Review Article

Journal of Applied Material Science & Engineering Research

Why We Need Nuclear Power Plants

Bahman Zohuri*

University of New Mexico, Department of Electrical Engineering and Computer Science Albuquerque, New Mexico 87131, US State

***Corresponding author**
Bahman Zohuri, University of New Mexico, Department of Electrical Engineering and Computer Science, Albuquerque, New Mexico 87131, US State, E-mail: bahmanz@aol.com

Submitted: 17 Nov 2017; **Accepted**: 10 Dec 2017; **Published**: 26 Mar 2018

Abstract
The major growth in the electricity production industry in the last 30 years has centered on the expansion of natural gas power plants based on gas turbine cycles. The most popular extension of the simple Brayton gas turbine has been the combined cycle power plant with the Air-Brayton cycle serving as the topping cycle and the Steam-Rankine cycle serving as the bottoming cycle for new generation of nuclear power plants that are known as GEN-IV. The Air-Brayton cycle is an open-air cycle and the Steam-Rankine cycle is a closed cycle. The air-Brayton cycle for a natural gas driven power plant must be an open cycle, where the air is drawn in from the environment and exhausted with the products of combustion to the environment. This technique is suggested as an innovative approach to GEN-IV nuclear power plants in form and type of Small Modular Reactors (SMRs). The hot exhaust from the Air-Brayton cycle passes through a Heat Recovery Steam Generator (HSRG) prior to exhausting to the environment in a combined cycle. The HRSG serves the same purpose as a boiler for the conventional Steam-Rankine cycle [1].

Introduction
In 2007 gas turbine combined cycle plants had a total capacity of 800 GW and represented 20% of the installed capacity worldwide. They have far exceeded the installed capacity of nuclear plants, though in the late 90's they had less than 5% of the installed capacity worldwide. There are number of reasons for this. First natural gas is abundant and cheap. Second combined cycle plants achieve the greatest efficiency of any thermal plant. And third, they require the least amount of waste heat cooling water of any thermal plant.

A typical gas turbine plant consists of a compressor, combustion chamber, turbine, and an electrical generator. A combined cycle plant takes the exhaust from the turbine and runs it through a Heat Recovery Steam Generator (HRSG) before exhausting to the local environment. The HRSG serves the function of the boiler for a typical closed cycle steam plant. The steam plant consists of a steam turbine, a condenser, a water pump, an evaporator (boiler), and an electrical generator. In a combined cycle plant, the gas turbine and steam turbine can be on the same shaft to eliminate the need for one of the electrical generators. However, the two shafts, two generator systems provide a great deal more flexibility at a slightly higher cost. In addition to the closed loop for the steam, an open loop circulating water system is required to extract the waste heat from the condenser. The waste heat extracted by this 'circulating' water system is significantly less per megawatt for a combined cycle system as the open Brayton cycle exhausts its waste heat directly to the air.

The layout for the components of a typical combined cycle power plant is given below in Figure-1.

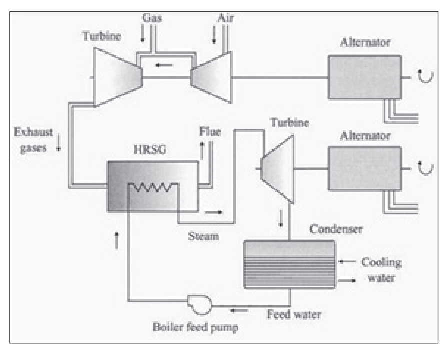

Figure 1: Typical Gas Turbine Combined Cycle Power Plant

GE currently markets a system that will produce 61% efficiency at design power and better than 60% efficiency down to 87% of design power for gas turbine combined cycle plants [2].

An approximate efficiency can be calculated for a combined cycle power plant by the following simple argument [3].

Brayton cycle efficiency = $\frac{W_B}{Q_{in}} = \eta_B$

Heat to Rankine cycle = $Q_R = (1-\eta_B)Q_{in}$

Rankine cycle efficiency = $\frac{W_R}{Q_R} = \eta_R$

Overall efficiency =

$$\frac{W_B + W_R}{Q_{in}} = \eta_T = \frac{\eta_B Q_{in} + \eta_R Q_R}{Q_{in}} = \frac{\eta_B Q_{in} + \eta_R (1-\eta_B) Q_{in}}{Q_{in}} = \eta_B + \eta_R - \eta_B \eta_R$$

$$\eta_T = \eta_B + \eta_R - \eta_B \eta_R$$

This efficiency must be corrected for pressure losses and assumes that all the heat in the Brayton exhaust is used in the Heat Recovery Steam Generator (HSRG). For a combustion gas turbine this is not usually possible if condensation of the water in the exhaust products is to be avoided. The detailed models developed in this effort give a more accurate answer.

For the nuclear reactor system, the heat transfer is in the opposite direction. All reactor components and fluids in the primary and secondary loops must be at a higher temperature than the peak temperature of the gas exiting the heat exchanger. This severely restricts the peak temperature that can be achieved for the air entering the turbine. However, all is not lost.

In a typical combustion system, there are pressure losses approaching 5% of the total pressure to complete the combustion process [4]. Heat exchangers can be built with significantly lower pressure drops than 5% approaching 1% [5]. Therefore, the most straightforward method to overcome this severe temperature limitation is to borrow a technique from steam power plants and implement multiple reheat cycles. That is the first heat exchanger heats the air to its peak temperature. Then the air is expanded through the first turbine. The air is then reheated to the same peak temperature and expanded through the second turbine. Based on the relative pressure losses that appear possible, up to five turbines might be considered. All five turbines will be driving the same compressor. Multiple compressors on concentric shafts driven by different sets of turbines might be possible, but that has not been considered here.

For a nuclear system to take advantage of combined cycle technology, there are many numbers of changes to the plant components that must be made. The most significant of course is that the combustion chamber must be replaced by a heat exchanger in which the working fluid from the nuclear reactor secondary loop is used to heat the air. The normal Brayton cycle is an internal combustion one where the working fluid is heated by the combustion of the fuel with the air in the combustion chamber. The walls of the combustion chamber can be cooled and peak temperatures in the working fluid can be significantly above the temperature that the walls of the chamber can tolerate for any length of time.

Methodology of Combined Cycle

The approach taken in the Combined Cycle (CC) code developed for this effort is to model the thermodynamics of the components making up the power conversion systems as real components with non-ideal efficiencies. Pressure drops are included for every component except the connected piping. The compressor design is modeled with a small stage polytropict efficiency to take, into account state of the art designs. The gas turbines are likewise modeled with a polytropic efficiency. The steam turbines are modeled with a simple overall thermal efficiency. Pressure drops in each of the heat exchangers are included. The input files specify the pressure drops and the heat exchangers are designed to meet these specifications if possible [6].

Some scientists are calling the nuclear power plants source of energy as 100 percent renewable energy and off course environmentalists arguably are saying that is wrong approach, just because in the core of these plants there exist Uranium or Plutonium as fuel when we are talking about fission type nuclear power plants that they exist in grid today and producing electricity to the net. However, on the other side of spectrum where, researchers and scientist at national laboratories and universities around the globe that are working toward fusion program to achieve a breakeven are passionately argue that nuclear power plants of fusion type are totally clean so long as the source of energy come in form of two hydrogen isotopes such as Deuterium (D) and Tritium (T) as source of fusion reaction and driving energy from it.

This is a dream that is too far away from reality of today's need and demand for electricity, yet is not out of scope of near future. Physics of Plasma for driving energy via Inertial Confinement Fusion (ICF) or Magnetic Confinement Fusion (MCF) are, in agreement with such innovative approaches [7,8].

Why We Still Need Nuclear Power

"Nuclear power's track record of providing clean and reliable electricity compares favorably with other energy sources. Low natural gas prices, mostly the result of newly accessible shale gas, have brightened the prospects that efficient gas-burning power plants could cut emissions of carbon dioxide and other pollutants relatively quickly by displacing old, inefficient coal plants, but the historical volatility of natural gas prices has made utility companies wary of putting all their eggs in that basket. Besides, in the long run, burning natural gas would still release too much carbon dioxide. Wind and solar power are becoming increasingly widespread, but their intermittent and variable supply make them poorly suited for large-scale use in the absence of an affordable way to store electricity. Hydropower, meanwhile, has very limited prospects for expansion in the United States because of environmental concerns and the small number of potential sites."

"The United States must take a number of decisions to maintain and advance the option of nuclear energy. The NRC's initial reaction to the safety lessons of Fukushima must be translated into action; the public needs to be convinced that nuclear power is safe. Washington should stick to its plan of offering limited assistance for building several new nuclear reactors in this decade, sharing the lessons learned across the industry. It should step up its support for new technology, such as SMRs and advanced computer-modeling tools. And when it comes to waste management, the government needs to overhaul the current system and get serious about long-term storage. Local concerns about nuclear waste facilities are not going to magically disappear; they need to be addressed with a more adaptive, collaborative, and transparent waste program."

These are not easy steps, and none of them will happen overnight. But each is needed to reduce uncertainty for the public, the energy companies, and investors. A more productive approach to developing nuclear power—and confronting the mounting risks of climate change—is long overdue. Further delay will only raise the stakes.

Is Nuclear Energy Renewable Source of Energy

Assuming for time being we are taking fission reaction as foundation for present (GEN-III) and future (GEN-IV) nuclear power reactors, as source nuclear energy source to somewhat degree, we can argue it is a clean source of energy.

Although nuclear energy is considered clean energy its inclusion in the renewable energy list is a subject of major debate. To understand the debate, we need to understand the definition of renewable energy and nuclear energy first. However, until we manage through future technology of these fission reactors to manage to bring down the price electricity per kilowatt hours driven by fusion energy down to the point of those by gas or fossil fuels, there is no chance to push these reactors beyond GEN-III.

However, efforts toward reduction price of electricity driven by nuclear fission power plants, especially using some innovative design of GEN-IV plants with high temperature base line in conjunction with some thermodynamics cycles such as Brayton and Rankine, is on the way by so many universities and national laboratory such as Idaho National Laboratory and Universities such as MIT, UC Berkeley, and University of New Mexico as well as this author.

Renewable energy is defined as an energy source/fuel type that can regenerate and can replenish itself indefinitely. The five renewable sources used most often are biomass, wind, solar, hydro and geothermal.

Nuclear energy on the other hand is a result of heat generated through the fission process of atoms. All power plants convert heat into electricity using steam. At nuclear power plants, the heat to make the steam is created when atoms split apart - called fission. The fission releases energy in the form of heat and neutrons. The released neutrons then go on to hit other neutrons and repeat the process, hence generating more heat. In most cases the fuel used for nuclear fission is Uranium.

One question we can raise here in order, to further understand whether, or not, we need present nuclear technology as a source of energy is that:

What is the difference between clean energy and renewable energy? Put another way, why is nuclear power in the doghouse when it comes to revamping the nation’s energy mix?

The issue has come to the forefront the time during the debate over the Waxman-Markey energy and climate bill and its provisions for a national renewable-energy mandate.

To simply put it, Republicans have tried-and failed-several times to pass amendments that would christen nuclear power as a "low-emissions" power source eligible for all the same government incentives and mandates as wind power and solar power.

Many environmental groups are fundamentally opposed to the notion that nuclear power is a renewable form of energy - on the grounds, that it produces harmful waste byproducts and relies on extractive industries to procure fuel like uranium.

Even so, the nuclear industry and pro-nuclear officials from countries including France have been trying to brand the technology as renewable, on the grounds, that it produces little or no greenhouse gases. Branding nuclear as renewable could also enable nuclear operators to benefit from some of the same subsidies and friendly policies offered to clean energies like wind, solar and biomass.

So far, however, efforts to categorize nuclear as a renewable source of power are making little headway.

The latest setback came in around August of 2009, when the head of the International Renewable Energy Agency (IRENA) - an intergovernmental group known as IRENA that advises about 140-member countries on making the transition to clean energy - dismissed the notion of including nuclear power among its favored technologies.

"IRENA will not support nuclear energy programs because it's a long, complicated process, it produces waste and is relatively risky," Hélène Pelosse, its interim director general, told in general"

Energy sources like solar power, Ms. Pelosse said, are better alternatives - and less expensive ones, "especially with countries blessed with so much sun for solar plants," she said it in 2009.

Argument For Nuclear as Renewable Energy

Most supporters of nuclear energy point out the low carbon emission aspect of nuclear energy as its major characteristic to be defined as renewable energy. According to nuclear power opponents, if the goal to build a renewable energy infrastructure is to lower carbon emission then there is no reason for not including nuclear energy in that list [9].

But one of the most interesting arguments for including nuclear energy in the renewable energy portfolio came from Bernard L Cohen, former professor at University of Pittsburg. Professor Cohen defined the term 'indefinite'(time span required for an energy source to be sustainable enough to be called renewable energy) in numbers by using the expected relationship between the sun (source of solar energy) and the earth. According to Professor Cohen, if the Uranium deposit could be proved to last as, long as the relationship between the Earth and Sun is supposed to last (5 billion years) then nuclear energy should be included in the renewable energy portfolio [10].

In his paper Professor Cohen claims that using breeder reactors (nuclear reactor able to generate more fissile material than it consumes) it is possible to fuel the earth with nuclear energy indefinitely. Although the amount of uranium deposit available could only supply nuclear energy for about 1000 years, Professor Cohen believes actual amount of uranium deposit available is way more than what is considered extractable right now. In his arguments he includes uranium that could be extracted at a higher cost, uranium from the sea water and, also uranium from eroding earth crust by river water. All, of those possible uranium resources if used in a breeder reactor would be enough to fuel the earth for another 5 billion years and hence renders nuclear energy as renewable energy.

Argument against Nuclear Energy as Renewable Energy

One of the biggest arguments against including nuclear energy in the list of renewables is the fact that uranium deposit on earth is finite, unlike solar and wind. To be counted as renewable, the energy source (fuel) should be sustainable for an indefinite period of, time, according to the definition of renewable energy.

Another major argument proposed by the opponents of including nuclear energy as renewable energy is the harmful nuclear waste from nuclear power reactors. The nuclear waste is considered as a radioactive pollutant that goes against the notion of a renewable energy source. Yucca Mountain is one of the examples used quite often to prove this point. Most of the opponents in the US also point at the fact that while most renewable energy source could render the US energy independent, uranium would still keep the country energy dependent as US would still have to import uranium.

Safety

Aftermath of the major accidents at Three Mile Island in 1979 and Chernobyl in 1986 and then, recent devastated Japan's Fukushima nuclear power plant frailer in Japan in March of 2011, pretty much nuclear power fell out of favor, and some countries applied the brakes to their nuclear programs. Concerns about climate change and air pollution, as well as growing demand for electricity, led many governments to reconsider their aversion to nuclear power, which emits little carbon dioxide and had built up an impressive safety and reliability record. Some countries reversed their phaseouts of nuclear power, some extended the lifetimes of existing reactors, and many developed plans for new ones.

Despite all these given concerns and issues in respect to the nuclear energy, still we are facing the fact of why we still need nuclear power as clean source of energy, particularly when, we deal with renewable source of energy arguments [11].

Today, roughly 60 nuclear plants are under construction worldwide, which will add about 60,000 megawatts of generating capacity—equivalent to a sixth of the world's current nuclear power capacity, however this movement has been lost after March of 2001 and Japan's Fukushima nuclear power episode.

Nuclear power's track record of providing clean and reliable electricity compares favorably with other energy sources. Low natural gas prices, mostly the result of newly accessible shale gas, have brightened the prospects that efficient gas-burning power plants could cut emissions of carbon dioxide and other pollutants relatively quickly by displacing old, inefficient coal plants, but the historical volatility of natural gas prices has made utility companies wary of putting all their eggs in that basket. Besides, in the long run, burning natural gas would still release too much carbon dioxide. Wind and solar power are becoming increasingly widespread, but their intermittent and variable supply make them poorly suited for large-scale use in the absence of an affordable way to store electricity.

Hydropower, meanwhile, has very limited prospects for expansion in the United States because of environmental concerns and the small number of potential sites [12].

As part of any nuclear power plant safety that one should consider as part of design and operation of such source of energy, is the reactor stability. Understanding time-dependent behaviors of nuclear reactors and the methods of their control is essential to the operation and safety of nuclear power plants. This chapter provides researchers and engineers in nuclear engineering very general yet comprehensive information on the fundamental theory of nuclear reactor kinetics and control and the state-of-the-art practice in actual plants, as well as the idea of how to bridge the two. The dynamics and stability of engineering equipment that affects their economical and operation from safety and reliable operation point of view. In this chapter, we will talk about the existing knowledge that is today's practice for design of reactor power plants and their stabilities as well as available techniques to designers. Although, stable power processes are never guaranteed. An assortment of unstable behaviors wrecks power apparatus, including mechanical vibration, malfunctioning control apparatus, unstable fluid flow, unstable boiling of liquids, or combinations thereof. Failures and weaknesses of safety management systems are the underlying causes of most accidents [13].

The safety and capital cost challenges involved with traditional nuclear power plants may be considerable, but a new class of reactors in the development stage holds promise for addressing them. These reactors, called small modular reactors (SMRs), produce anywhere from ten to 300 megawatts, rather than the 1,000 megawatts produced by a typical reactor. An entire reactor, or at least most of it, can be built in a factory and shipped to a site for assembly, where several reactors can be installed together to compose a larger nuclear power station. SMRs have attractive safety features, too. Their design often incorporates natural cooling features that can continue to function in the absence of external power, and the underground placement of the reactors and the spent-fuel storage pools is more secure.

Since Small Modular Reactors (SMRs), are smaller than conventional nuclear plants, the construction costs for individual projects are more manageable, and thus the financing terms may be more favorable. And because they are factory-assembled, the on-site construction time is shorter. The utility company can build up its nuclear power capacity step by step, adding additional reactors as needed, which means that it can generate revenue from electricity sales sooner. This helps not only the plant owner but also customers, who are increasingly being asked to pay higher rates today to fund tomorrow's plants [14].

With the U.S. federal budget under tremendous pressure, it is hard to imagine taxpayers funding demonstrations of a new nuclear technology. But if the United States takes a hiatus from creating new clean-energy options—be it SMRs, renewable energy, advanced batteries, or carbon capture and sequestration—Americans will look back in ten years with regret. There will be fewer economically viable options for meeting the United States' energy and environmental needs, and the country will be less competitive in the global technology market.

Conclusion

It seems like at the heart of debate lies the confusion over the exact definition of renewable energy and the requirements that needs to be met in order, to be one. The recent statement by Helene Pelosi, the interim director General of International Renewable Energy Agency (IRENA), saying IRENA will not support nuclear energy programs because it is a long, complicated process, it produces waste and is relatively risky, proves that their decision has nothing to do with having a sustainable supply of fuel [15]. And if that's the case then nuclear proponents would have to figure out a way to deal with the nuclear waste management issue and other political implications of nuclear power before they can ask IRENA to reconsider including nuclear energy in the renewable energy list [16].

One more strong argument against fission nuclear power plants as source of renewable energy comes from Dr. James Singmaster in August 3, 2009 and has been republished here as follow:

"The basic problem of the climate crisis is the ever-expanding overload of heat energy in the closed biosphere of earth. Temperatures going up indicate the increasing heat energy overload. Everyone reading this should check out Dr. E. Chaisson's article titled "Long-

Term Global Warming from Energy Usage" in EOS, Trans. Amer. Geophys. Union, V. 89, No. 28, Pgs. 253-4(2008) to learn that nuclear energy, be it fission or fusion, being developed should be dropped with money put into it being put to developing renewable energy supplies using the sun, wind and hydrogen.

The hydrogen needs to be generated from splitting water using sunlight with the best one or two of seven catalysts reported in the last two years. Or with excess solar or wind collection generating electricity, that could be used to generate hydrogen by electrolysis of water.

There is no way that nuclear power can avoid releasing trapped energy to increase the energy overload, so it should be forgotten.

To remove some of the energy as well as some of the carbon overload in the biosphere, we need to turn to pyrolysis of massive ever-expanding organic waste streams to remake charcoal that will be removing some of both overloads. It will require using renewable energy and the pyrolysis process expels about 50% of the carbon as small organic chemicals that can be collected, refined and used foe fuel that is a renewable one. For more about using pyrolysis, search my name on GreenInc blog or google it for other blog comments on pyrolysis.

References

1. Zohuri B (2015) Combined Cycle Driven Efficiency for Next Generation Nuclear Power Plants: An Innovative Design Approach.
2. GE Energy FlexEfficiency 50 Combined Cycle Power Plant, e-brochure (2012).
3. Horlock JH (1997) Cogeneration-Combined Heat and Power (CHP), Krieger Publishing Company, Malabar FL (1997).
4. Mattingly JD (1996) Elements of Gas Turbine Propulsion, McGraw-Hill, Inc., New York, 1996.
5. Mattingly JD, ibid.
6. Zohuri B, McDaniel P, De Oliveira C (2015) Advanced Nuclear Open-Air Brayton Cycles for Highly Efficient Power Conversion, Nuclear Technology Journal.
7. Zohuri B (2017) Inertial Confinement Fusion Driven Thermonuclear Energy, Springer Publishing Company.
8. Plasma Physics and Controlled Thermonuclear Reactions Driven Fusion Energy (2016), Springer Publishing Company.
9. Johnson K, "Is Nuclear Power Renewable Energy," Wall Street Journal.
10. Cohen BL (1983) "Breeder Reactors: A Renewable Energy Source". Am J Phys 51: 75.
11. Zohuri B (2018) Hybrid Energy Systems: Driving Reliable Renewable Sources of Energy Storage 1st ed. 2018 Edition, Springer Publishing Company.
12. Moniz E, http://energy.mit.edu/news/why-we-still-need-nuclear-power/
13. Zohuri B (2016) Neutronic Analysis For Nuclear Reactor Systems, Springer Publishing Company.
14. Fraas AP (1989) Heat Exchanger Design, 2nd Ed., John Wiley & Sons, New York.
15. Kanter J, "Is Nuclear Power Renewable," New York Times.
16. Chowdhury D (2012) 'Is Nuclear Energy Renewable Energy", Stanford Physics Department.