Future Energy

John Reinker
Energy & Propulsion Technologies
GE Global Research
Niskayuna, New York

The availability of abundant, low cost energy is key to a modern society and a necessity for continued economic expansion. A balance of energy is required to provide transportation, electricity and industrial requirements. Beyond the desire for low cost energy solutions, today's society is requiring that its choice is environmentally sound. In this presentation, I will focus on the development of the United States current electrical energy position, and discuss leading-edge technology developments that will transform the energy portfolio of the future and allow for sustained growth. Subsequent presentations will address the future of the energy needs of the transportation segment.

Electrical Energy: Historical Perspective

Societies have continually increased productivity through the harnessing of different energy sources, which has allowed for economic expansion and the development of the modern world. Early industry in the United States was tied to the water for both transportation and for hydropower. The advent of harnessing electricity allowed for the use of a clean energy carrier, thereby breaking the tie between energy source and energy use. The combination of the harnessing of electricity and the development of the internal combustion engine at the turn of the 20^{th} century further accelerated the economic development of the country.

The early development of the electrical grid in the United States was achieved through the use of hydropower. Many of the earliest hydroelectric dams that were put into production are still operating throughout the country. As the grid spread across the country, major changes in the waterways occurred as a result of hydroelectric power projects and many of the natural hydropower sources were utilized. Restricted by availability of new hydropower locations, additional technologies beyond hydropower were required in order to meet the growing electrical needs of the country.

Tremendous increases of electric power were achieved through the harnessing of coal. Overall power plant efficiencies were in the 10% range, but steady increases in technologies including improved materials that allowed for higher steam pressures and temperatures. Improvements to the Rankin cycle including feed water heaters and the reheat cycles resulted in steady increased efficiency approaching 40% with nominal 1000°F, 3500psi steam conditions common in today's grid.

As an outgrowth of the nuclear developments mid-20^{th} century, nuclear power plants became economically attractive and over 100 plants were in installed in the United States, providing 16% of the world electrical output. The reactors in these plants are light water reactors providing the energy for the steam turbine generators. The aftermath of the Three Mile Island incident resulted in a shift away from new nuclear power plants in the United States. Other nations continued to build nuclear plants across the world with France producing approximately 80% of their electricity from nuclear power. Within the

United States, nuclear operators focused on improving plant performance and drove plant availability from 60% to over 90%.

Development of the jet engine allowed for the transition of gas fired turbines into the power industry. Combining the combustion process and turbine technologies into a single package resulted in a high power-density system. The gas turbine as a power producer initially provided great peak power capabilities to the grid with its fast start-up capabilities, and low installed cost. However, advancement of combined-cycle technology where the waste heat of the gas turbine is captured through a heat recovery steam generator and then converted to electricity through a steam turbine generator resulted in highly efficient power plant. A large number of these plants have been constructed in the past decade.

Most recently, renewable technologies are entering the utility purchase portfolio with large blocks of wind power being installed by major utilities, and solar panels are becoming cost effective in the southwestern United States.

As a result of this historic selection of electrical generation, the US produces approximately half of the electricity from coal, with natural gas, nuclear and hydropower filling in the majority of feedstocks as shown in figure A. Comparing the USA to other regions of the world shows significant variation by region, mainly driven by the availability of natural resources like coal and hydropower, but also driven by acceptance of nuclear power. The overall electrical feedstock usage for the world is shown in figure B, where traditional electrical feedstocks lead the world's usage, with an increased usage of renewable sources.

Figure A: ENERGY AROUND WORLD

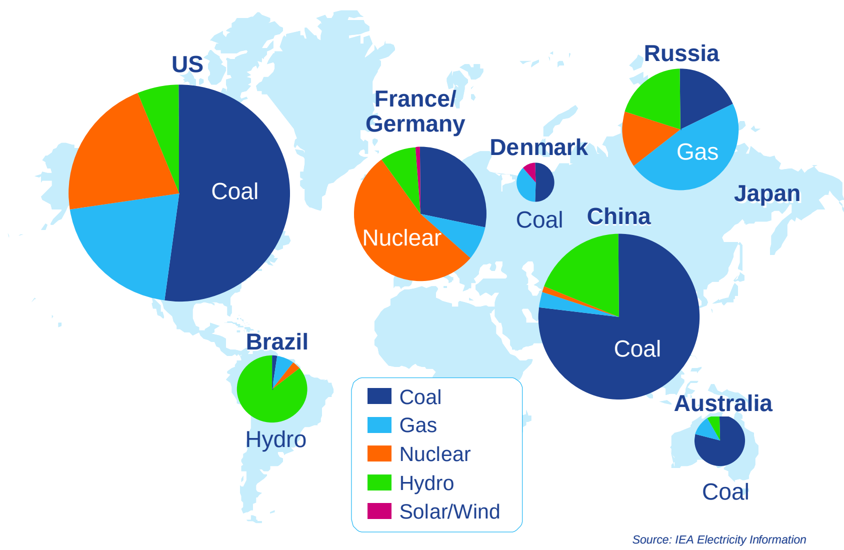
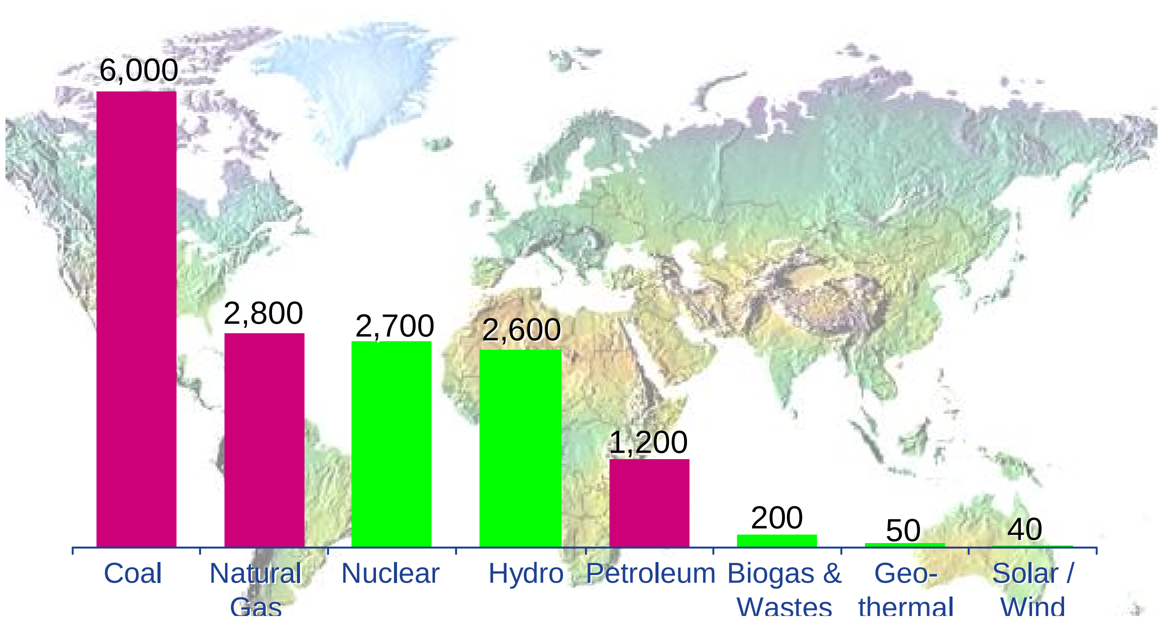


Figure B: World Electrical Generation Sources



Economic Drivers

Decisions on energy investments are large bets by corporations on technology, fuel pricing and sales expectations. One may assume that overall efficiency of a power plant is the primary driver, however this can be offset by high fuel costs. For example, most of the natural gas fired combined cycle power plants commissioned in the recent US power bubble represent the state of the art with respect to efficiency, however many did not operate long as a result of a spike in natural gas pricing. The most efficient plant could not overcome the cost penalty associated with fuel costs and market based electricity pricing. Boardrooms balance these risks by assuring long-range fuel contracts and sales agreements as much as possible. Emissions portfolio management is also required under today's regulations, and potential carbon taxes of the future.

To help encourage new technologies, governments can encourage the investment in certain energy sources by providing incentives. Some regions of the US have put in Renewable Portfolio Mandates that renewable based power must be managed from an intermittency perspective. The intermittency of wind and solar power must be managed at the regional level to assure continual energy delivery to the end customer.

Renewable Power Technology Immergence

Major advances in the wind turbine technologies have been occurring. The majority of installed plants have been in the 1 MW class units, but with the development of larger platforms, 5 MW off shore units are now being developed that reduce the capital investment and make wind more competitive in the market place.   Key technologies to make these large units are longer blades, active wind controls, and power electronics to manage the conversion of the shaft torque to electrical power.

Figure C: Wind and Solar Power

Solar power has an advantage over other power sources in that it is competing at the residential price point versus the lower cost wholesale electricity price point.   The disadvantage is this technology must be much more refined to reach the end consumer as part of the overall energy solution. The technology continues to develop and today we are seeing the emergence of an integrated solar technology being provided in new home construction, as shown in Figure C.

From a bio-energy perspective, the use of landfill and coal gases to generate electricity is economically attractive. Technology developments are underway to look at ways of utilizing agricultural feedstocks to generate electricity, but currently this is in the research stage.

Return to Coal/ Nuclear Power

The increase in natural gas prices, the availability of low cost coal, and the continued strong performance of the nuclear fleet are making the traditional coal and nuclear plant more attractive. To ensure that the technology is acceptable to the industry, regulators and public, many enhancements from the existing plants are have been developed.

One clear technology game changer for the coal industry is the development of advanced coal gasification technologies. Conventional coal plants pulverize coal and then burn them in traditional boilers, with emission clean-up post combustion and generate power through a conventional Rankin cycle. Through the use of a coal gasifier, Integrated Coal Combined Cycle Plants (IGCC) transforms the coal into a syngas, allowing for the removal of many of the contaminants prior to the combustion process. In addition, the creation of the syngas allows for the replacement of the Rankin cycle with the highly efficient combined cycle power plant.

Longer range, additional opportunities for increased performance and lower emissions can be achieved with advances in gas turbine enhancements. Over the past 20 years, firing temperatures have increased from 2000° F class turbines to 2600° F class temperatures as a result of improved materials, coatings and heat transfer/cooling technologies. The overall improvement of cycle efficiency has improved from 50% to 60% while improvements in combustion technologies have brought emissions an order of magnitude improvement. Some manufactures have increased performance by adding a second combustion system to improve overall efficiency at lower firing temperature. Longer range, solid oxide fuel cells could replace the combustion system of the gas turbine, resulting in a hybrid SOFC which could increase overall efficiencies to the 70+% range.

Similar advancements are currently being made in the nuclear industry. The major rector manufacturers are currently applying for licensing for the next new plants within the USA. These plants will have larger power ratings than the historic plants, resulting in lower operation & maintenance costs per kW. In addition, these plants will have inherently safer designs with advance control technologies, resulting in even further improvements in availably. Regulatory improvements include the ability of an owner to apply for combined license instead of having to build a plant under single construction license and then to follow-up with an operating license. Large quantities of CO_2 free power will be required in the future grid as the world expands its energy needs.

Future Energy

As is the case in the world today, no single right energy solution will exist for any region. It is clear by the scientific and governmental discussions, we will be living in a carbon-constrained world in the future. Renewables will be part of the solution, but a portfolio of solutions will be required, including nuclear power. Technology advancement will continue to be key for the development of the products required for tomorrow.

Clear regulatory frameworks will provide industry the assurance that a return on the investment of the necessary technologies which will improve efficiencies and control emissions/greenhouse gasses. Energy equipment manufacturers will invest in a portfolio of solutions to support customers for their needs. We realize that satisfying the world's demand for energy will require a balanced portfolio of energy options including coal, natural gas, nuclear, wind, hydropower, solar and in the future bio-energy.