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NUCLEAR POWER

And It's Emerging Role in Green Energy

Abstract

A report on the efficacy of alternative green methods of energy production.

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Green & Sustainable Energy

What is it, and why do we need it?

"Green" energy, simply put, is energy with a minimal impact on our environment, the greener it is, the less damage it does. Renewable energy is energy that will last for such a long time that it may as well be considered unlimited, as in that time it will have renewed itself, quite like taking the energy from a star, as in solar power.

No matter your opinion on the level of damage we are taking out on the planet, we can at least agree that a smaller impact on our environment, local or global, especially such things as our liveability in it, and the preservation of other species, essential to the upkeep of certain ecosystems, is both a noble goal and a necessary one. Some models propose climate change apocalypse within the next 50-100 years, while others suggest a loss of greater than 50% of species on our planet within a similar timespan. Whether we need it fast or not, looking for cleaner, longer-term, and more reliable sources of energy is surely an admirable and useful goal for our society.

What are our options?

Currently, our greatest energy producers globally are coal (40.8%), natural gas (21.6%), and Hydroelectricity (16.4%). Renewables such as solar, geothermal, and wind, make up 6.3%[1]. Coal is often heralded as the worst of these, given its contributions to climate change. The idea here is that when burnt to create heat, the carbon that is the main contributor to the chemical makeup of any coal joins with oxygen in the air, i.e. in combustion, producing carbon dioxide which then contributes to climate change. Natural gases on the other hand are chemically composed of hydrocarbons – compounds made up of hydrogen and carbon atoms. When burnt, they react with oxygen to produce Carbon Dioxide, and Water (H2O). Many argue that the effects on our atmosphere are exaggerated and are unrealistic for the time span of humanity. While it is true that it is often exaggerated by the media to the extent that we will suffer from these effects, i.e. in the case of the apocalyptic predictions that have been given for the past 100 years by parts of the scientific community, the evidence that some affect is being had on our atmosphere, globally, or even locally in areas around industrial production, such as in places like Beijing, where many wear facemasks for the amount of pollution found in the air. Based on this, what is seen left are the renewables, which seem like a godsend in the way they are portrayed by our society. Some of these do reflect their portrayal, and are perfectly reasonable, such as hydroelectricity, but for others, namely solar, there is in fact much left to want from a perfect energy source. Solar energy, although not commonly known, produces great amounts of waste, because of how unreliable they are in bulk. There are currently no laws requiring those using solar to have plans for proper disposal of waste. The average solar panel lasts around 25 years, based on which, given we would want to use them in such a great amount, the wastage created would be 34,000 cubic metres for every Trillion kilowatt-hours of energy produced[2]. For reference, in 2013, the world energy production was 19,504 Trillion kilowatt-hours. Both solar and wind, to be a stable energy source, either need massive breakthroughs in battery technology to be viable, given that they only function for some parts of the day, or need a backup power source. Geothermal also needs similar breakthroughs in energy transport and deep

[1] International Energy Agency, 2017, *Key World Energy Statistics*, https://www.iea.org/publications/freepublications/ [10/05/19]
[2] Environmental Progress, 2019, *Are we headed for a solar waste crisis?*, http://environmentalprogress.org/big-news/2017/6/21/are-we-headed-for-a-solar-waste-crisis [13/05/19]

boring to be able to make its systems produce more energy than they take in, in most areas of the world. All three of these energy sources use great amounts of many materials, such as concrete, steel, and glass, all per unit of energy of course[2].

Introduction to Nuclear

Another option, which accounts for a further 10.6% of energy production[1], is Nuclear power. Nuclear power produces no greenhouse gases in energy production, as it utilises nuclear reactions for energy, rather than combustion reactions. It also has less construction costs per unit of energy than solar, geothermal, hydroelectric, or winds, being only beaten by solar in less use of concrete (a ratio of 76:35), while solar still uses ~50x as much steel as nuclear[2].

How does it work?

Nuclear powers defining quality is the usage of nuclear fission, the splitting of atoms, to create heat. This heat is transferred into some substance, known as the coolant, usually water, to produce gas, which rises through the system to spin a turbine, producing kinetic energy, then able to be converted into electricity. The most common implementation of this system is known as the "lightwater" reactor model. Lightwater reactors use water as their coolant, and uranium-235, a specific isotope of uranium, as a fuel. Alternate methods include thorium power, which hasn't entered commercial use yet, but is in the process of doing so. A theoretical energy source that many cite as being a better alternative is the usage of fusion rather than fission reactions, to combine rather than break apart atoms. Fusion has not yet been created such that it produces more energy than it consumes, which for now seems unfeasible for many reasons we will delve into later.

What are the issues related with it?

In terms of nuclear weaponry, we can describe how this process is affected by nuclear power. Nuclear fuel, the uranium-235 is normally mixed with less potent uranium-238. Nuclear weaponry requires extremely energy intensive enriching of this already enriched fuel to above 90% uranium-235. This means that the proliferation of this form of uranium into nuclear weaponry isn't just something one can whip up in their backyard, but is still quite capable of happening, although nuclear power itself doesn't really help the process, as the enrichment done there is nearly negligible relative to the power required to enrich to a weapon-cable point. US-based warheads often also utilise plutonium-239, an artificial transuranic element which is quite hard to manufacture in bulk or sometimes at all, to reduce the required uranium for warheads. This element isn't naturally occurring, so its usage doesn't pose an issue to the ease-of-creation of these bombs generally. Development of nuclear techniques can however arguably contribute to development of nuclear weaponry techniques. A little-known idea of nuclear weaponry is the use of depleted uranium, i.e. used nuclear fuel with very little radiation left over as a construction material in military ammo or vehicle/tank plating, as it is an extremely dense material. One could make the argument that this increases violence and war, making the classical "war bad" fallacy, and suggesting "why can't everyone just be nice". This argument is a little naïve in terms of human nature and other factors, but the ability of a country to use spent nuclear fuel as material in other uses not only reduces wastage by a form of recycling, but promotes the stalemate created by power between countries. For example, any two countries with nuclear warheads have huge incentive not to fight each other, as the use of nuclear warheads would trigger nuclear war, which no one would want, as most people don't find it preferable to die by nuclear explosion[3]. This idea is explored in the cited paper, which argues that the spread of nuclear weapons may better the world by reducing the incentive for war. Many would criticise the idea of this, in terms of accidental firings, and other things, but given that we don't have international power, a single country having nuclear warheads may suggest that it is safest for multiple others to have them as well. Perhaps a world without them would be better, but if anyone has them, why not allow everyone to wield equivalent power.

Aside from proliferation, the main issues presented against nuclear power are feasibility and waste storage. The feasibility argument can be broken into two parts: start-up costs, and construction time. Yes, the start-up cost is quite quickly paid back from a business perspective, but many power plants are left unfinished because builders went bankrupt from this process[4]. Some in this industry, or even from an analysing point of view argue that governmental regulation is to blame. A study showed that between 2005 and 2014 both nuclear regulations and maintenance/operational costs were increasing, and throughout this time there were more than 1000 regulations to every million dollars in maintenance costs[5]. Given that we are presenting an argument in this report for nuclear powers legalisation in Australia and other countries, this goes with wanting to reduce their regulation, which right now sounds like a horrific thing, but as explored later in this report in the section on nuclear accidents, it isn't as concrete as it seems. A comprehensive list of shut down/cancelled nuclear projects in the USA, one of the leaders of nuclear technology and usage shows that most projects are not cancelled from construction costs, as is often portrayed, but are cancelled at the planning stage[6] due to either feasibility issues, in which case relatively little money is lost, or in regulatory issues in which case money can be lost from organisational costs, paperwork/processing costs, and in both cases in land purchasing costs. So, the idea that reactors are often left as this unfinished shell is extremely rare, at least in developed countries where economic growth allows for the use of nuclear power. Despite this, it is not rare for reactors themselves to get cancelled. Millions were lost in the nuclear boom in the USA from cancellations due to an overestimation of the energy market's needs, describing a major failure. Beyond this, 30 new reactors in the USA were planned in 2009, only two of which are still under construction. Based on this, it is clear to see that the governmental subsidies that contributed to nuclear are rather unwise as with most new production schemes, and it would have been best to leave it to a market decision. Secondarily in feasibility is the exorbitant construction time for nuclear power. These times can range between 5-30 years, with an average of 7.5 years, and 85% of reactors being below the 10-year mark[7]. There was also no correlation found between construction time and years run for, and most commonly problem reactors had very long construction times and were of the Russian/Soviet VVER V models. This construction time is more than other forms of electricity and is often criticised as we supposedly don't have time in the wake of climate catastrophe for nuclear. This argument is quite useful and does describe a flaw in the nuclear ideology in current society, but this does not call for heavier regulation around the subject, as a market decision for nuclear

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[3] International institute for Strategic studies, Kenneth Waltz, 1981, *The Spread of Nuclear Weapons: More May Better*, https://www.mtholyoke.edu/acad/intrel/waltz1.htm [25/05/19]
[4] Union of Concerned Scientists, Unknown Date (recent), *Nuclear Power Cost: Cheap Dreams, Expensive Realities*, https://www.ucsusa.org/nuclear-power/cost-nuclear-power [25/05/19]
[5] American Action Forum, 2017, *Putting Nuclear Regulatory Costs in Context*, https://www.americanactionforum.org/research/putting-nuclear-regulatory-costs-context/ [6/06/19]
[6] Wikipedia Listing, 2019, *List of Cancelled Nuclear Reactors in the United States*, https://en.wikipedia.org/wiki/List_of_cancelled_nuclear_reactors_in_the_United_States#cite_note-IAEA_PRIS_US-6 [7/06/19]
[7] Euan Marns, 2016, *How long does it take to build a nuclear power plant?,* http://euanmearns.com/how-long-does-it-take-to-build-a-nuclear-power-plant/ [7/06/19]

wouldn't come at detriment to the issue. Further than this, the construction times for alternate energy sources, wind, solar, and mostly hydro, are only quick and dirty to set up for low amounts of power. To try and supply a whole world or even country on renewables takes more than a few years of innovation. So yes, construction time is a large issue, but in terms of the issues we have at hand it is not nearly enough to justify the rejection of nuclear, not even a reason to consider it.

The final unmentioned issue of nuclear power is waste storage and radiation safety around it. As the basis for arguing this case, we need to know the three types of radiation. Alpha: released Helium atoms, stoppable by a few sheet of paper; Beta: electrons or positrons, stoppable by a sheet of aluminium foil; and Gamma: concrete or lead casing is needed to stop it, this stuff is the stuff we care about and may penetrate skin, and cause the cliched poisoning we all hear about. Gamma radiation is a form of energy, which we are exposed to everyday through background radiation from UV light and other sources. The average amount of natural radiation is measured at ~1.5 millisieverts per year, with a healthily sustainable amount of 10 millisieverts per year[8]. The issue with gamma radiation comes from what is known as ionising radiation – radiation that can change the structure of an atom and therefore in bulk can create changes in somethings chemical makeup, creating mutations or alterations. Medical procedures such as CT-Scans and X-Rays expose us to this radiation at rates of 5 millisieverts and 0.06 millisieverts respectively. In nearly all nuclear-enabled countries, nuclear is one of the only energy sources that by government mandate takes care of all its waste, rather than dumping it for landfill. This is not just because it is toxic, but because it is thought about much more than other waste issues for toxic (heavy-metal rich) wastes such as defunct solar waste, and thermal generation waste (see intro). Geological waste storage plans have been developed in most nuclear countries and has been assessed as an extremely safe and viable solution. Some suggest that geological storage can still bring radiation to the surface, but the radiation emitted once absorbed does such a little amount of change that an underground solution would first pose no problems of radiation to future generations, and wouldn't poison or render surrounding land infertile like a fallout might, or heavy metal industrial wastes do[9]. Based on this, the important point to take away is that waste can cause some damage, but only if not contained properly, which it nearly always is, because there is a great legal incentive to, and also the developers of nuclear power would only be able to create energy if surrounding populations are not damaged by it, so the great incentive to store this waste properly is much greater than what is gained from simply dumping it.

Nuclear Usage

Nuclear Accidents/History

Often cited sob stories and arguments against nuclear are the few mass nuclear accidents that have happened, and the damage caused. These include the Chernobyl, Three-Mile Island, and Fukushima reactors. Two of these three accidents were cases of what is known as Nuclear Meltdowns. Meltdowns happens where the fuel in the reactor melts, due to design/construction flaws, or incorrect operation of the plant, most often by human actions. When the reactor core is heated way above its operational temperature, via incorrect operation of control rods in the reactor, the fuel inside will melt and then become gas, and is released by the plant into the atmosphere. This release

[8] ARSPANSA, 2015, *Ionising Radiation and Health*, https://www.arpansa.gov.au/sites/default/files/legacy/pubs/factsheets/IonisingRadiationandHealth.pdf [13/06/19]

[9] World Nuclear Association, 2018, *Storage and Disposal of Nuclear Waste*, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/storage-and-disposal-of-radioactive-wastes.aspx [13/06/19]

then falls from the sky, resulting in what is known as Nuclear "Fallout". This fallout can irradiate surrounding crops, land, and most living matter, including humans. Major chemical releases from this fallout include iodine which may be produced by decay of the fuel. Iodine and other chemicals, when in the released radioisotopes is poisonous to humans. However, the human body will reject these chemicals in digestion, the main source of radiation intake and poisoning from fallout, if the body already has great amounts of the chemical (relatively). This amount needed is quite low, as the body does not greatly rely on these chemicals. As such, iodine, as well as other radioisotope tablets often stored for this occasion to be supplied can counteract most short-term effects of fallout.

The usage of these tablets is employed in most nuclear safety plans and was used after the Fukushima accident resulting in death counts ranging from no deaths[10] by irradiation from the plant, i.e. in the form of cancers and other poisoning, to a few hundred (most of which), with an unknown but negligible increase in cancer in later life. No workers died from radiation/reactor activity-based deaths during the accident. These numbers may confuse some that have heard of thousands of deaths from this accident, but the real damage caused was by the ~25,000 deaths caused by the tsunami that triggered the accident. Given how little the increase in deaths seemed to be, especially after an unavoidable event, it is reasonable to rule out Fukushima as a useful example of death by nuclear meltdown. As for the economic damage caused by this meltdown, within 5 years, food contamination in the area was at approx. 0.1% of food being contaminated, and crops and forests still thriving in the surrounding areas, despite high radiation. The radiation caused in the area decreases in a depreciating way, such that high radiation will be around for a long, long time, but nowhere near as high as at the accident. This exposure is at an unhealthy amount, but not to such a degree that it is immensely dangerous (0.1-1 millisieverts)[11]. Hazardous material equipment is not required unless directly entering the reactor buildings core section. Governmentally gathered stats on the radiation have long been claimed to be skewed by many factors, including placement and surrounding cleaning of the area.

The second oft-cited source is the Three Mile Island accident, is described as the largest nuclear accident in US history, hence the high attention. The accident here wasn't actually a case of nuclear meltdown or fallout but was caused by a leakage of irradiated coolant (pressurised water) from incorrect operation of the plant. This leakage exposed around two million people in the surrounding area of the plant to receive a dosage of around 14 micro-sieverts of ionizing (damaging) radiation, fourteen one thousandths of a millisievert[12]. An increase in radiation could not be found in soil samples in the surrounding area, and radioisotope release was mostly contained, releasing some amount of noble gases (non-dangerous), and iodine-131 on a very low level. The counted deaths from this was zero short term, and an unknown or negligible amount of increase in later life cancer.

The final example, and the most famous for its damage is the Chernobyl reactor meltdown in soviet-controlled Russia in 1986. The Chernobyl reactor was a common form of Russian reactor, the RBMK, or in English the "High Power Channel-Type Reactor". The reactor was undergoing a safety test, to simulate the effects of an electrical power outage, for development of safety procedures. The supposed cause of the meltdown was the incorrect fulfilment of safety procedures by staff, and some design flaws in the RBMK type reactor, resulted in dangerous circumstances. Afterward,

[10] American Nuclear Society, 2011, *Fukushima Accident: Radioactive Releases and Potential Dose Consequences*, http://www2.ans.org/misc/FukushimaSpecialSession-Caracappa.pdf [17/06/19]
[11] IRSN, 2016, *Fukushima Daichii in 2016: Environmental Impact*, https://www.irsn.fr/EN/Pages/home.aspx [17/06/19]
[12] International Atomic Energy Agency, 2006, *Environmental Consequences of the Chernobyl Accident*, https://inis.iaea.org/collection/NCLCollectionStore/_Public/13/677/13677904.pdf [17/06/19]

emergency safety systems were intentionally disabled in order to counteract some issues, resulting in a chain reaction of the nuclear fuel in the core, resulting in a large outbreak of fire in the complex, namely the reactor core[13]. Because of these great inefficiencies in soviet design and operation, radiation was released into the air, causing radiation poisoning for a large amount of people. The actual number here is often disputed, as the UN has placed casualties at around 4,000 radiation related deaths (not including fire deaths in the plant), whereas environmental groups such as Greenpeace have placed this number at around 200,000 people[14]. It is highly disputable as to the biases between such groups, but Greenpeace having an already anti-nuclear agenda, versus the UNs more general political peace agenda, seem to have greater stake in which way this assessment goes.

These big three accidents show, that the wider effects on the environment from nuclear accidents can be large, but the exaggeration shown in most media sources is way off the actual figures. This is quite visible in the death statistics for each energy source as shown in the introduction section of this report. As for the effects on crops and plant life, as well as liveability, with only 6 accidents causing damage to more than a localised region in the entire lifetime of nuclear fission, the costs here of 5-20 years of crop failure in a region, and 3-8 years unable to live there, do not come close to the major benefits of providing people with cheap and reliable energy, saving many more lives than it takes.

Further Hopes for Nuclear Technology

As for where we can take nuclear from here, many options have been found for improving, or completely overturning the nuclear industry. The three main innovations that have been made or are being worked on are Fusion, rather than Fission, such as the energy created by our sun and other starts, the use of incredibly potent and cheap thorium as reactor fuels, and the discovery and development of Molten Salt Reactors (MSR) as a form of reactor that makes nuclear tens of times safer, prevents meltdowns entirely, and most of all doesn't use a high pressure coolant.

The first of these innovations, fusion, has been under research for a long time now, and once looked like a solution to all our nuclear problems, but innovation has slowed, and looks now like a pipe dream, or will take too long to develop that it isn't a solution for at least fifty years.

Thorium is an element that when occurs in the fertile isotope thorium-233, which when a neutron is added to to make thorium-234, decays into an artificial and fissionable isotope of uranium, uranium-233. Thorium is extremely common, and has the greatest deposits found in Australia followed by the USA. As well as this, thorium is found all as isotope 233, not that unenriched uranium stuff. This seems like an amazing fuel, and our deposits of it could last hundreds of years for the whole world just on what portion we have discovered. Unfortunately, this potency means it is, which great research, easily convertible into nuclear weaponry. For this reason, many suggest mixing it with depleted and useless uranium fuel, as when mixed these elements are extremely hard to separate, i.e. via new and more complex enrichment methods. Given that any country could decide to utilise thorium for weaponry, it is probably better that we all can, as mentioned previously in the issues with nuclear section.

The last major innovation in nuclear has been made around the MSR, and was derived from a US military experiment known as the MSRE (molten salt reactor experiment), which was hidden under

[13] Brad Eden, 1999, Encyclopedia Britannica CD 99, *Electronic Resources Review* [20/06/19]
[14] Irish Times, 2019, *Chernobyl Anniversary: The disputed casualty figures,* https://www.irishtimes.com/news/world/europe/chernobyl-anniversary-the-disputed-casualty-figures-1.2595302 [20/06/19]

military confidentiality for decades. The experiment involved the development of a smaller reactor, for function on military vehicles, such as ships or planes, meaning it needed much lower chances of accident. Through the development of the MSRE which ran for four years, and provided enormous amounts of energy (relatively), the usage of molten salt as a coolant was born. Molten salt, unlike the pressurised water in a PWR doesn't need pressurising, and as such in many times less prone to leakage and further damage from pipe/valve failure. As well as this, the operational temperature for molten salt reactors is so low that it is virtually impossible to raise it to a level where the fuel can melt, i.e. causing a meltdown, and then nuclear fallout. Not only does this make it extremely safe, it removes the need for large exclusion zones, making the footprint of the plant hundreds of times smaller, as well as removing the need for cooling towers, which make up the bulk of reactor material costs, as well as containing the most concrete, the process for making which releases massive amounts of CO_2[15]. As this was under military guard for many years, just before disposal it was remembered, and archived, and now multiple Canadian companies are developing and passing through plans to build these reactors, but of course this bureaucracy can take tens of years. Even so, this solves many problems posed against nuclear, despite its already amazing attributes.

Concluding

In conclusion, because of the nature of nuclear accidents as rare but highly dangerous, most of us see it as a great evil, and not something for humanity to exploit, but looking deeper into the overall statistical damage, if we start investing in nuclear power soon, it may lead us to a massively more prosperous future than otherwise.

[15] Oak Ridge National, 2016, *The Molten-Salt Reactor Experiment*, https://www.youtube.com/watch?v=tyDbq5HRs0o [20/06/19]

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