee Valley Authority Meteorologist, "Temperature and Demand Forecasting in a Large Utility," available at: http://www.esig.ucar.edu/electricity/workshop/Presentations/pdf/Walshe.pdf. Accessed 21 April 2003.

[9] Patrick Walshe, personal communication, 21 April 2003.

[10] Calculation:
$350\,\mathrm{MW}/^{\circ} \times 24\,\mathrm{h/day} \times \$135/\mathrm{MWh} = \$1134{,}000/\mathrm{deg.day}$

[11] "Earth Science Enterprise Applications Strategy for 2002–2012," op. cit., p. 2.

For instance, satellites such as ACRIMSAT and the aforementioned QuikScat yield solar irradiance and sea wind data, respectively, that would be very valuable for generating energy with photovoltaics and wind turbines. Using energy demand and cost estimates from the Department of Energy (DoE) and assuming a growth rate of 25% for solar and wind power, ESE calculates the yearly POWER benefits to this part of the renewable energy industry to be \$1.5 billion by 2010 and \$7.13 billion by 2017.[12] Remotely sensed weather data also affect the production of fuels from agricultural sources, such as corn-derived ethanol. Projections of the yearly benefits to the biomass energy industry, also assuming a growth rate of 25%, show benefits of \$3.32 billion by 2010 and \$15.8 billion by 2017 (see footnote 12). ESE sees further value of POWER to energy resource planning for the combined energy market (including fossil and nuclear sources) as well as to the architecture and commercial building industries through energy efficiencies in office buildings. In total, they estimate the benefits to the US energy industry over the period 2002–2017 to be \$153 billion, with an error margin of $\pm 50\%$. Total costs to NASA over this period are assumed to be \$12 million, yielding an overall benefit/cost ratio for the POWER project of $\sim$12,400:1 $\pm 50\%$ (see footnote 12). These predictions are preliminary and very optimistic, but if true this would represent a spectacular value to industry—\$77 billion even at the low end of the spectrum.

3. Public welfare benefits

In the long term world energy demand will rise with population growth, and energy supply from traditional sources will diminish. The future energy supply and demand function could have serious consequences for global public welfare. Increasing population with finite energy resources means that the cost of energy is going to go up and standards of living are going to go down. The US Department of Energy predicts that, even if world population stabilizes at 10 billion, with the average person consuming a meager 3 kW per person, global energy demand will surpass supply by 20% by 2030.[13] The gap widens at an accelerating pace thereafter because of the exhaustion of fossil fuel reserves. Modern industrial societies are dependent upon reliable energy and inadequate energy availability poses direct risks to public health and welfare. Blackouts can have disastrous effects by shutting down traffic lights, medical facilities, refrigeration systems, etc. Energy shortages in the future will also cause price volatility and could contribute to political tension around the world, leading ultimately to concerns of national and international security.

Increased energy supply and greater supply- and demand-side efficiencies will be essential to solving this problem. Remote sensing technology can make a significant contribution to this end. As noted in the previous section, the exploration of traditional and renewable energy resources, fuel production, electricity generation, transmission and distribution can all be made less costly and less wasteful through the use of earth observation systems. The primary benefits of remote sensing for these functions are easily measured in dollars and cents, but the secondary benefits to public welfare—for the very same functions—are much broader and have long-term effects on society.

There is also a relatively recent short-term obstacle to stable energy costs and reliability: deregulation of the electric power industry. This is already occurring in the USA and could potentially happen in Europe as well. Electric power transmission and distribution systems are highly complex structures. The ability to control the power grid will become even more difficult as a result of deregulation. Management of the system will be complicated by a flood of new, independent energy generators using a variety of resources, as well as increased distribution of both generators and users across regions. This situation can easily lead to energy shortfalls, bottlenecks, price spikes and blackouts. Such was the case in California a few years ago when grid management problems were exacerbated by the foul play of some energy traders manipulating the energy market, creating artificial shortfalls and bottlenecks. Yet another contributing factor to California's problems was an unusually warm El Niño summer. Had a more effective system been in place to forecast and act upon seasonal weather conditions, the pressure on California's power grid could have been eased. Remote sensing technologies for meteorology can play a central role in power grid decision making, and thus increase reliability for energy consumers.

Researchers at Sandia National Laboratories and the Pacific Northwest National Laboratory believe that deregulation will significantly add to the uncertainties that already exist in electricity distribution and believe that "without comprehensive data, there will be no capability to predict reliability and maintain reasonable planning activity".[14] This uncertainty will be a major

[12] Charles H. Whitlock and Paul W. Stackhouse, Jr., "An Estimate of NASA/ESE/POWER Program Benefits to the US from 2002 through 2017," 3 June 2002. Obtained through Jackson D. Collier, Outreach and Applications, NASA's Earth Science Applications Division, Jackson.D.Collier@nasa.gov.

[13] "The US and ITER: The Path to Fusion Energy," Office of Science, Department of Energy. Available at: http://ofes.fusion.doe.gov/ITER/ITER%20Brochure_final.pdf. Accessed 27 February 2003.

[14] M. Ivey, A. Akhil, D. Robinson, J. Stamp, and K. Stamber of Sandia National Laboratories and K. Chu of Pacific Northwest National Laboratory, "Consortium for Electric Reliability Technology

problem unless other uncertainties are reduced elsewhere. Weather and climate are a major source of uncertainty in energy generation, transmission and system load. They affect generation availability of hydroelectric, solar and wind sources. The capacity to transmit electricity through power lines can be hindered by inefficiencies resulting from high ambient temperature, or it can be disrupted completely by damage from severe winds, lightning or ice storms. In addition, temperature, precipitation and cloud cover can all increase energy use and thus the load put on the system.

One conclusion of the Sandia/Pacific Northwest report is that new technologies will be needed to support a new decision-making framework for management of the electric power grid operation. Among the necessary technologies will be "new information sources, including real-time monitoring information, probabilistic component information, and historical or statistical information for large systems".[15] Advanced remote sensing technologies could contribute to this need by providing increased weather forecast accuracy through greater spatial, temporal and spectral resolution of data from meteorological satellites.

Satellite derived weather data is important for energy consumers in the developed world, but can be even more so for those in developing countries. In many parts of the globe there simply is no electrical power grid for the local population to connect to and the price of fuel for cooking is often more expensive than the food itself. A leading energy option for people in these regions is small-scale, localized energy generation from solar or wind energy. Most developing countries are located near the equator, making them particularly well situated to harvest solar radiation. Unfortunately, relatively few ground-based weather stations and less-than-perfect datasets make it difficult to determine the viability of renewable energy projects in remote parts of these nations. To assist researchers, non-profit organizations and private companies make these decisions, NASA/ESE (in partnership with DoE and industry) makes its archives of satellite weather data open to the public.

Surface meteorology and Solar Energy (SSE) data sets are provided free to anyone with access to the internet. The most recent SSE release contains satellite data of surface solar energy, temperature, surface pressure, relative humidity, and wind speed for the entire planet (at a 1° latitude by 1° longitude spatial resolution) and from the years 1983–1993 (at a monthly temporal resolution).[16] These data can be used for positioning and sizing of photovoltaics, wind turbines, battery storage systems and to assist solar–thermal applications such as home construction and solar cooking. Satellite-derived weather datasets such as SSE will simultaneously benefit industries that manufacture and sell renewable energy technologies to both the developing and developed world.

Urban growth is another public welfare issue which affects the local energy demand of populations in cities around the world. The simple concentration of people into urban areas will increase the electricity load requirements of those areas, and the utilities will have to meet these needs. Replacing natural vegetation with concrete and asphalt can alter local climates and further affect energy demand. Greater energy production from fossil resources results in greater pollution in these areas, decreasing the quality of life for inhabitants. Wide-view orbital imaging from satellites such as Landsat and SPOT can monitor urban growth and provide municipalities with a useful tool for forecasting future energy demand. Pheonix, Arizona, as well as other cities across the USA, have collaborated with NASA on using Landsat data to manage their own community growth.[17]

4. Environmental benefits

Comprehensive energy policy not only takes into account the positive effects of energy use, but the negative ones as well. Most energy is generated from the burning of fossil fuels, a major consequence of which is air pollution that contributes to acid rain, urban smog and global climate change.[18] The fuels themselves can also cause great damage if there are accidents during transport. The recent sinking of an oil tanker off the shores of Spain, for example, resulted in disaster for coastal ecosystems and economies. In order for governments to make informed decisions about the role of

(*footnote continued*)
Solutions, Grid of the Future White Paper on Accommodating Uncertainty in Planning and Operations," prepared for the Transmission Reliability Program, Office of Power Technologies, Assistant Secretary for Energy Efficiency and Renewable Energy, US Department of Energy, 30 August 1999, p. 19.

[15] M. Ivey, A. Akhil, D. Robinson, J. Stamp, and K. Stamber of Sandia National Laboratories and K. Chu of Pacific Northwest National Laboratory, "Consortium for Electric Reliability Technology Solutions, Grid of the Future White Paper on Accommodating Uncertainty in Planning and Operations," prepared for the Transmission Reliability Program, Office of Power Technologies, Assistant Secretary for Energy Efficiency and Renewable Energy, US Department of Energy, 30 August 1999, p. 21.

[16] Charles H. Whitlock, Donald E. Brown, William S. Chandler and Roberta C. DiPasquale of Science Applications International Corporation, Nathalie Meloche and Gregory J. Leng of Natural Resources Canada, Shashi K. Gupta and Anne C. Wilber of Analytical Services & Materials, Inc., Nancy A. Ritchey of Computer Sciences Corporation, Ann B. Carlson, David P. Kratz, and Paul W. Stackhouse of NASA Langley Research Center, "Release 3 of the NASA Surface Meteorology and Solar Energy Data Set for Renewable Energy Industry Use," available at: http://eosweb.larc.nasa.gov/cgi-bin/sse/, accessed 1 April 2003.

[17] Presentation of Ghassem Asrar to IAFF 224: Issues in US Space Policy on 3 February 2003.

[18] Altalo et al., op. cit., p.67.

pollution in energy policy, or whether to enter into international environmental treaties like the Kyoto Protocol, they must have a reliable knowledge base from which to draw. Remote sensing technologies can aid the science required to understand the relationship between pollutants and the environment. In addition, they can assist in preventing pollution disasters and managing such disasters when they occur.

Carbon dioxide is the primary waste product of fossil fuel burning and as a greenhouse gas it plays a major role in anthropogenic global warming. Plant life on Earth requires carbon dioxide to survive and can thus act as a "carbon sink" to sequester the carbon pollution, but the degree to which this can occur is still uncertain. NASA currently uses satellites to measure the Earth's carbon "metabolism." The Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra and Aqua satellites can produce composite maps of the Earth's net carbon production every eight days. The instrument's high spectral resolution allows it to see the difference between the amount of carbon dioxide that is absorbed by vegetation through photosynthesis and emitted through respiration.[19] This kind of monitoring is essential to discovering trends in global carbon dioxide levels and for determining the capacity of the natural environment to absorb man-made carbon dioxide.

Satellites can also provide an ideal platform for directly measuring the atmospheric content of greenhouse gasses resulting from the combustion involved in energy generation. The National Space Development Agency of Japan (NASDA) [now part of JAXA] has made significant efforts in this area. The Interferometric Monitor for Greenhouse Gases (ING) that flew aboard NASDAs original ADEOS satellite (now inoperative) observed the three major greenhouse gases: carbon dioxide, methane and nitrous oxide.[20] The ADEOS-II uses another instrument called the Improved Limb Atmospheric Spectrometer-II (ILAS-II) to make stratospheric observations of nitrous oxide and methane. ILAS-II also measures levels of nitric acid, a product primarily of coal combustion that contributes to acid rain.[21]

The Space agencies of Europe, Japan and the USA are all proposing next-generation satellite systems for monitoring greenhouse gases and global warming. As part of their Global Monitoring for Environment and Security (GMES) initiative, the European Space Agency (ESA) will incorporate an instrument called MethMOnitEUr onto one of its future satellites specifically for observing atmospheric methane levels in the European region.[22] NASDA's proposed Global Change Observation Mission (GCOM) would also detect atmospheric carbon dioxide and methane within the larger context of integrating our understanding of the Earth's energy, water and material cycles.[23] NASA plans to launch the Orbiting Carbon Observatory (OCO), which would make the first global dry air mole fraction measurements of carbon dioxide from space and would have an accuracy of one part per million.[24]

Environmental regulations at the national and international level may lead to higher resolution remote sensing instruments for observing atmospheric chemistry at specific locations on the earth and at specific altitudes. Governments could utilize such technology to enforce pollution laws and energy utilities could use it to ensure that they are staying in compliance. In its report "Defining the Requirements of the US Energy Industry for Climate, Weather, and Ocean Information," the Science Applications International Corporation sees a role for satellites in treaties such as the Kyoto Protocol:

> Adherence to global protocols on emission reductions and energy consumption will be self-monitored and reported based on a mass balance evaluation of fuel consumption. There will be strong incentives for nations and entities to underreport fuel consumption and emissions… Large power plants and industrial sites will be responsible for anywhere from one-half to two-thirds of all carbon dioxide emissions and spot monitoring may be possible. A development of a system to assist in the monitoring of power plant and industrial park emissions via satellite or some other means would greatly facilitate the reporting process.[25]

This kind of orbital spot monitoring could also benefit both industry and environment by providing more reliable data for the emissions trading market. Accurate scales in any market are valuable to both buyers and sellers.

[19] "NASA Satellite Measures Earth's Carbon Metabolism," Goddard Space Flight Center, The Earth Observing System Project Science Office, 22 April 2003, available at: http://eospso.gsfc.nasa.gov/newsroom/viewStory.php?id=416. Accessed 22 April 2003.

[20] "'Midori' Advanced Earth Observing Satellite ADEOS," National Space Development Agency of Japan, available at: http://www.nasda.go.jp/projects/sat/adeos/component_e.html. Accessed 22 April 2003.

[21] "Outline of ILAS-II," National Institute for Environmental Studies, available at: http://www-ilas2.nies.go.jp/en/ilas2/index.html. Accessed 22 April 2003.

[22] "Global Monitoring for Environment and Security," European Space Agency, available at: http://earth.esa.int/gmes/. Accessed 23 April 2003.

[23] "Global Change Observation Mission (GCOM) SGLI (Second-generation GLI)," Office of Satellite Technology, Research and Applications, National Space Development Agency of Japan, available at: http://sharaku.eorc.nasda.go.jp/GLI/meet/2001/11.pdf. Accessed 22 April 2003.

[24] "Orbiting Carbon Observatory," Earth System Science Pathfinder, Goddard Space Flight Center, NASA, available at: http://essp.gsfc.nasa.gov/oco/index.html. Accessed 10 April 2003.

[25] Altalo et al., op. cit., p. 69.

Global climate change is perhaps the most significant long-term environmental effect of energy use from traditional fuels, but important short-term consequences exist as well. On 19 November 2002 the oil tanker *Prestige*—carrying more than 20 million gallons of oil—split in half off the coast of Spain, releasing its cargo into the Atlantic Ocean and onto Spanish shores.[26] This is the most recent and visible example of man-made mineral oil spills, which can happen accidentally because of tanker damage or intentionally through illegal tanker discharges. The necessary task of monitoring spills can be done with aerial surveys, but these are expensive for large areas and limited to daylight hours and good weather conditions. Satellites are much more convenient and cost-effective in identifying and tracking oil slicks with synthetic aperture radar (SAR) instruments. Because oil smoothes the surface of water, the back-scatter of radio waves emitted by SAR is dampened and oil slicks appear as dark patches on images of ocean water. Radar is an active system, emitting its own "light" and eliminating the need for reflected sunlight. In addition, cloud cover is transparent to radio waves, thus allowing SAR to operate even in bad weather. The Mediterranean Sea is a high traffic waterway for oil tankers and so Europe has a particular interest in this technology. ESA has put SAR equipment on ERS-1, ERS-2 and Envisat satellites,[27] which were used extensively in the days following the breakup of the *Prestige*. ESA provided daily SAR images from ERS and Envisat to relief agencies and to the European Commission.[28]

Remote sensing applications also exist for the construction and maintenance of gas and oil pipelines. Operational and regulatory requirements of pipeline companies necessitate inventories of their facilities, mapping, pipe inspections and environmental reporting. To aid them in these processes, companies often contract out for services of automated mapping, facilities management and geographic information systems (AM/FM/GIS). The Massachusetts-based Algonquin Gas Transmission Company, for example, hired the James W. Sewall Company to provide such a service for them. The Sewall Company entered into a partnership with NASA through EOCAP to create an AM/FM/GIS tailored to their customer's needs. The result was a product called Monitoring Algonquin Pipeline System (MAPS), a computerized system for storing and retrieving digital aerial photography of pipeline rights-of-way. A byproduct of this collaboration was the Digital Aerial Rights-of-way Monitoring System (DARMS) that consists of a charge coupled device (CCD) digital camera and high-capacity data recorder and which NASA can use for similar missions in the future.[29] While this case deals with the usage of aerial photography, it provides a good example of the potential that exists for space-based remote sensing systems to perform tasks of energy resource management. Moreover, it demonstrates the ability of public space agencies to partner with the private sector to meet these goals.

5. Conclusion

These examples represent only a small set of the possible economic, public welfare and environmental uses of remote sensing for energy policy. Clearly there is tremendous value in all three aspects. Data from Earth observation satellites can make more productive use of the energy resources available to us, can make energy transport to end users more reliable and cost-effective, and can mitigate the negative environmental consequences of using certain energy resources. An essential part of any national or international energy policy must involve innovation in remote sensing technologies for these purposes.

The advantage Earth observation systems offer is perspective. High resolution cameras, radar systems and image enhancing software all exist here on the surface, but it is the vantage point from which satellite-based sensors operate that gives them their value. Orbiting platforms and sophisticated sensory equipment are only means to an end. What we are really talking about here is not the value of a physical product, but the *information* it can yield. In this regard, a satellite by itself is useless without the supporting IT infrastructure to support the flow of data and make sense of it. Faster, more powerful computing platforms must be integrated with higher resolution on-orbit instrumentation to enable more precise modeling of Earth systems.

The data, too, are useless unless they can be accessed and interpreted by people who need the information they hold. As remote sensing systems are government owned and operated, the information they produce is a public good and should be made freely available to the public (such as the SSC datasets) and in file formats of the most commonly used data processing software. To extend the utility of this information as a public good, space agencies should make efforts to actively seek out energy companies, other government agencies and

[26] "Galicia (Spain) Oil Spill, November 2002," Earthnet Online, European Space Agency, available at: http://earth.esa.int/cgi-bin/printer_friendly.cgi?/ew/oil_slicks/galicia_sp_02/index.html?28.04.2003. Accessed on 1 May 2003.

[27] "Oil Slicks," Earthnet Online, European Space Agency, available at: http://earth.esa.int/ew/oil_slicks/. Accessed on 1 May 2003.

[28] "Galicia (Spain) Oil Spill, November 2002," op. cit.

[29] "Success at Stennis: Earth Observation Environment and Resources Management," Commercial Technology Program, Stennis Space Center, NASA, available at: http://technology.ssc.nasa.gov/suc_stennis_earthobserv.html. Accessed 15 March 2003.

environmental organizations that could be making good use their data but currently do not. Communicating the data to non-scientific communities who may be unfamiliar or uncomfortable with it may involve a greater investment in creative endeavors such as science writing and graphic design. It may also require a certain degree of marketing, which should not be regarded as separate from the mission of government space agencies.

Bridges must be built between the scientists and engineers of space agencies and the users of their data, be they groups or individuals, public or private. The EOCAP and proposed POWER programs in the United States and the comprehensive GMES program in Europe are positive steps in this direction. Ultimately, though, the information must flow in both directions. End users should know what products exist and how they can be used. Space agencies should know what is important to end users so that they can improve these products. Learning must surely take place on both sides of this equation, but it is the responsibility of a space agency to educate its scientists and engineers on the points of connection between remote sensing and specific applications.

Finally, a closer relationship between the public and private sector should be fostered in the interest of improving technology and reducing costs in the long run. As noted earlier, government to industry technology transfer in space technology was very successful in the telecommunications industry. Privately owned and successful satellite imaging companies such as Space Imaging, EarthSat and Spot Image have all built upon government funded technology. Space agencies should encourage the energy industry to use their data not only because it is a public good, but because it could become a valuable private good. Companies in the energy industry may begin to invest more heavily in privately owned remote sensing technology if it is tailored to their specific needs and seen as cost-effective. This is already the case with companies like EarthSat and the Sewall company who sell remote sensing products to the energy industry. With these services taken over by the private sector, government space agencies can focus on their primary responsibility: advancing the cutting edge of science and technology and expanding capabilities for the future.