Goodrich Testimony Oregon House Bill 3445

5/19/15

Thank you for having this hearing on House Bill 3445. My name is Sam Goodrich and I am currently pursuing a PhD in Nuclear Engineering at Oregon State University. I appreciate the opportunity to make a statement regarding nuclear energy in Oregon.

The sources of energy we use to power our lives are diverse, but they can be subdivided into two groups: those whose ultimate source is the sun, and those which provide useful energy independent of the sun. In order to power the industrial revolution and beyond, mankind has tapped into deep reserves of stored solar energy in the form of fossil fuels. Burning millions of years of stored carbonaceous energy from the sun over a handful of decades is resulting in global consequences that are difficult to understand and quantify because of their complexity and severity. Carbon dioxide has been singled out as the primary threat associated with fossil fuel consumption though there are many negative externalities resulting from fossil fuel dependence such as decreased air quality and pollution. Sources of energy that don't trace back to the sun include geothermal, tidal energy and nuclear. Of these, only nuclear has been harnessed at a meaningful scale.

Nuclear energy derives from reactions at the level of the atomic nucleus, whereas combustion only scratches the atomic surface by re-arranging a few electrons in the outer shell of an atom. This difference accounts for a staggering discrepancy in energy density. One molecule of methane combusting releases approximately 9 eV of energy, whereas splitting the nucleus of one atom of Uranium-235 (fission) results in the release of approximately 200,000,000 eV of energy (a difference of over twenty million). One example of how this energy density may be harnessed is the way our nuclear-powered aircraft carriers and submarines circumvent the globe over and over without ever needing to be refueled for the life of the ship. Another way we can tap into this vast energy source is by using it in commercial nuclear power reactors to convert heat into electricity.

In 2014, the state of Oregon derived approximately 59% of our electricity from conventional hydroelectric power stations. The remaining portions were natural gas (21%), wind (13%) and coal (5%) with the remaining 2% spread across a variety of sources [1]. While this energy mix is one of the most respectable for any state in the Union with respect to renewables, 26% of the electricity generated in Oregon in 2014 was generated from the combustion of fossil fuels [1]. This combustion of natural gas and coal in Oregon (producing 10^{15} Joules of energy) resulted in the emission of 11.1 million tons of carbon dioxide into the atmosphere. In order to put this into perspective, that's a little less than twice the mass of the Hoover Dam [2, 3]. In the year 2014, there were approximately 1.9 million passenger vehicles registered in the State of Oregon (see Appendix A) which produced a total of 9.8 million tons of CO_2 in that year. So, even if every single passenger vehicle in Oregon were eliminated, it would not have as large of an impact on the state's carbon dioxide emissions as building a single nuclear power plant to replace our natural gas and coal-derived electricity.

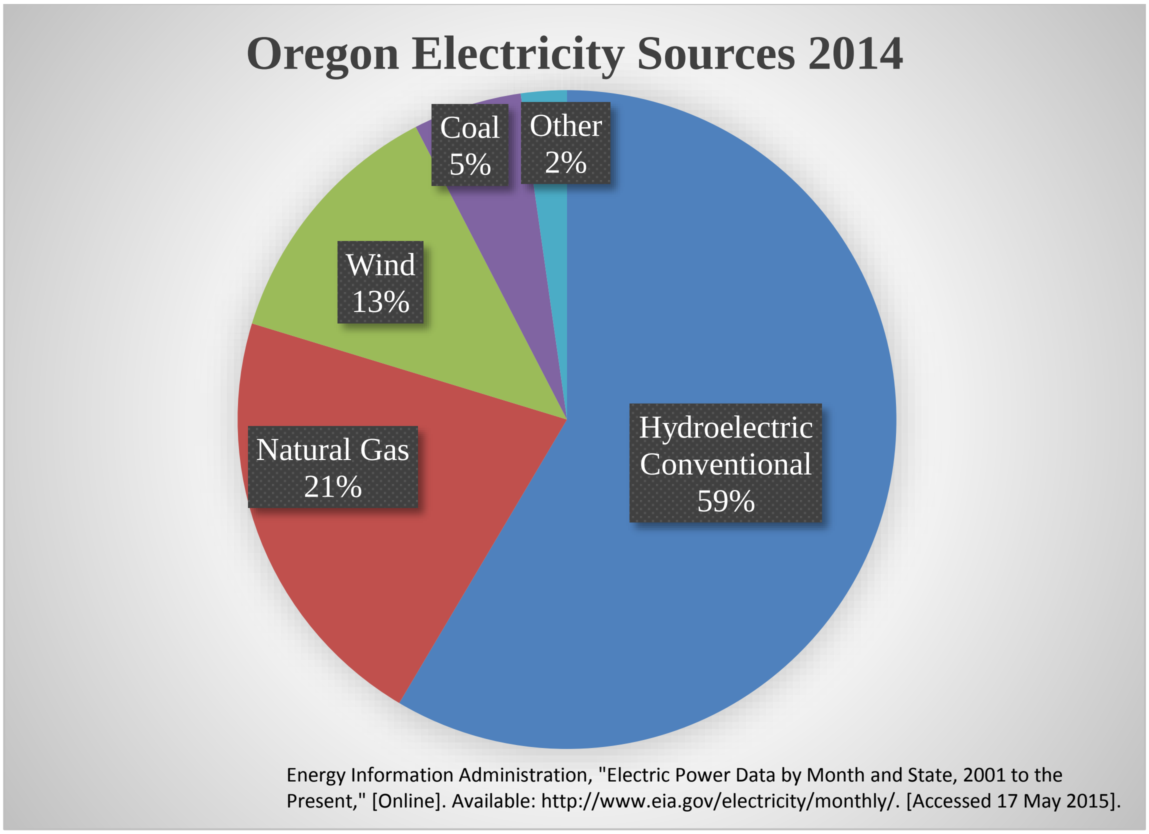

Figure 1 Relative Oregon Electricity Sources

If CO_2 reduction is a goal that Oregon voters care for, then the metaphorical low hanging fruit in this case is replacing fossil fuels as a source for electricity. According to the Energy Information Administration, nuclear energy has an overnight capital cost of $5530 per kWe installed capacity, with a 91.7% capacity factor (in 2014) [4, 1] where capacity factor indicates what percentage of possible power is generated by the plant, averaged over time. Replacing the current 1.8 GW of fossil fuel electricity with a nuclear power plant (likely a dual unit) would have a capital cost of approximately $10.9B. There may be a certain amount of sticker shock and perhaps there are better carbon-free alternatives.

The estimated capital cost of 1.8 GWe of solar photovoltaic can be found using the same methodology. While the capital cost is about 2/3 that of nuclear ($3873/kWe), the capacity factor for PV in Oregon is about 12.7%, meaning that for 1.8 GW of electricity to be produced, 14.2 GWe of solar PV capacity would need to be installed [4, 5] at a cost of approximately $55.1B. For the case of wind, having a lower overnight capital cost and higher capacity factor than solar PV ($2213/kWe and 33.9%, respectively), the capital cost would be approximately $11.8B. Solar and wind alone in such large percentages of the electric mix would likely de-stabilize the grid requiring approximately $5B more in battery storage if 12 hours of capacity (2.1×10^7 kWhr) were installed, which may require additional capital for windmills and solar panels to charge the batteries during peak production times [6]. This data is summarized in Figure 2.

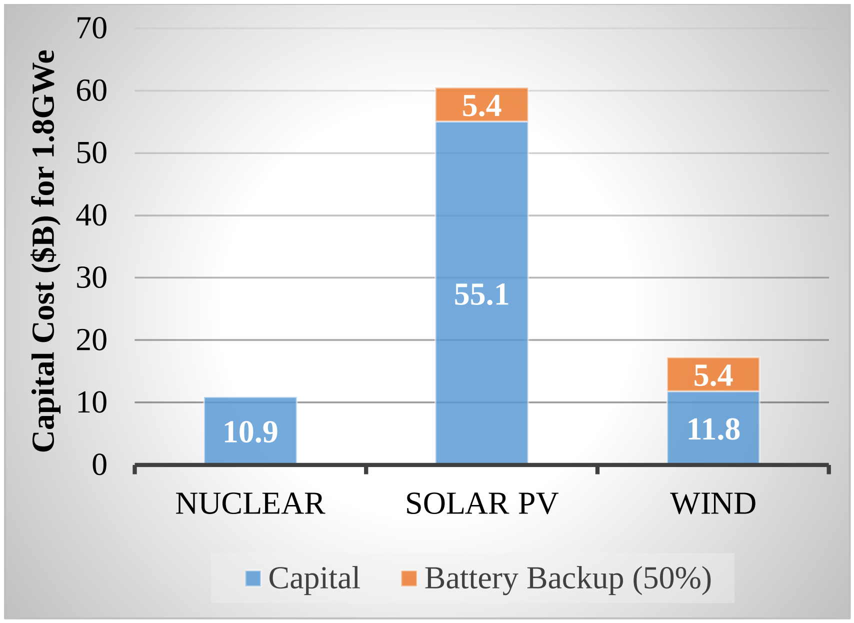

Figure 2 Capital cost comparison of carbon-free electricity sources [1, 4]

In addition to the capital cost associated with carbon-free electricity sources, there is a land cost as well. For 1.8 GWe of electricity generation, a dual unit nuclear power plant would have a land requirement of approximately 0.2 square miles, while solar and wind would take up approximately 861 and 521.5 square miles, respectively (see Appendix B). To give some perspective the solar land requirement is approximately the same size as Representative Mark Johnson's Hood River District or, for another reference, roughly the size of Sherman County. Certainly Representative Johnson wouldn't likely consider his district small after campaigning across it in 2010 and 2012.

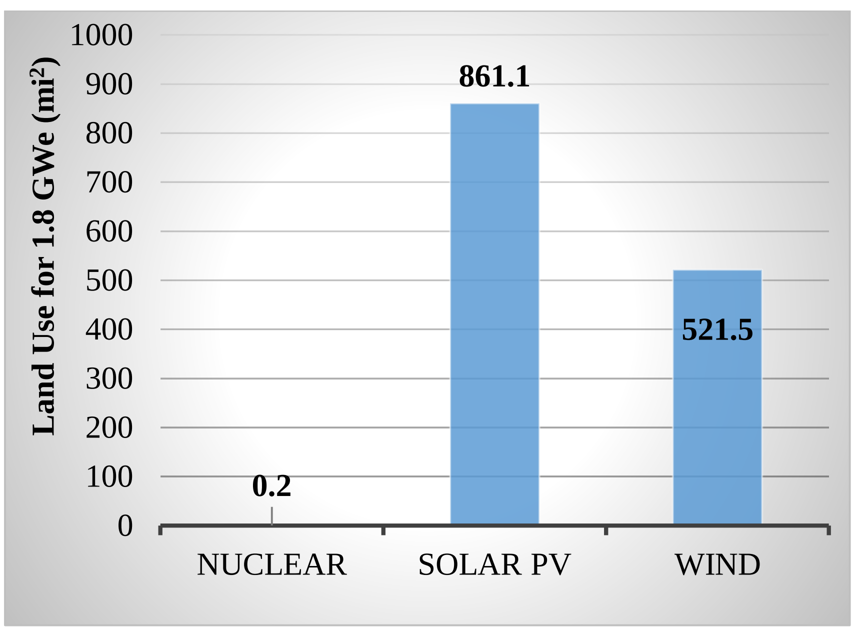

Figure 3 Land use for carbon-free power sources

One might look at the Oregon electricity pie chart and wonder why, if hydroelectric has served our state so well in the past and present, why not stick with a good thing and simply expand hydroelectric capacity. This is a complicated question but the summary is essentially that although there are enough un-tapped or under-utilized rivers in Oregon to add as much as 3 GWe to the Oregon electricity grid, 99% of those waterways impact a species listed under the Endangered Species Act, 99% of them intersect protected lands, in addition to other complicating factors [7]. Essentially, we may have installed too many dams in Oregon as it is, and certainly adding more may lead to negative externalities that outweigh the benefit of carbon-free electricity.

Conservation and energy efficiency, while extremely important, will not by themselves solve the energy problem because in order to conserve energy, there needs to be energy to conserve. Additionally, energy usage per capita is strongly correlated with quality of life, and Oregon's 0.45kWe/person is well below the 5kW threshold at which the highest quality of life with current technology can be achieved (i.e. hospitals, lights, communication, education, food quality, and hygiene)[1] [8].

Every energy source has advantages and drawbacks. There is no silver bullet to providing Oregon with the energy it needs to keep our economy thriving. However, if an intellectually honest and reasoned approach is taken toward the analysis of the energy problem, certain options will differentiate themselves as being more appropriate than others. The practice of extracting millions of years of stored carbon from the ground and releasing it into the environment has real and global consequences, and the first large step for Oregon to take toward a solution is to open a dialogue about the possible re-introduction of nuclear power into the state. Being a nuclear engineer, people often ask me whether I think nuclear power has much of a future in the world and I usually tell them the same thing: I think that if people want to maintain their lifestyle and be good stewards of the environment, then it is inevitable that nuclear energy will play a large role in powering our future.

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[1] 5 kW per person would also include the total energy consumed by that person, including food, transportation, and industry supporting their lifestyle

Appendix A – Passenger Vehicle Estimations

From [9], one finds this quote: “In 2011, the weighted average combined fuel economy of cars and light trucks combined was 21.4 miles per gallon (FHWA 2013). The average vehicle miles traveled in 2011 was 11,318 miles per year.” From other sources one finds that in the year 2000 there were 134 million passenger vehicles and 281 million people in the United States [11, 10]. This data was used to estimate the number of passenger vehicles in Oregon by finding the number of passenger vehicles per capita in the year 2000 and multiplying it to Oregon’s population of 3.97 million. This resulted in an estimate of 1.9 million passenger vehicles in Oregon. Gasoline combustion emits approximately 8.9 kg of CO_2 per gallon of fuel, and so Oregon’s total CO_2 emission due to the operation of passenger vehicles (assuming they maintain the FHWA average mileage from 2013) is 8.86×10^6 tons. This is approximately 13% less than what is generated burning natural gas and coal for 1.8 GWe of Oregon’s electricity production.

Appendix B – Land requirements

From [12] [13], one can establish that there is about 240 W/m^2 of solar radiation that reaches the earth's surface that can be harvested by PV solar panels under the best of circumstances. For large swaths of Oregon, especially those cloudier regions the average can be much lower, such as in Gladstone where the average from 1980 to 2006 was only 142 W/m^2 [14]. If one assumes a PV efficiency of 15% [15], and the capacity factor of 12.7% [5], and a solar irradiation annual average of 160W/m^2 (to account for Oregon weather as well as losses due to dirt and other factors) then the total installed PV capacity required to make up for the removal of 1.8 GWe of fossil fuel is 14.2 GWe and the total area taken up by this array is approximately 860 square miles.

The largest wind array in Oregon in 2009 was the Biglow Canyon Phase 1 site at 400 MWe and it takes up a land area of 25.31 hectares/MWe [16]. For 1.8 GWe from wind power, with a capacity factor of 33.9%, there would need to be 5.37 GWe of capacity installed and land use would be approximately 521 square miles, though with wind power the space taken up on the surface of the ground is mostly the base of the windmills, which in this case would total to about 1.3 square miles, with debatable functionality of the space between the windmills for other uses.

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