NUCLEAR POWER, ITS WASTE IN THE WORLD AND IN TURKEY

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INTRODUCTION

Nuclear power plants were born in 1950s. Taking only 30 grams of used fuel annually for a person's energy consumption many countries built their own nuclear power plants. In this story, there is the fuel on one hand and the waste on the other. In general sense, used up fuel rods from nuclear reactors and the waste from reprocessing plants are referred to as nuclear waste. These wastes can be stored for decades in the cooling pools of nuclear reactors (world-nuclear.org). Nuclear power plants are only one source of nuclear wastes, the others are medicine, research facilities, oil and gas extraction, mining, etc. Not all of this waste is produced inside reactors, but they come from concentrated natural structures. This waste is divided into three categories, yet, the boundaries between the categories differ from country to country.

- High Level Waste (HLW): This waste is still very radioactive and continues to produce heat. Only 2% of nuclear waste falls into this category but 98% of radioactivity comes from this. They are transported by dry cast storage containers which weigh 100 tons when empty and can contain 12 tons of HLW and cost €1.5 million each. If used reactor fuel is to be reprocessed, the final liquid HLW product needs to be solidified. This product is made into a glass of borosilicate.
- Intermediate Level Waste (ILW): It usually comes from reprocessing plants, research facilities and turned-off reactors. They are transported by several cylindrical containers that are painted yellow for identification. The wastes are compressed to save from volume.
- Low Level Waste (LLW): This category is still radioactive and produces a small amount of heat but does not require cooling. The majority of all nuclear wastes are considered LLW. Like ILWs, they are transported by several cylindrical containers that are painted yellow for identification. The wastes are compressed to save from volume.

Nuclear Waste	Share	Radioactive content
HLW	3%	95%
ILW	7%	4%
LLW	90%	1%

Table: Nuclear waste categories (world-nuclear.org)

Some of the nuclear waste keep generating heat, some of HLW and ILW can heat up their close surrounding up to 200ºC. Next, not only nuclear power plants but also medical centers, industry, and the military produce nuclear wastes.

Nuclear waste cannot be recycled like conventional wastes. They are carried to repurposing plants to gain plutonium which is used for building weapons. There are only two such facilities in Europe, one in England (accepting waste from the UK, Japan, Germany, Switzerland, Spain, Sweden, Italy, the Netherlands and Canada) and one in France. Yet, not all states carry out repurposing, for example, Germany banned transportation of nuclear waste to reprocessing plants in 2005 since they see it hazardous to the environment. Plutonium oxide is sometimes mixed with uranium oxide that gives us MOX, mixed oxide fuel (world-nuclear.org). Technetium-99 containing liquid LLWs can be discharged into the sea. This tracer isotope can be distinguished for hundreds of kilometers. However, the amount of radiation received is lower than naturally occurring background radiation (world-nuclear.org). For the special case of the USA, an MIT study on nuclear power summarizes the current situation as follows (The Future of the Nuclear Fuel Cycle, 2011).

- Nuclear waste cannot be destroyed; therefore, a permanent repository is needed.
- Spent nuclear fuel from LWRs can be processed in order to recover the fissile and fertile parts to be reused in forthcoming days.
- Waste management did not occur as an integrated part of fuel cycle.
- There is no integrated waste management plan in the USA for nuclear wastes.
- Waste management in the USA saw practical and official letdowns.

Afterwards, generating power from uranium requires an extra step: enrichment. Only 7 parts in 1,000 uranium atoms are the required isotope of Uranium-235 that is fissile. From 7/1,000, enrichment takes the concentration to 2 to 4% in a process which also produces depleted uranium which cannot be used. In the end, for every 1 ton of enriched uranium, 7 tons of depleted uranium is formed (Seibert, Nuclear Waste).

Depleted uranium is stored as uranium hexafluoride which is a gas that is radioactive and highly toxic. Scientists are still in search of disposal methods for this gas as only in the USA approximately 700 kilotons of it is stored (ead.anl.gov). Adding more to the problem, uranium hexafluoride reacts with water to produce the corrosive hydrofluoric acid (Piper, G., 30.6.2007). There is a disputed traffic of uranium hexafluoride from Europe to Russia. Russian institutes can enrich uranium hexafluoride further which then comes back to Europe. German ARTE TV broadcasted a documentary on this issue in the past decade showing satellite images of uranium hexafluoride containers even without a roof over them (Seibert, Nuclear Waste).

VOLUME AND COST OF NUCLEAR WASTE

Handling and disposing of nuclear wastes characteristically make up of 1/20 of the total electricity production (world-nuclear.org).

The table below shows the amount of nuclear waste generated in the last 50 years. The table excludes the spent fuel left.

	High-level Waste (m3)	Greater than Class-C Low-level Waste (m^3)	Low-level Waste (m^3)	Cesium and Strontium (m^3)
Once-through fuel cycle	70,990	2,500	367,500	0
Reprocessing with fast re-actors	55,000	416,500	2,677,500	5,655
Reprocessing with thermal and fast re-actors	54,000	400,500	2,449,500	5,655

Table: Amount of nuclear waste generated in the last 50 years (ucsusa.org)

There are unforeseeable costs of nuclear waste disposal. There are huge cost issues. The Nuclear Decommissioning Authority in the UK assumes the cleaning up process would take somewhere between £95 and £219 billion. These figures are derived from the readily available data. As more data is obtained the scale of the clean-up will be clearer (theglobaldispatches.com). The media adds to the story, that, £43 billion was the cost estimate yet now the government sees that £48 is necessary to clean-up Britain's nuclear waste. A new body is required to be founded in order to carry out and regulate this massive campaign. For the next 10 to 15 years an additional £1 billion is required each year for the project (dailymail.co.uk).

German nuclear power plants will need decades to dismantle their plants. The government agreed on to be responsible for the waste disposal and the fund will receive around €24 billion. Wolfgang Irrek, professor for energy management at Ruhr West University of Applied Sciences in Germany, says that cost estimation is not possible for waste management and disposal since we are not aware of a technical notion (theglobaldispatches.com).

200 to 350 m^3 of LLW and ILW are produced annually by a 1,000 MWe light water reactor. Also, 27 tons of used fuel is discharged every year from the same facility. When put into storage units, it contains 75 m^3 of space and after reprocessing 3 m^3 of HLW is

produced which takes 28 m^3 of space in encapsulations (world-nuclear.org).

More than 1.5 million tons of depleted uranium is stored. 300 kilotons of used nuclear fuel is stored and around 270 kilotons of it is stored in pools but dry storage is growing. Every year more than 10 kilotons of new used fuel emerges and 2 kilotons of it goes under reprocessing (world-nuclear.org).

Robert Alvarez, senior policy adviser to the Secretary of Energy during the presidency of Clinton, brings the Fukushima example back. After the explosions at the Fukushima Dai-Ichi station spent fuel pools were left without a roof over them. The owner of the plant, Tokyo Electric Power, uses enormous amounts of water to keep the station cool. An amount of 65,000 tons of spent fuel of which ¾ of it is sitting in American nuclear power plant pools may catch on fire and explode just like in Japan.

Alvarez takes down the suggestion of stocking all of this waste under a football field. He comments that there would be enough plutonium to fuel 150,000 nuclear weapons, dwarfing Chernobyl and Fukushima accidents. If anything goes wrong, this would be deadly to thousands and perhaps millions of people. The adviser recommends taking any spent fuel older than five years old into dry and hardened storage containers just like in Germany. This would take a decade costing $3.5 to $7 billion, then giving an additional increase of $0.004/kWh for consumers (thenation.com).

SOLUTION IDEAS

Long term solutions are offered by scientists. The space, the core of the earth, the bottom of the ocean are candidates for nuclear wastes:

- **The space:** Putting the nuclear wastes into a rocket and shooting them into space seems straightforward. Yet, the cost effect is immense. It is calculated that for every unit of electricity produced for that given amount of nuclear fuel, we need 5 times the energy to get rid of it using this method. Also, just imagine that something goes wrong and the rocket explodes over our heads – catastrophe!
- **The core of the earth:** We are not actually aiming for the core here, but a safe depth that the nuclear wastes would not come back to surface. So far, we did not even reach 13 km of depth and going past that with today's technology does not seem possible.
- **The bottom of the ocean**: It was believed that contaminated water from the bottom of the ocean would take millennia to reach the surface, however, recent studies show it takes less than 800 years. Also, the cement and glass containers dissolve. Still, since 1967 IAEA states 100 kilotons of nuclear waste was dumped into the oceans in this sense.

More options for long-term waste management are listed below. Some ideas are out of date. some of them are still being discussed.

Ideas	Examples
Long-term above ground storage	Investigated in France, Netherlands, Switzerland, UK and USA. Not currently planned to be implemented anywhere.
Disposal in outer space (proposed for wastes that are highly concentrated)	Investigated by USA. Investigations now abandoned due to cost and potential risks of launch failure.
Rock-melting (proposed for wastes that are heat-generating)	Investigated by Russia, UK and USA. Not implemented anywhere. Laboratory studies performed in the UK.
Disposal at subduction zones	Investigated by USA. Not implemented anywhere. Not permitted by international agreements.
Sea disposal	Implemented by Belgium, France, Federal Republic of Germany, Italy, Japan, Netherlands, Russia, South Korea, Switzerland, UK and USA. Not permitted by International agreements.
Sub seabed disposal	Investigated by Sweden and UK (and organizations such as the OECD Nuclear Energy Agency). Not implemented anywhere. Not permitted by international agreements.
Disposal in ice sheets (proposed for wastes that are heat-generating)	Investigated by USA. Rejected by countries that have signed the Antarctic Treaty or committed to providing solutions within national boundaries.
Deep well injection (for liquid wastes)	Implemented in Russia for many years for LLW and ILW. Investigations abandoned in the USA in favor of deep geological disposal of wastes in solid form.

Table: Other ideas for disposal (world-nuclear.org)

Dry casks are seen as a short-term solution. Waste pools inside nuclear power plants became overcrowded as they store the nuclear waste until it is cool enough to be handled and carried. Then come the idea for repositories. The Nuclear Waste Policy Act of 1982 of USA stated the obligation to start carrying nuclear waste to a repository assigned by the federal government by 1998. Yet, no such permanent place has been assigned (ucsusa.org).

The Nuclear Regulatory Commission asked nuclear power plants to store up to 5 times the waste what they were designed for. Since the USA failed to designate a permanent repository the problem continues (ucsusa.org). Furthermore, before President Obama cancelled the Yucca Mountain project, President Bush wanted to speed things up for the repository. However, there was not satisfactory evidence on how safe the project would be. The project was proposed to contain radiation for 10 millennia but the federal court ruled that it should provide protection for 1 million years (scientificamerican.com). Transportation of such wastes across the USA gives birth to other risks as well that fears the citizens.

Moreover, worries continue climbing as more accidents happen. Just in May 2017, state of emergency was declared in Hanford, Washington in USA after a tunnel collapsed which was used to store radioactive materials and equipment (rt.com). The Yucca mountain project for a permeant repository is still under debate (ucsusa.org) although President Obama cancelled the project USA still is in search for a new designated area.

A leap occurred in Finland. The Finns are building their permanent repository on Olkiluoto Island. The project is for the next 100 millennia. After that? We are not sure (theglobaldispatches.com).

Each country takes things into their own measures. Here is a table of approaches of different countries.

Country	Policy	Facilities and progress towards final repositories
Belgium	Reprocessing but moving to direct disposal	Central waste storage at Dessel Underground laboratory established 1984 at Mol Construction of repository to begin about 2035
Canada	Direct disposal	Nuclear Waste Management Organisation (NWMO) set up 2002 Deep geological repository confirmed as policy, retrievable Repository site search from 2007, planned for operation by 2035
China	Reprocessing	Central used fuel storage at Lanzhou in central Gansu province Repository site search from 1986, selection to be completed by 2020 Underground research laboratory 2015-20, disposal of HLW from 2050
Finland	Direct disposal	Program start 1983, Posiva Oy set up 1995 to implement confirmed policy of deep geological disposal Underground research laboratory Onkalo under construction since 2004 Repository being built from this, near Olkiluoto, to open in 2023
France	Reprocessing	Underground rock laboratories in clay and granite Parliamentary confirmation in 2006 of deep geological disposal, containers to be retrievable and policy ‘reversible’ Construction and operating licence for Bure expected in 2018, construction to start 2020
Germany	Reprocessing but moving to direct disposal	Repository planning started 1973 Used fuel storage at Ahaus and Gorleben salt dome Geological repository may be operational at Gorleben after 2025, decision due 2019
India	Reprocessing	Research on deep geological disposal for HLW
Japan	Reprocessing	Used fuel and HLW storage facility at Rokkasho since 1995 Underground laboratory at Mizunami in granite since 1996 Used fuel storage built at Mutsu, expected to open 2018 NUMO set up 2000, site selection for deep geological repository under way to 2025, operation from 2035, retrievable
Russia	Reprocessing	NO RAO set up in 2012 to manage HLW and its disposal Underground laboratory in granite or gneiss in Krasnoyarsk region from 2015, may evolve into repository by 2024 Pool storage for used VVER-1000 fuel at Zheleznogorsk since 1985 Dry storage for used RBMK and other fuel at Zheleznogorsk from 2012 Various interim storage facilities in operation

Country	Policy	Facilities and progress towards final repositories
South Korea	Direct disposal, wants to change	Waste program confirmed 1998, Korean Radioactive Waste Management Co. (KRWM) set up 2009 Mid-2013 KRWM rebranded as Korean Radioactive Waste Agency (KORAD) Central interim storage facility pending construction
Spain	Direct disposal	ENRESA established 1984, its plan accepted 1999 Central interim storage at Villar de Canas from 2016 (volunteered location) Research on deep geological disposal
Sweden	Direct disposal	Central used fuel storage facility – CLAB – in operation since 1985 at Oskarshamn Underground research laboratory at Aspo for HLW repository Östhammar site selected for repository (volunteered location), likely to open in 2028
Switzerland	Reprocessing	Central interim storage for HLW and used fuel at ZZL Würenlingen since 2001 Smaller used fuel storage at Beznau Underground research laboratory for HLW repository at Grimsel since 1983
United Kingdom	Reprocessing	HLW from reprocessing is vitrified and stored at Sellafield Repository location to be on the basis of community agreement New NDA subsidiary to progress geological disposal
USA	Direct disposal	Policy since 1977 to forbid reprocessing DoE responsible for used fuel from 1998, accumulated $40 billion waste fund Considerable research and development on repository in welded tuffs at Yucca Mountain, Nevada The 2002 Congress decision that geological repository be at Yucca Mountain was countered politically in 2009 Central interim storage for used fuel now likely

Table: Country-specific policies (world-nuclear.org)

PUBLIC COMPLAINTS AND THE GREENHOUSE EFFECT

Another complaint with the nuclear wastes comes in the transparency field. Citizens speak out that they are not aware of the route of nuclear wastes and the authorities say the path is kept secret to avoid any attacks on the wastes. This makes it impossible for the citizens and emergency planning if something goes bad. When contained properly, these wastes are safe to carry, on the other hand, if there is a leakage then it is an enormous hazard for the environment and since there are only a few reprocessing facilities in the world, international transport of these wastes takes place continuously.

In USA, the government failed to open a permanent repository. The companies started suing the government as it did not comply with its promises. Still, there is a large grey area where people do not know what to do with their nuclear wastes. The overcrowded amounts piled in-situ damage facilities. Correspondingly, it is unclear till when this will continue as it is (ucsusa.org).

The other problem is that nobody wants the nuclear wastes in their backyard – NIMBY as an acronym. Yucca Mountain repository in Nevada was opposed by the Nevadans themselves. Only 130 km away from Las Vegas, citizens are worried about possible earthquakes and erosions altering the natural formations and bringing havoc into the area for thousands and thousands of years to come. Once the repository becomes unstable, the radioactivity will be a constant hazard carved into the area (scientificamerican.com).

Mycle Schneider, the lead author of the annual World Nuclear Industry Status Report suggests that geological storage is eternally well. He thinks it is an arrogant approach to say a facility will hold up for tens of thousands of years. The scientist also adds that the European approach of getting cooled waste out of water into dry storage as soon as possible is a better option, yet, the water should never be permitted to escape. Otherwise, we could be talking about much larger catastrophes than the one in Chernobyl (theglobaldispatches.com).

Personally speaking, I was only a 1-year old baby when the notorious disaster in Chernobyl occurred. As, the human kind, we did not know how to handle that havoc, three decades later, we still do not. Nuclear power is a project that does not end in a few centuries. As Ruby Russel states the issue, it is a project for a million years (theglobaldispatches.com).

German Chancellor Angela Merkel stated that Germany will switch off all of their nuclear power plants by 2022 in favor of green energy. In 1977, Germany was a forerunner of disposal as Gorleben salt mine was suggested to be a repository. Years and years of discussions later, the government took the issue back into their agenda in 2017. The project is expected to be built in 2050. This very example shows us the intensity of discussions, complaints, and objections rising. From suggestion to building, the repository needs almost 80 years.

In France, it is debated that the public was not properly consulted over the proposal of building a repository in the village of Bure. Protests are growing. In addition, the parliament is expected to take a vote on the issue (theglobaldispatches.com).

Last year, in 2016, nuclear power plants generated more than 2,400 TWh of electricity which provided around 11% of the global consumption. It is calculated that even if the cleanest fossil fuel, i.e. natural gas, was employed to produce the same amount of energy, an extra amount of 2.4 billion tons of CO_2 would be in the atmosphere, this is roughly equivalent to a quarter billion cars on the road (world-nuclear.org).

Energy Source	Lifecycle emissions (gCO_2eq/kWh)	Estimated emissions to produce 2,417 TWh electricity (million tons of CO_2)	Potential emissions avoided through the use of nuclear power (million tons of CO_2)
Nuclear Power	12	29	N/A
Gas	490	1,184	1,155
Coal	820	1,981	1,952

Table: CO_2 emissions avoided through the use of nuclear power (world-nuclear.org)

In the report "IEA finds CO_2 emissions flat for third straight year even as global economy grew in 2016", it is stated that nuclear power plants helped in stagnating the CO_2 levels along with an increase in natural gas consumption. China, the United States, South Korea, India, Russia, and Pakistan connected new nuclear power reactors to their power grids (iea.org). The table above confirms the amount of greenhouse gas inhibited before it is generated by switching from coal to nuclear power.

NUCLEAR POWER IN TURKEY

Every year an increase in energy demand of more than 5% occurs in Turkey. The country demands to increase variety of energy sources. Turkish Ministry of Energy and Natural Resources lists in their report why the country is looking forward to opening their first nuclear power plants in the near future (Nuclear Power Program and NPP Projects in Turkey, March 2013).

- Nuclear power does not depend on climatic conditions
- Nuclear power does not emit as much greenhouse gases as fossil fuels
- Millions of tons of carbon dioxide, sulphur dioxide, nitrogen oxides, and ash will be eliminated
- Less amount of fuel is used than in conventional methods resulting in less contamination and waste
- Nuclear fuel already spent can be repurposed and reused
- Nuclear power brings new jobs
- Life of nuclear power plants is longer than other power plants

The same report claims that Turkey's potential for generating electricity would not suffice the growing energy demand and the country needs to build its first nuclear power plant. As seen in the table below, Turkey is not the only nation looking forward to produce nuclear energy.

Region	Country
Europe	Greece, Italy, Poland, Portugal, Turkey
Eastern Europe/Eurasia	Albania, Belarus, Croatia, Estonia, Georgia, Kazakhstan, Latvia
Middle East	Bahrain, Jordan, Kuwait, Qatar, Saudi Arabia, Syria, UAE, Yemen
Asia	Bangladesh, Indonesia, Malaysia, Mongolia, Myanmar, Philippines, Singapore, Thailand, Vietnam
North Africa	Algeria, Egypt, Libya, Morocco, Tunisia
Sub-Saharan Africa	Eritrea, Ghana, Kenya, Namibia, Nigeria, Senegal, Sudan, Tanzania, Uganda
Latin America	Chile, Cuba, Dominican Republic, Ecuador, Jamaica, Paraguay, Peru, Uruguay, Venezuela

Table: Nations interested in building their first nuclear power plants (Jewell, 2011)

For four decades, Turkey showed her intentions for getting nuclear power plants. The first nuclear power plants will be foreign-built. The first one is going to be built in Akkuyu (received a 49-year electricity generation licence, valid until June 2066) in southern Turkey by Russians starting in 2018 (world-nuclear-news.org). The second one is going to be constructed in Sinop in the north by a French and Japanese consortium. Then, the third one is expected to be built in İğneada by the Chinese.

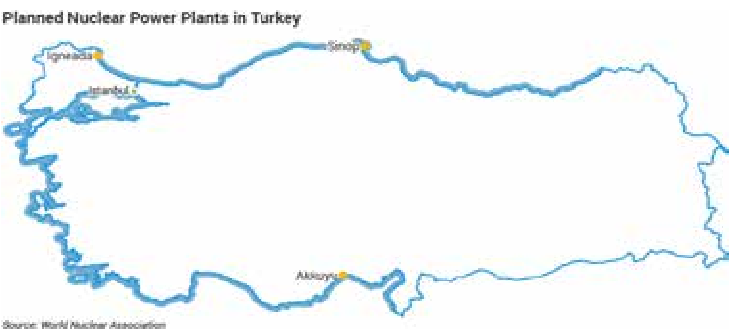

Image: Planned nuclear power plants in Turkey (world-nuclear.org)

A nuclear reactor was built at Istanbul Technical University in 1979. Turkish Atomic Energy Authority regulates the reactor. The other reactor built in 1981 (TR-2) of 5 MWe is located in Çekmece in Istanbul (world-nuclear-news.org).

As a net importer of natural gas and oil, Turkey (importing more than 90% of both hydrocarbons) is looking for means of energy production to secure her position and security.

Almost half of Turkey's energy production comes from natural gas and about 30% of it comes from coal. In the country, the energy demand grows by 8% each year and the expected amount of investments required to secure energy supply is about $100 billion by 2023. Alternative sources of energy are sought to lower dependency on Russian and Iranian natural gas. A 4.8 GWe of nuclear capacity is on its way.

Turkish Atomic Energy Authority (TAEK) sets the criteria for building and operating the plants since late 2007 as a new law concerning Construction and Operation of Nuclear Power Plants and Energy Sale was passed by the parliament. Then, in late 2013, IAEA prepared a report which came positively on Turkey, nevertheless, endorsed finalizing a national plan on nuclear energy, solidification the regulatory body, and evolving a national strategy for human resource development.

Reactor	Type	MWe gross	Construction Start	Operation Start
Akkuyu 1	VVER-1200	1200	2018	2023
Akkuyu 2	VVER-1200	1200	2019	2023
Akkuyu 3	VVER-1200	1200	2020	2024
Akkuyu 4	VVER-1200	1200	2021	2025
Sinop 1	Atmea1	1150	2017	2023
Sinop 2	Atmea1	1150	2018	2024
Sinop 3	Atmea1	1150	?	?
Sinop 4	Atmea1	1150	?	?
İğneada 1-4	AP1000x2 CAP1400x2	2x1250 2x1400	?	?

Table: Planned nuclear power plants in Turkey (world-nuclear.org)

Akkuyu location received its license years ago. Sinop's advantage is that the sea water is around 5°C cooler than in Akkuyu making it more efficient. Then, İğneada is chosen to be close to Istanbul, the biggest city in Turkey.

In central Anatolia, the Temrezli deposit contains uranium. Both national and international companies are seeking to work in the site. The studies on the site showed that the cost of uranium extraction will not be higher than in other sites. Extraction costs are expected to be around $37/kg U_3O_8 (also known as "yellowcake"). Resources measured at the Temrezli are a little more than 2,350 tU of which is 1,170 ppm U. Tulu Tepe, Akcami, Delier, and Sefaatli are other candidates for uranium extraction.

Wastes produced at Akkuyu were requested by TAEK to be taken back to Russia in the beginning. Later on, as of 2014, the issue was not clarified (world-nuclear.org).

CONCLUSION

ILW and LLWs are transported without a hassle but when HLWs are carried it makes into the news.

Wastes are generally national and countries want to keep things to themselves for security and independence measures.

Reprocessing gives nuclear pollutants into the air and water which are carried globally. Nuclear waste problem never stays local but it becomes a global issue. Under ideal conditions everything seems perfectly fine, however, when there is an accident, a leakage, or an efficacious attack, things give birth to a catastrophe (Seibert, Nuclear Waste).

The MIT report on the problem brings the following recommendations (The Future of the Nuclear Fuel Cycle, 2011).

- A risk-based waste management plan is wanted.
    - A waste classification system is necessary.
    - For each of these wastes, a suitable facility of disposal is required.
- An independent body responsible only for durable nuclear wastes should be founded.
- Integrated waste management plans to be included into fuel cycles.

If I may say, the humanity is still like a toddler when it comes to nuclear power. We learnt how to produce energy from it but we do not know how to clean up after ourselves for the time being. Relatively cheap and clean electricity comes with a gigantic "what if?" every single time we consider switching to nuclear energy.

Billions and billions of dollars need to be spent on nuclear waste containment and disposal. Doing nothing about them would, in the end, cost the whole thing.

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