Figure 5. Aerial photograph of the footprint of the Bingham Canyon mine, Utah (source: U.S. Geological Survey, 2012). The mine is currently ~4.4 km wide and 1.2 km deep (Rio Tinto, 2009).

risen dramatically in recent years, it currently produces only 7% of the world's total. As a result, Chinese companies are aggressively making deals in other parts of the world to secure copper resources for the future.

Global gold production also reached an all-time high in 2011 (Fig. 7). Although gold has many industrial uses (e.g., in electrical wiring in computers and cell phones, as a heat reflector, and in dentistry), its major use is as a substitute for money, either as bullion or, in much of the world, jewelry. From 1910 to 2011, per capita production has oscillated somewhat (by a maximum factor of 2.4) with the global economy and world events; global production of gold has more or less followed the rise in world population.

The remarkable change in global gold production is the recent dominance of China as the world's leading producer (Fig. 8). For over 100 years, South Africa's Witwatersrand gold deposits dominated global production, but China captured the lead in 2007 and has steadily increased its production since then.

A clear challenge for the future is to meet global demand for mineral resources such as iron, copper, and gold. Exploration geologists, geochemists, and geophysicists (collectively, "geos") need to find, and engineers need to develop and mine, huge resources to meet current demand (e.g., the equivalent of one Bingham Canyon–size copper deposit each year). Clearly geos, with their knowledge of ore systems, tectonic environments, regional geology, and potential environmental consequences will be the leaders in discovering new deposits.

EXPANDING USES OF MINERAL RESOUCES

Whereas nearly every naturally occurring element has several significant uses today, 80 years ago far fewer elements were widely used (Fig. 9). In 1932, during the Great Depression, mineral production and industrial activity in the United States had plummeted, relative to boom years after World War I. At that time, uranium and the rare earth elements had only minor uses, and the U.S. Bureau of Mines wasn't tracking the production or

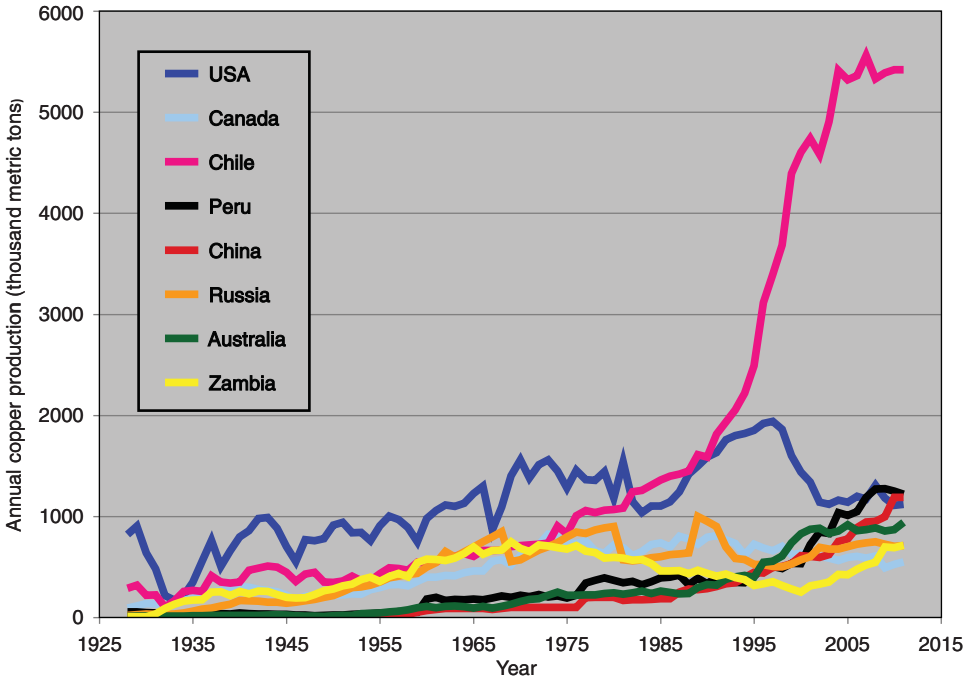

Figure 6. Annual copper production by major producing countries, 1928–2011 (data from U.S. Geological Survey and U.S. Bureau of Mines).

Figure 9. Switchgrass is a perennial grass that can be grown across the United States and used as a cellulose-based feedstock. Source: Tinker and Lynch (2012). Photo courtesy Wilson Waggoner.

in part because of uncertainties about the potential profitability of cellulosic ethanol (Bullis, 2012).

There is a limit to the capacity of soil and water to grow biomass. Biofuels currently make up only a small fraction (0.2%) of the gasoline consumed worldwide. But the contribution of biofuels is expected to grow, with positive impacts including reductions in greenhouse gases, improved energy security, and new income sources for farmers (de Fraiture et al., 2008). However, unless significant improvements in yields are realized, the increased production of biofuels will result in more land used for feedstock production. "It is estimated that 3.7 million additional acres will be required to produce 15 BGY [billion gallons per year] of corn ethanol in the United States in comparison with their baseline estimate of 12 BGY ethanol from corn in 2016. This increase in land use, especially the increase in the use of marginally productive lands, is likely to also result in increased water, fertilizer and pesticide use, and soil lost to erosion" (Powers et al., 2010 p. 255).

Technology and the role of geosciences. Two types of facilities exist for the production of ethanol from starch-based feedstocks—dry mill and wet mill—the main difference being in the initial treatment of the grain. Dry mill is the most common production method in the United States, owing to the lower cost. The process of producing ethanol from sugar-based feedstocks is simpler because they do not need to be heated and require no added enzymes. Instead, they need only to be treated with yeast, which eats the simple sugars contained in the feedstocks to produce ethanol. Producing ethanol from cellulosic feedstocks is more complicated because it is difficult to break down the long chains of sugar molecules that comprise cellulosic materials into usable sugars that can be treated with yeast. Current methods for treating the feedstocks include treatment with an acid such as sulfuric acid, heat treatment, and exposure to expensive, specially selected enzymes. Biodiesel is produced by chemically reacting alcohol (commonly methanol) and the animal fats in biodiesel feedstocks. Substances are added to the mixture to speed up the chemical reaction, which creates organic chemical compounds called esters, the main components of biodiesel.

The role of geosciences in biofuels revolves in part around water, soil science, hydrogeology, fertilizers, weather, climate, and other aspects of agriculture to produce feedstocks. Remote sensing such as airborne lidar and satellite-based instruments (e.g., Interferometric Synthetic Aperture Radar [InSAR]) are also being used to measure biomass, monitor crops, and study moisture patterns. Since the 1950s, global irrigated agriculture has expanded by 174%, accounting for 90% of fresh-water consumption (Scanlon et al., 2007). Feedstock water requirements range from "500 to 2000 liters of water per liter of ethanol produced to approximately 1000 to 4000 liters of water for soybeans per ethanol-equivalent liter of biodiesel. By contrast, ethanol conversion facilities use only 2–10 L of water per liter of ethanol produced" (Powers et al., 2010 p. 256). However, biomass production for energy will also compete with food crops for scarce land and water resources, already a major constraint on agricultural production in many parts of the world (de Fraiture et al., 2008), especially regions where water supplies are already stressed.

Benefits and challenges. Biofuels offer a number of benefits over fossil fuels. They can reduce dependence on imported fossil fuels and thus reduce net carbon dioxide emissions. Biofuels are biodegradable and safer to handle than fossil fuels, making spills less hazardous and easier to clean up. In time, biofuels may reach cost parity with fossil fuels. If so, however, the sheer acreage required to fuel global transportation will be a limiting factor (NCEE, 2012).

In addition to the large water demands, there are a number of disadvantages to certain biofuels, such as corn ethanol, which could result in higher food costs and potential food shortages (Timilsina et al., 2012). More land will be needed to grow more crops, which could contribute to deforestation and soil erosion. Finally, biofuel production can produce strong and noxious smells, which are undesirable to nearby communities (U.S. EPA, 2011).

Natural Gas

What is it and how is it used? Natural gas is the general name for several forms of produced gas, dominantly methane, but also including propane, butane, pentane, and other natural gases in lesser amounts. Natural gas is the most versatile of the primary energy sources, because it can be used to generate electricity; for heating, cooling, and cooking; and directly in vehicles as CNG or LNG. As a source of energy, natural gas is readily combustible, gives off few emissions, and is abundant in the United States and globally. Common household uses include cooking, space heating, cooling, and drying. More than half of the homes in the United States are heated by natural gas, and an increasing number of homes are cooled by gas-powered air conditioners (American Gas Association, 2008). Between 1986 and 1999, the number of newly constructed single-family homes

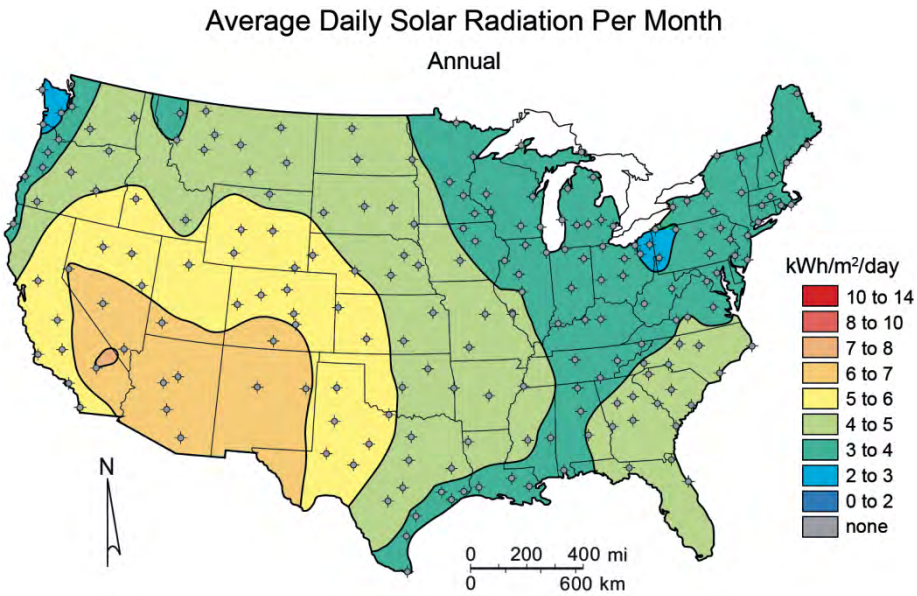

Figure 23. U.S. average daily solar radiation per month. Source: U.S. DOE (2012b).

towers use large mirrors to focus the Sun's energy and boil water, making steam to turn a turbine. Parabolic trough mirrors reflect and concentrate solar radiation onto pipes containing synthetic oil, which heats up and circulates next to water pipes; the water boils and generates steam (Fig. 24). In other words, in mirrored systems, solar radiation is converted to thermal energy in steam, mechanical energy in the turbine, and finally electrical energy through the generator.

Concentrated solar power technology is relatively new. Today, there are around ten such plants in the United States, including several in California and Arizona, one in Nevada, one in Florida, one in Colorado, and one in Hawaii (NREL, 2011).

Solar radiation can also produce electricity directly through photovoltaic cells, commonly known as solar cells. Photovoltaic cells are composed of thin, transparent layers of boron and phosphorous-enriched silicon. Simple photovoltaic systems are commonly used to provide power for small consumer items such as toys, calculators, and wristwatches. Larger systems provide electricity for other purposes, including water pumps, road and traffic signs, and communications satellites. These systems are sometimes installed on the roofs of houses and buildings or as parking lot shade canopies (Fig. 25). The most complex and largest systems are those used in photovoltaic power plants. Today, there are only a handful of commercial plants in the United States, including ones in California, Nevada, New York, Arizona, and Florida. Several more have been proposed.

Geoscientists are needed for the exploration and production of an array of necessary raw materials such as silicon, gallium, cadmium, and copper.

Benefits and challenges. Solar energy has a number of advantages over other sources of energy. First, solar energy systems do not produce air pollutants. This includes active and passive solar heating systems, concentrated solar power systems, and photovoltaic systems. Second, following set-up and maintenance costs, the solar radiation is free. Third, photovoltaic panels are relatively simple and durable, require little maintenance, can

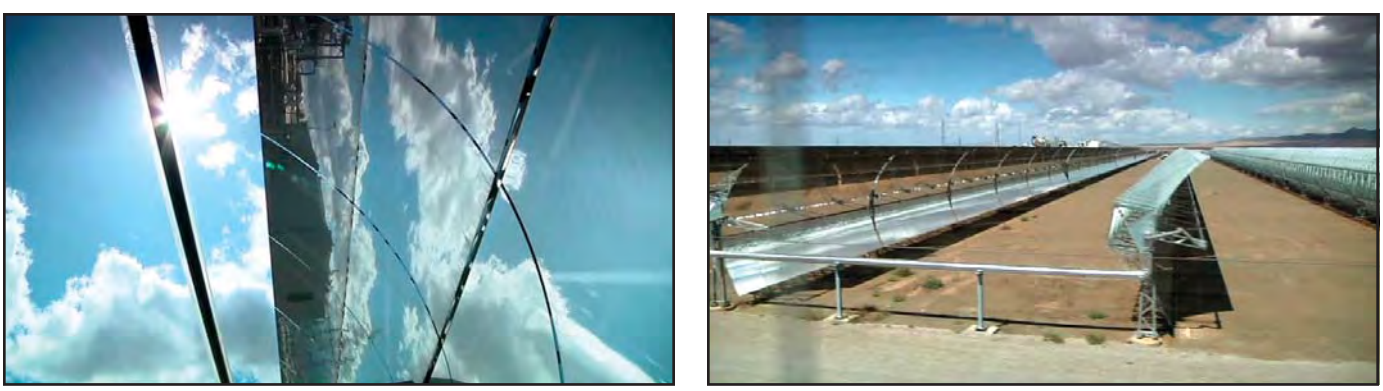

Figure 24. Parabolic troughs in Spain. Source: Tinker and Lynch (2012). Photo courtesy Wilson Waggoner.

irrigation and power plant cooling remained constant. This seems remarkable in view of the fact that both the population and generation of energy grew steadily during the period. Most hydrologists believe that there is abundant water in the humid parts of the United States; yet the water supply as represented by withdrawals did not increase after 1975. Solley et al. (1998) pointed out that the per capita water use declined by 32% from 1975 and 1995. Wood (2003) commented on this phenomenon:

> In the United States, there appears to have been an economic crossover point at which increasing per capita income resulted in a per capita decline in water use.

While Wood (2003) seemed to suggest that economics is the explanation, he went on to state:

> It is not clear if this (per capita decline in water use) is dependent upon climate, structure of the economy, imported agricultural products, or other factors.

I suggest a different explanation below.

New users of water often find it difficult to obtain water, even users who are quite willing to pay handsomely to obtain water. This problem with respect to irrigation in the West is discussed above. In the rest of the country, the problem manifests itself most explicitly with respect to power plants; Sovacool (2009) lists 13 cities where power plants are having difficulties being built because of water availability (Table 2).

Power plants pose other environmental problems; once-through cooling raises stream temperatures that can cause a water-quality problem especially during periods of low flow. However, Sovacool (2009) argues that water supply is the major issue holding up construction.

Since power generation steadily increased from 1975 to the present, while the withdrawals of water for cooling are constant since 1975, the power industry appears to be more efficient in its use of cooling water. Unfortunately, we have only withdrawal data and not data on water consumption as a basis for analysis. Once-through cooling is the most efficient form of cooling; it consumes the least amount of water. Closed-loop cooling systems consume more water because they depend upon evaporative cooling in cooling towers. Gas-fired power plants are more energy efficient than steam plants because the fuel is burned directly in the turbine; they require less water per unit of energy produced.

It is surprising given the low rate of consumption that additional power generation is difficult to build, or that the availability of water for cooling is the major problem that it is reported to be.

TABLE 2. METROPOLITAN AREA POWER PLANTS HAVING DIFFICULTY BEING BUILT BECAUSE OF WATER-SUPPLY ISSUES, LISTED BY DIFFICULTY

Humid area	Arid area
Charlotte, North Carolina	Denver, Colorado
Chicago, Illinois	Portland, Oregon
New York, New York	San Francisco, California
Atlanta, Georgia	
Dallas, Texas	
Washington, D.C.	
Baltimore, Maryland	
St. Louis, Missouri	
St. Paul, Minnesota	
San Antonio, Texas	
Houston, Texas	
Raleigh, North Carolina	

Note: From Sovacool (2009).

INTENSITY OF FRESH-WATER WITHDRAWALS

Another way to approach the water resources of the humid areas of the country is to examine the intensity of fresh-water withdrawals.

Comparison of the runoff with the intensity of withdrawals for the United States (Figs. 11 and 12) shows that the withdrawals are a significant fraction of the runoff over large areas of the country—in places as much as one-third to one-half of the runoff is withdrawn. When one considers that much of the runoff comes as storm flow, the withdrawals constitute a significant fraction of the base flow of many streams.

How does one reconcile the facts that (1) the water withdrawals have remained constant since 1975 even as the population and economic activity increased, especially if there is plenty of water; and (2) major new users as reflected by power plants have difficulty obtaining water? My hypothesis is that in the humid areas of the country, the various stakeholders in a drainage basin reach a consensus on how water is to move through the basin. The consensus may be either informal or formal. A new major water user coming into the basin upsets the existing consensus, and a

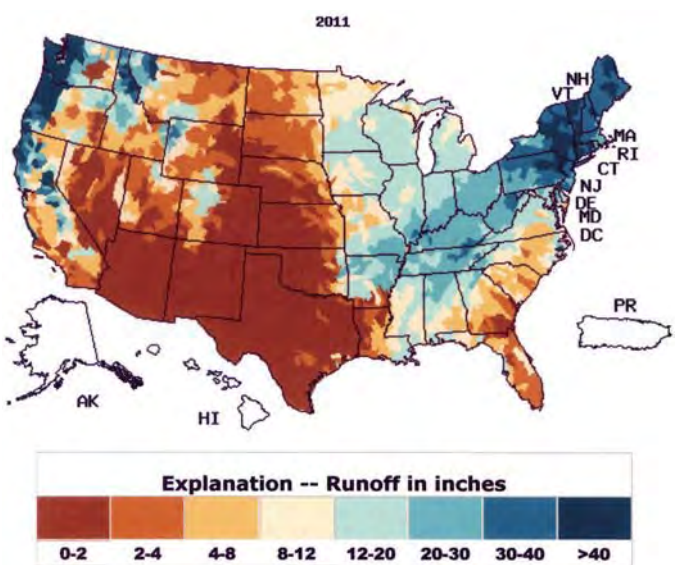

Figure 11. Runoff map for 2011 water year (data from U.S. Geological Survey).

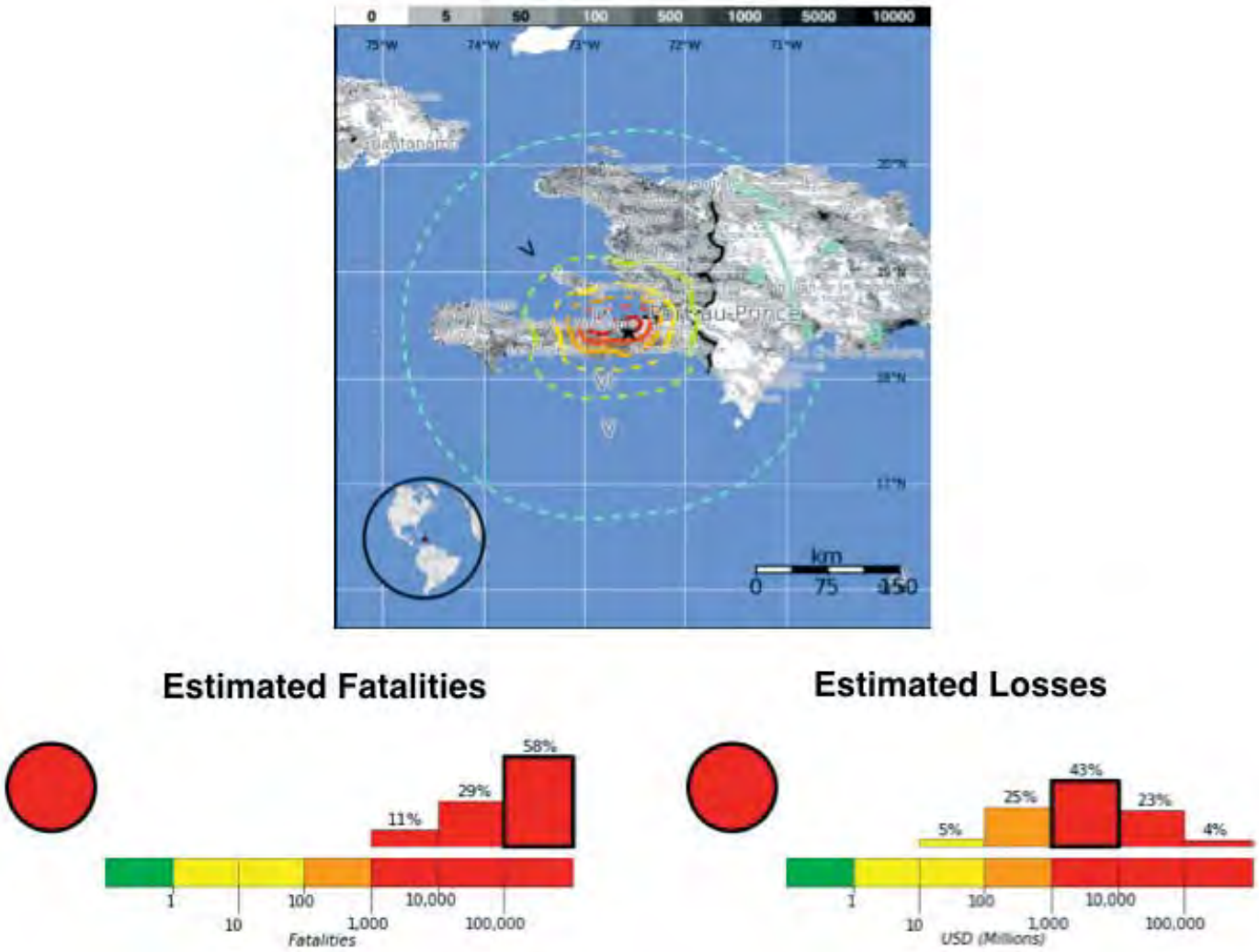

Figure 8. Portions of the U.S. Geological Survey Prompt Assessment of Global Earthquakes for Response (PAGER) notification for the January 2010 Mw7.0 Haiti earthquake (from http://earthquake.usgs.gov/earthquakes/pager/events/us/2010rja6/index.html).

(number of casualties, displaced families, and shelter needs) of earthquakes (Wald et al., 2003).

The Smithsonian Institution (SI), through its Global Volcanism Program (GVP), has long been the world leader in compiling and publishing data on volcanic eruptions and impacts (Simpkin and Siebert, 1994). Through close collaboration with the world's volcano observatories and a series of publications (e.g., Siebert et al., 2010) and their website (http://www.volcano.si.edu/index.cfm), the GVP maintains up-to-date information on the world's active volcanoes The data include the chronology and magnitudes of eruptions and periods of unrest, as well as data on fatalities, evacuations, and frequency of eruptions. In partnership with the USGS, the GVP also produces an online weekly update on worldwide volcanic activity. Collectively, these databases provide the principal means to estimate global exposure to volcano hazards, and they play an important role in helping define the potential for future eruptions at individual volcanoes.

Geodesists and volcanologists have also developed systems for open and real-time access to their data. In the United States, a university-governed geodetic consortium was created in 1984 (and became known as UNAVCO in 2001, http://www.unavco.org). It serves as a principal archive for geodetic data including GPS, SAR, and InSAR, Terrestrial and Airborne Laser Scanning, strain and seismic borehole measurements, and the meteorological data that are used to enhance geodetic data. Additionally, a number of universities in the United States and in other countries provide data archives for geodetic data. At the global scale, the International Global Navigation Satellite System Service (IGS) is a federation of more than 200 worldwide agencies that pool resources and provide satellite global positioning station data and data products from both U.S. and Russian systems.

Other real-time satellite data are now becoming available, from space agencies and commercial imagery companies, to address natural hazards. For example, international protocols are

tributaries. This provision, later referred to as the Refuse Act, was the first U.S. Government environmental law.

Today, there is a complex suite of public laws that protect the air, water, land, and endangered species. Many of them are amendments to previous laws. These laws are supervised by the Environmental Protection Agency. Significant environmental policy includes the National Environmental Policy Act (1969), the Clean Water Act (1972), the Clean Air Act (1963 and later amendments), and the Oil Pollution Act (1990).

National Environmental Policy Act

In 1969, Congress passed the first major piece of environmental legislation, the National Environmental Policy Act (Public Law 91-190). NEPA created and enforced a set of procedures to examine and minimize the environmental impacts of government activities. The regulations did not extend to the private sector, but were the first set of environmental regulations on Federal actions. The goals of NEPA were "to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans."

NEPA was signed into law on 1 January 1970, but was negotiated by the U.S. House of Representatives and U.S. Senate with overwhelming bipartisan support (the House passed NEPA with a 372-to-15 vote). The ideas of the bill were not new, and were very similar to the failed Resources and Conservation Act of 1959, which had been introduced by Senator James Murray of Montana. However, during the 1960s there was a growing public awareness of environmental issues and the effects of pollution, influenced by an increasing environmental literature such as Rachel Carson's *Silent Spring* (Carson, 1962). An important immediate impetus for the passing of NEPA was the Santa Barbara crude oil spill (the third largest in U.S. history, after the 2010 BP Deepwater Horizon and 1989 Exxon Valdez spills), which leaked from a Union Oil platform from January to February of 1969 (Fig. 9).

NEPA contains three primary provisions. It lays out a set of national environmental policies and goals, it establishes a set of procedures to ensure that these policies and goals are met, and it created a Council on Environmental Quality (CEQ) within the executive office of the President to oversee the enforcement of these provisions. The main purpose of NEPA is to make sure that environmental priorities are weighted equally with other goals in all decision-making processes by all Federal agencies. This applies to global policies as well as to regional issues such as licensing a landfill or building a highway. The NEPA legislation describes the "continuing responsibility of the U.S. Government to use all practicable means, consistent with other essential considerations of national policy, to improve and coordinate Federal plans...[so] that the Nation may —

- Fulfill the responsibilities of each generation as trustee of the environment for succeeding generations;
- Assure for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings;
- Attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences;
- Preserve important historic, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity, and variety of individual choice;
- Achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities; and
- Enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources."

The means for ensuring that these goals are met is through the development of environmental impact statements (EISs) for government actions to assess environmental implications before any actions are taken. Certain government activities can be granted a categorical exclusion if they have a history of not involving any environmental impacts. In most cases, a Federal action requires an environmental assessment (EA), which leads to either a FONSI (Finding of No Significant Impact) or an EIS. The EIS includes an assessment of the impacts of a particular action or policy, reasonable alternatives to the action, and the resources that would be required to be expended if the proposed action was implemented.

The CEQ consists of three members who are appointed by and report to the President. The CEQ was modeled after the Council of Economic Advisors, which had been established in 1946. One of the activities of the CEQ is to assist and advise the President in the construction of an annual State of the Environment report that includes an assessment of the performance of the government in meeting the requirements of NEPA. One of the strengths of NEPA and its many amendments is that it

Figure 9. Photograph of the oil piled up on a sea wall at Santa Barbara, California, USA, that resulted from an oil spill from an offshore platform in 1969. This oil spill helped motivate public and government sentiment into passing the Clean Water Act and establishing the U.S. Environmental Protection Agency. (USGS archive; http://www.fnal.gov/pub/today/archive_2009/today09-03-30.html.)