American Nuclear Society 2013 Student Conference – Massachusetts Institute of Technology
Boston, Massachusetts, USA, April 4-6, 2013, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2013)

CARBON DIOXIDE EMISSIONS FROM THE NUCLEAR FUEL CYCLE COMPARED TO EMISSIONS FROM A COAL-FIRED POWER PLANT

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1. INTRODUCTION

The current carbon dioxide emissions from electricity production contribute to global climate change. These emissions can be greatly reduced using alternative energy sources, such as nuclear power, to produce electricity. The life-cycle emissions from a nuclear power plant have been estimated through many methods including direct emission data from the emission origin. This paper attempts to combine multiple life-cycle analyses into a coherent average of carbon dioxide emissions and finally relate the total to that of Environmental Protection Agency estimated CO_2 emissions from a coal-fired power plant, the current leading technology in electricity production in the United States. The analysis covers the entirety of the nuclear fuel cycle from mining through the temporary storage at the reactor using the once through model used in the United States. This analysis finds nuclear power to be a virtually CO_2 emission free when compared to coal, thus making nuclear power a viable low carbon energy source.

2. MINING AND MILLING

The mining and milling of the raw uranium ore has the third largest impact on the carbon dioxide emissions of the fuel cycle. This is due in large part to the concentrations of the uranium ore. The emissions are also dependent on the method of mining used.

2.1. Mining

The most common mining operations use four distinct methods of extraction: underground mining, open pit mining, in situ leach mining and heap mining. The purity of the ore that is being mined largely determines the method used as the traditional methods of mining are only useful for deposits of higher purity whereas chemical mining techniques are needed in cases of lower purity. The emissions from the different mining techniques cannot be directly compared due to the differences in purities.

2.2. Milling

The milling process is dependent on the mining method. For a traditional mine the milling process is straight forward and thus easy to calculate the emissions. This ease is due to the milling process being entirely mechanical and thus the energy consumed can be used to simply back calculate the CO_2 emissions. For chemical mining this is more difficult to calculate as it is not only the mechanical process and calculate the emissions from but also the chemical reactions.

2.3. Total Emissions

The fact that most mine sites also serve as mill sites means that all data is for the combined mining and milling process. While this seems less precise it does allow for better comparison between the methods. These emissions range from 10.3 tons of CO_2 per ton of pure yellowcake uranium oxide (U_3O_8) to 252 tons of CO_2 per ton uranium, depending on the mining process used [3]. The average of these mines produce approximately 1.1 grams of CO_2 per kilowatt-hour electric [1]. This is much lower than the mining of coal due to the large difference in the energy densities of the two products. The mining of coal is estimated to produce 9.7 grams of CO_2 per kilowatt-hour electric [1].

3. CONVERSION AND ENRICHMENT

The milled ore is not able to be used directly in the nuclear fuel cycle, with the notable exception to the CANDU reactor type. This milled ore must be converted from a solid yellowcake into a gas that can then be enriched. The conversion is estimated to produce only 0.2 grams of CO_2 per kilowatt-hour [1].

The enrichment can be done by three distinct methods, two that have any commercial research and one just licensed by the Nuclear Regulatory Commission. All of these methods use a gaseous uranium hexafluoride; thus the conversion is always included in the total emissions of the process. This is the single largest emission source of the entirety of the nuclear fuel cycle.

Emission data is only available as estimates for the gas centrifuge enrichment process in the US. The estimate assumes 70% of the electricity consumed is produced by coal. The total estimate is 15 grams of CO_2 per kilowatt-hour [1]. The emissions from enrichment account for approximately 62% of the total emissions from the nuclear fuel cycle [1]. The emissions from gaseous diffusion enrichment are higher due to the inefficiency of the process. If gaseous diffusion plant is powered entirely by fossil fuels the emissions may be as high as 80 grams per kilowatt-hour electric [2].

The emissions from final fuel fabrication are more comparable to that of the conversion process than that of the enrichment process. The estimated CO_2 emissions form fuel fabrication are 0.7 grams per kilowatt-hour electric [1].

4. NUCLEAR POWER PLANT CONSTRUCTION

While often overlooked in life cycle analysis the construction emissions of a nuclear power plant are not negligible. This is due in large part to the difference between the vast quantities of materials needed in a nuclear power plant that are not needed in the construction of other power plants. A nuclear power plant, on average, requires between 32,000 and 66,000 tons of steel, 44 miles of piping, and 300 miles of electrical wiring. The vast amount of materials require complex mechanical processes in the manufacturing and thus have large amounts of released carbon dioxide associated with them. The construction of a nuclear power plant amounts to approximately 12% of the total life emissions from the power plant or 2.8 grams of CO_2 per kilowatt-hour [1].

The CO_2 emissions from the construction of a nuclear power plant are in line with that of the construction of a coal fired power plant. The difference in emissions from the construction of the two power plants is 0.8 grams of CO_2 per kilowatt-hour electric with a coal fired power plant producing higher emissions [1].

5. POWER PLANT OPERATION

There are not direct emissions from the burnup cycle of nuclear fuel however there are secondary emissions due to the need for backup electrical supply. This is also true for the storage of spent nuclear fuel. For both of these steps in the nuclear fuel cycle the total emissions were calculated showing that the burnup contributes very little to the overall emissions while the storage is a large percent due to the transportation. The storage does not contribute a large portion to the total emissions even with the transportation included. It amounts to approximately 0.7 grams of CO_2 per kilowatt-hour [1].

6. CONCLUSIONS

The nuclear fuel cycle is not a truly emission free source of energy; however it does produce far fewer emissions than coal thus making it a better option for baseload power. The current emission estimate ranges from approximately 22 to 69 grams of CO_2 per kilowatt hour electric for nuclear power [1,2,5]. The highest emission rate estimated is 288 grams of CO_2 per kilowatt hour electric, this is still far lower than the 705.6 grams of CO_2 per kilowatt-hour electric produced by a coal fired power plant [2,4]. This can further be improved by the use of low emission power sources to operate the conversion and enrichment plants as well as the mining and milling operations.

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