Containing climate and pollution crisis through plastic incineration by use of Small Modular Reactors

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Declaration

A. I declare that this work submitted has been composed by me. ☐✓

B. I declare that all verbatim extracts contained in the thesis have been distinguished by quotation marks and the sources of information specifically acknowledged. ☐✓

C. I agree to my thesis being deposited in the NCI Library online Open access repository NORMA. ☐✓

D. I declare that no material contained in the thesis has been used in any other submission for an academic award. ☐✓

Acknowledgement

To begin with, I pay obeisance to the supreme soul who continues his blessings in many unknown ways whose glimpses of greatness have risen to innumerable schools of thought and due to whom the mystic sages to modern philosophers, artists, poets and thinkers continue to create beauty in all forms. I am grateful for the guidance and assistance of my supervisor Mr Victor Del Rosal for his continues input and feedback at crucial times during my preparation of the thesis. My appreciation and thanks to all my lecturers at the NCI who guided me throughout the course.

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Abstract

There have been many studies and research done in the area of nuclear physics and its immense benefits and destruction brought throughout the 20th century. Like with any cutting edge of science it has developed exponentially over the decades and will continue to be a mainstay of energy for the foreseeable future of humanity. Similarly the use of plastics has been even more profound and ubiquitous in the world and has brought enormous benefits to the people. Like any double edge sword analogy both these industries have wrecked destruction and havoc as well.

This paper has a specific focus on use of nuclear energy for plastic incineration as it is an important issue in the current waste management system. With the growing population and the increasing consumption of plastic materials, the disposal and reuse of these materials has become a challenge for many countries. Nuclear energy has been proposed as a potential solution for this problem. This proposal will outline the benefits of using nuclear energy in plastic reuse and incineration and provide a framework for how it could be implemented. This study also aims to examine the current scientific evidence on the use of nuclear energy and reactors to reduce the global plastic problem. The citations given and the model proposed using the PowerBI tool is specifically for an upcoming economy and developing country for India in the context of it being the populated country on earth yet more that 70% of the population is still living below middle class conditions and experiencing rapid urbanization and grappling with the gigantic amounts of plastic waste yet to be addressed.

Background

Plastic waste is the most abundant form of pollution on the planet, and it is a serious environmental and health hazard. Plastic waste has been linked to numerous environmental issues, including land and water pollution, climate change, and health issues. In recent years, there has been an increase in the amount of plastic waste generated, making it a major global issue. The nuclear fuel is very dense and energy is especially important for the future of economies. The use of nuclear energy for plastic incineration has been proposed as a potential solution to this problem.

Introduction

Every country on the globe has enormous landfills overflowing with municipal waste which consist of plastic and organic waste. It is convenient to use and easy to transport while its safe disposal requires great technical expertise and capital outlay hence countries (especially developing and underdeveloped) tend to dispose of these in landfills and oceans through the rivers. The rotting plastic releases enormous amount of methane which is much more harmful than Carbon dioxide or they burn the plastic in landfills which causes health hazards (US EPA, 2016). Since nuclear energy emits no carbon dioxide as a by-product we shall see the benefits of how it can be used to incineration in a controlled environment.

Literature Review

A look at nuclear reactor industry

The growing role of nuclear reactors in the energy needs fulfilment in the world

Major economies in the world are already using nuclear as a part of consumer electricity demands. The below graph shows the same (World-nuclear.org, 2023)

There is a need to shift the way we view nuclear energy due to the advancement in the different technology and also consider the other factors like carbon free fuel emissions, reliability and safety of these plants.

The use of nuclear energy in developing countries has been increasing in recent years especially in India and China. Several factors are driving this trend, including the growing demand for energy, concerns about climate change, and a desire for energy independence.

Many of these countries are experiencing rapid economic growth and population growth, which is leading to an increase in energy demand. Nuclear energy is seen as a reliable and cost-effective way to meet this demand, particularly as the technology has advanced in recent years.

Another factor driving the use of nuclear energy is the need to address climate change. Nuclear power plants emit little to no greenhouse gases, making them an attractive option for countries looking to reduce their carbon footprint. In addition, nuclear power is more reliable than many renewable energy sources, which can be intermittent depending on weather conditions.

Finally, many developing countries are looking for ways to become more energy independent. Nuclear power plants can provide a reliable source of energy that is not dependent on imports, which can help countries to reduce their dependence on foreign energy sources.

Despite these benefits, there are also concerns about the safety and security of nuclear power. Developing countries may lack the expertise and resources needed to safely operate nuclear power plants and manage nuclear waste. In addition, there is always the risk of nuclear accidents or intentional misuse of nuclear materials.

Overall, the growing use of nuclear energy in developing countries is a complex issue that requires careful consideration of the benefits and risks involved. As the technology continues to advance and safety measures improve, it is likely that more countries will turn to nuclear power as a way to meet their energy needs.

Let us look at the basic facts for nuclear energy

Reliability

It is one of the most reliable sources of clean energy available in order to achieve the climate goals set for COP26 agenda. The fuel and the plant once set to run can be operated for at least a year or two without maintenance and manual intervention. In stark contrast to this the coal and natural gas plants require regular maintenance and need constant refuelling. The renewal plants are large and complex in design and need a backup source and varying capacity. The nuclear plants are very reliable safe and run at the optimum capacity at any weather conditions.

The capacity factor

It is another crucial element in the energy industry to be considered. The definition is the maximum power that is capable of being generated by the energy source. In this index all the other energy sources dwarf in comparison to the nuclear energy (Energy.gov, 2020).

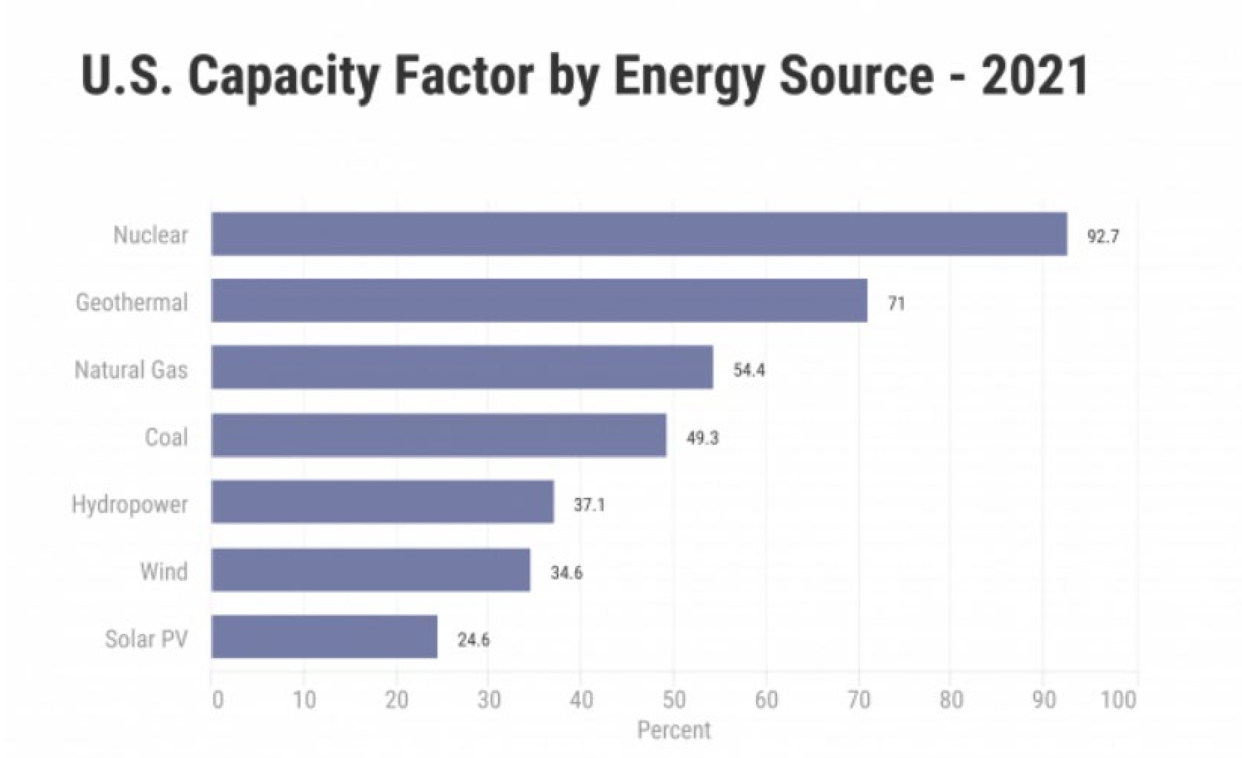


Figure 1

In other words the nuclear reactors operate at roughly 92% on an average or the conversion ratio for the usage of the energy created is very high. As we can also note that the wind and solar power have very low capacity factor and any future with non-fossil fuels should include nuclear energy as a big slice of the pie so to speak. To put in perspective, a typical 1GW nuclear power plant produces the same amount of power as 100 million commercial LED bulbs or 431 Wind turbines or 3.125 million solar panels.

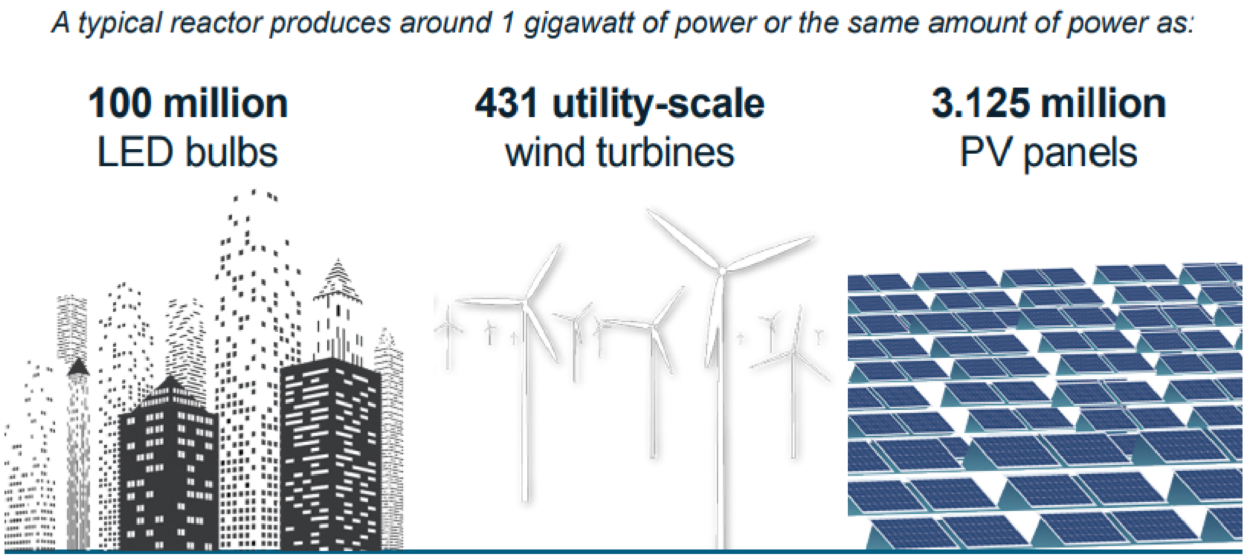


Figure 2

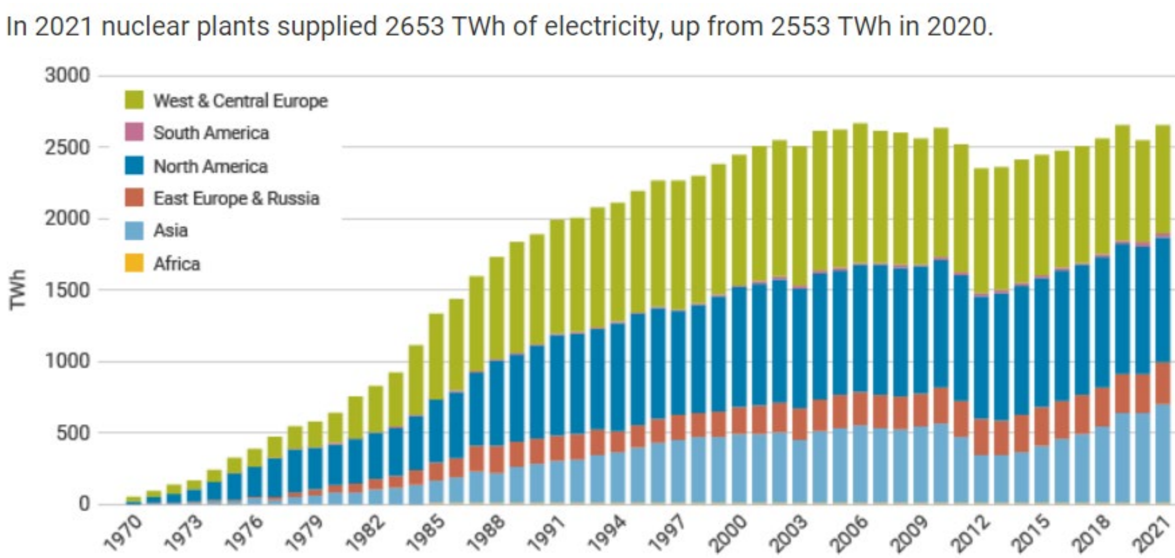


Figure 3

Addressing climate through nuclear

As per the COP 26 statement the goals have been set and even then the pandemic has shown how the air pollution can be drastically reduced with reduction in vehicular emissions. The WBCSD has issued a statement that if we do not reduce emissions drastically we might need climate lockdowns regularly over the next decade (World Business Council for Sustainable Development (WBCSD), 2020). This would severely curtail economic activity and cause a catastrophic recession especially in developing and underdeveloped countries. According to the director general at the time Mr Rafael Mariano Grossi “Without nuclear power, many of the world’s biggest economies would lack their main source of clean electricity” (IAEA.org, 2021).

Carbon emission factor

Nuclear energy produces no CO2 hence much better than conventional fuels and the future reactors are set to improve further. Let us look at the enormous benefits of nuclear energy in general

The effect of electricity consumption on environment purely on the basis on carbon dioxide is as shown (Weber, 2021)

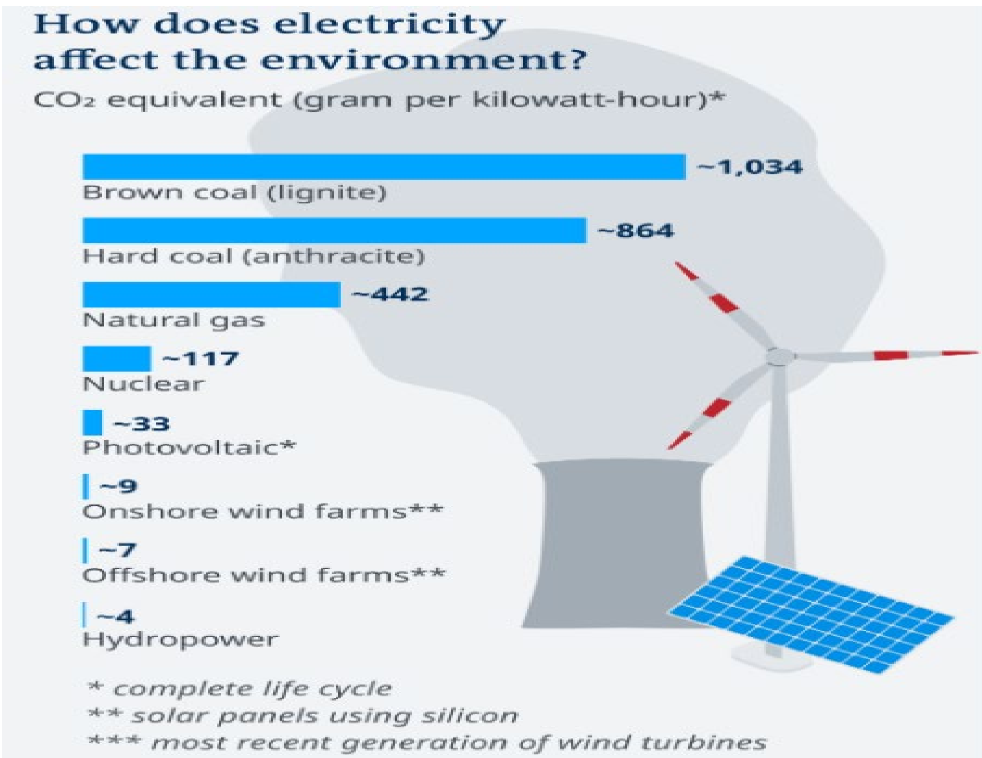
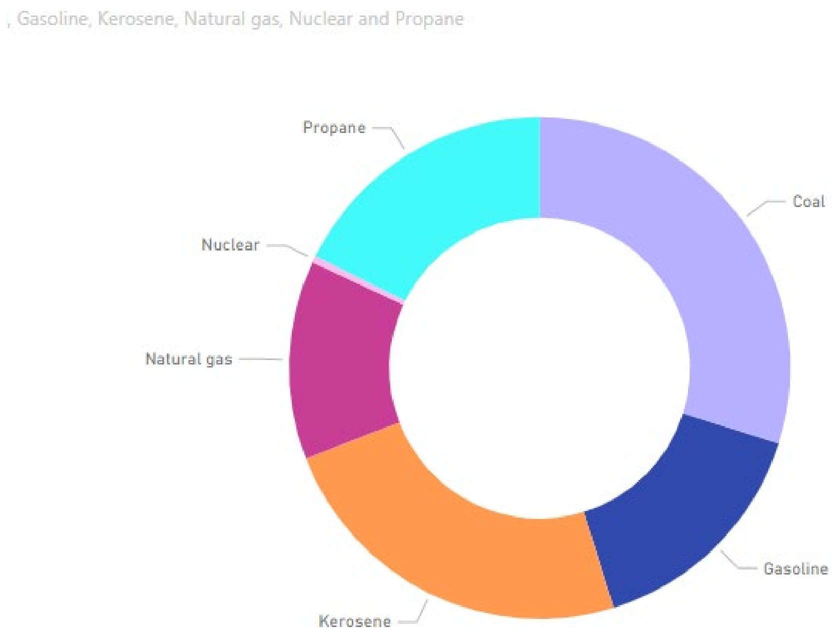


Figure 4

When looking at the carbon emissions alone the nuclear energy registers just as a blip on the radar compared to the fossil fuels most commonly used. The below model shows the carbon emission in grams for each kilo watt hour.



Model 1

Density factor

The nuclear fuel i.e. Uranium is extremely dense hence does not involve great transport cost to be used in a reactor as shown below.

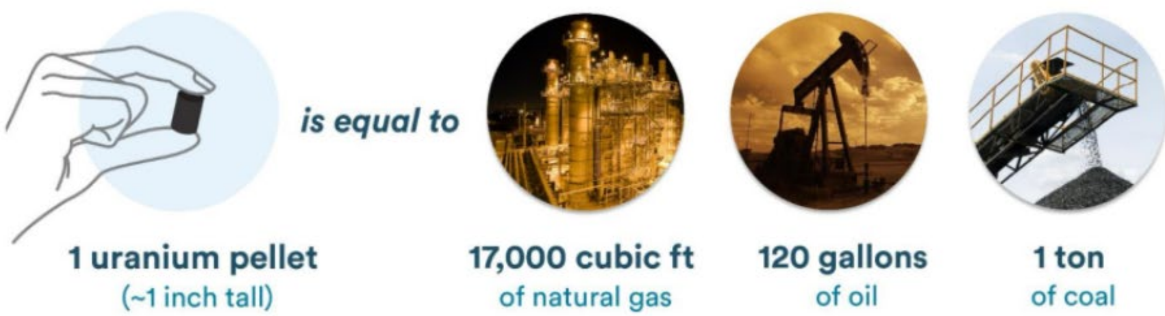


Figure 5

History and growth

The rapid growth of nuclear started from the 1980s onwards with the successful adoption of second generation nuclear reactor with the improvements in design and safety. The brief evolution of nuclear power through different generations is shown below.

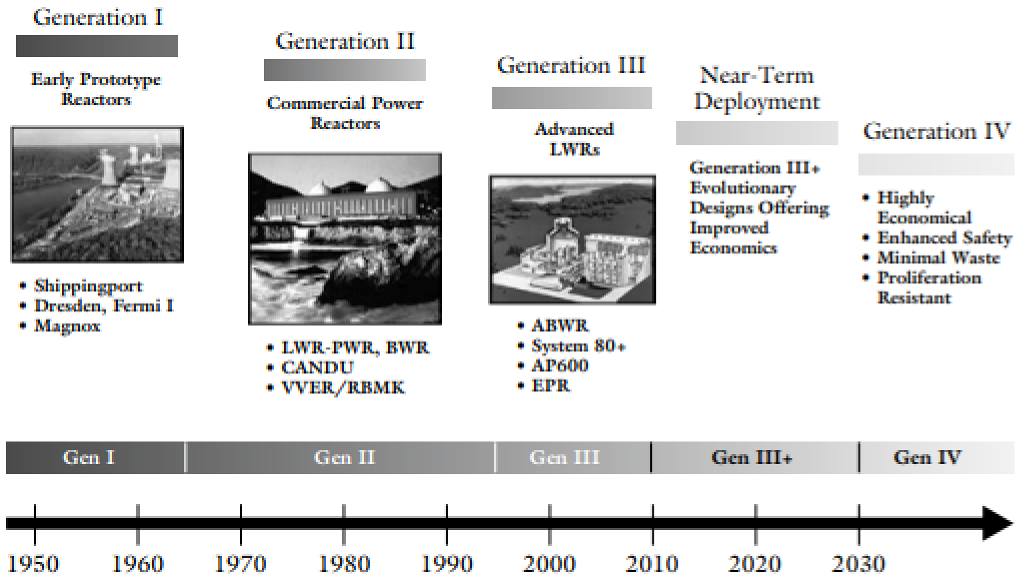


Figure 6

The latest next generation nuclear reactors have vast improvements in efficiency of power output, adoption of risk management including automatic shutdowns in case of calamities and reduction in size. This is propelling towards wide spread commercial and industrial use of the small modular reactor (henceforth addressed as **SMR** throughout the paper) bringing it in parity to fossil fuels. The difference in the price is a small price to pay towards greening the environment by emission and also reducing the plastic waste in the communities.

The resiliency features of SMRs are many

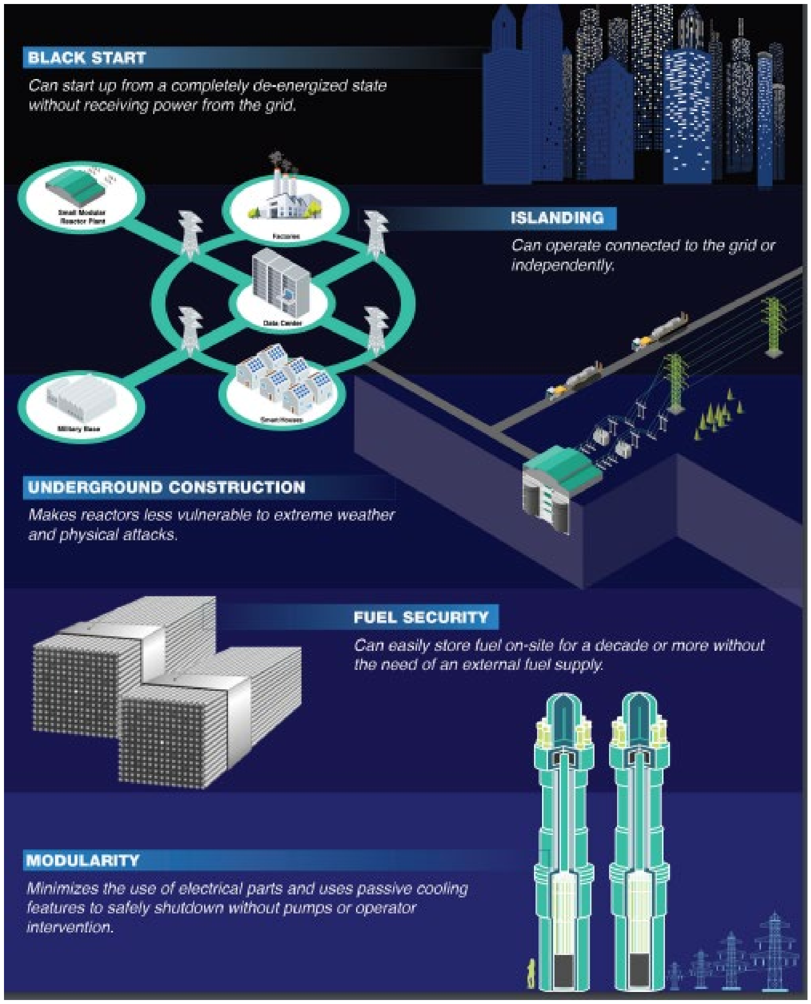


Figure 7

1) Setting up of nuclear power plants.

The older general nuclear plants (I and II) were much more complicated to setup and run compared to gen III nuclear plants onwards. Many of the first generation nuclear power plants are already shut as of now understandably due to safety issues and enormous cost in maintaining them. The following improvements have since taken place in generation III reactors

a) A more standardized design after consulting with scientists and industry experts have reduced the construction time reduced the initial capital needed and modular design makes it easier to operate.

b) Another important factor is the lifespan, the fuel rods last longer (typically around 60 years) and have lesser vulnerability to operational shocks.

c) The nuclear core has the highest risk of a meltdown and older gen reactors were operating with additional redundancies in mechanical systems and pressure relief valves. The new reactors have automated and remotely monitored system hence the redundancies are reduced.

d) The grace period after the nuclear reactor has been shutdown is now close to 72 hours (World-nuclear.org, 2021) increasing the safety of workers.

e) The compact and hard design makes it more resistant to accidents in case of natural disasters like earthquakes, flooding etc.

f) The nuclear waste of the spent fuel is further reduced due to more efficient burning of the fuel and also the absorbers of the poisonous waste is used which reduces the risk of health hazards.

Since the reactors use modular construction i.e. the structural parts are assembled near the nuclear site the construction is faster and less fuel is used in transporting of these raw materials as well.

g) The SMRs can operate on plug and play mode hence can be independently connected to the power grid, making the decarbonisation goal simpler.

Another common sense approach taken was a joint collaboration and standards being set for generation IV nuclear reactors thereby safety could be universal and knowledge sharing encouraged. At least 12 countries have joined the initiative with US, France, Russia, China among others (World-nuclear.org, 2021).

Currently there are 440 nuclear power plants in operation worldwide and another 60 reactors under construction (World-nuclear.org, 2023). It's vital to note that all these reactors are new generation reactors.

Generation IV SMR reactors (operational from 2030 onwards)

The below figure shows the simplistic technical design of a SMR.

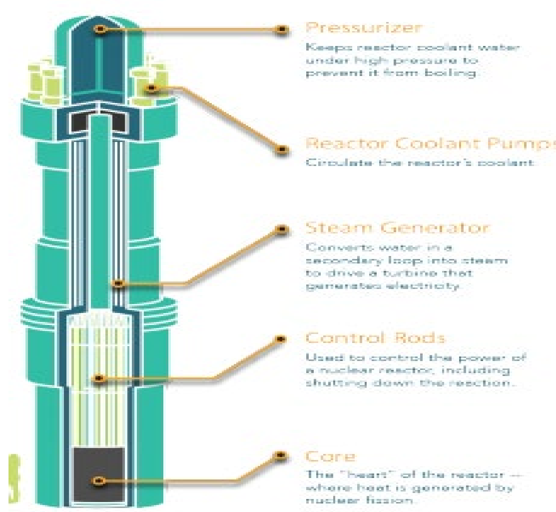


Figure 8

Technical working of a SMR

The chain reaction starts with the fission process as the split atoms from the core generate heat by energy release. They further split into smaller atoms and hence in a controlled manner the core spends its nuclear fuel. The control rods are used which regulate the energy output by absorbing the neutrons emitted in the core and hence act as a barrier to uncontrolled explosion. The coolant water absorbs the heat from this reaction and is circulated through a steam generator and this steam in turn drives a turbine that generates electricity. The pressurizer at the top maintains the pressure to keep the water from boiling. The use of smart materials further increases the efficiency of the plant by reducing human exposure, increasing fuel life cycle and reducing corrosion of the structure itself (Litnovsky et al., 2017)

The need of SMRs for particular task of plastic incineration

The landfills, especially in developing countries like India are situated in densely populated urban centres. They are hazardous and surrounded by poor communities and there is no proper segregation between the landfill and the housing of the people. So an SMR which needs very less space can be setup close to the plant and there is no need of sourcing of the plastic as well. The SMRs are very attractive to investors as well as construction time is low as India is building new reactors in a fleet mode i.e. the design is kept constant for mass production and technical specifications remain the same. They work in an off-grid mode i.e. not connected to the main power grid of the city hence low chance of it affecting the commercial power supply. Another game changing factor to be considered is the multipurpose use of the SMR plants. Let us consider that 1 landfill can be closed down due to eventual elimination of a landfill, and then the SMR can be repurposed for just generated clean power or various industrial purposes like manufacturing green hydrogen, desalination, producing essential chemicals among others. This can indeed be done with minimum changes to the overall design of the reactor.

The design of the reactor as a waste to energy plant is discussed in sections below, an SMR is ideally suited for plastic incineration and it produces optimum energy keeping an eye on the safety standards and since it has a lower energy output, it can be shut down quickly without causing harm to the public.

Case study of France using nuclear energy

France has been one of the largest producer and consumer of nuclear energy for decades, using it as a way to reduce its dependence on fossil fuels and combating climate change. Nuclear power has provided France with a reliable, cost-effective source of energy that has allowed it to reduce its carbon footprint, achieve energy independence and become one the great industrial powers.

France currently operates 56 nuclear reactors, which provide more than 70% of its electricity. This makes France the second-largest producer of nuclear power in the world, behind only the US. The country has invested heavily in nuclear energy since the 1970s, when it embarked on a program of nuclear power expansion to reduce its reliance on imported oil from the Middle East and other places.

France's nuclear power program has been highly successful in achieving its goals of energy independence and reducing greenhouse gas emissions. By relying heavily on nuclear power, France has been able to reduce its greenhouse gas emissions significantly, with emissions from the energy sector falling by more than 80% since the 1970s even though the population has increased significantly (Spglobal.com, 2022).

France's nuclear power program has also been highly effective in terms of cost and reliability. Nuclear power plants have a high upfront cost but are relatively cheap to operate, making them an attractive option for countries looking for reliable, low-cost energy sources and indeed France is partnering with China, India and other countries to set-up nuclear plants in their respective countries.

France has remained committed to nuclear power and has taken steps to address these issues. The country has implemented strict safety regulations and invested heavily in research to develop safer, more efficient nuclear power technologies. France has also invested in the development of renewable energy sources, such as wind and solar power, as a means of diversifying its energy mix and reducing its dependence on nuclear power. The energy matrix of France is shown below and how it has profited from the use of advanced nuclear energy plants.

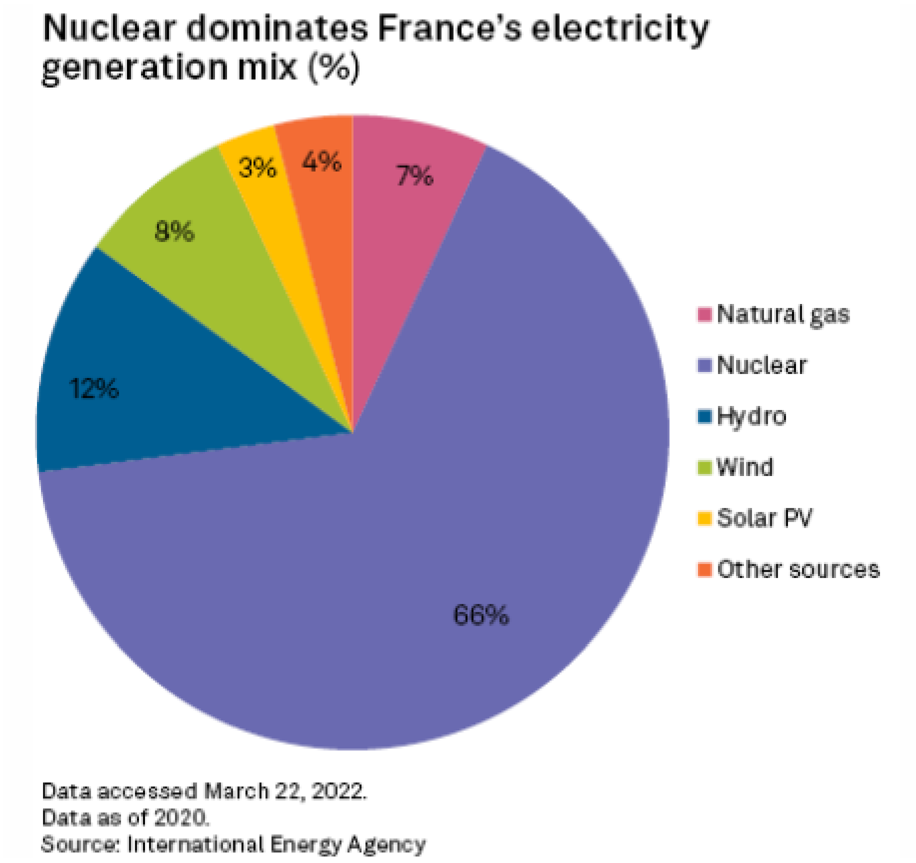


Figure 9

A view of the current state of plastic pollution

The figure below gives an idea into the enormous problem of plastic waste mapping its way across from discarding to going to partially getting incinerated to finally ending up in landfills. As shown only a small portion of it ends up getting either re-used or incinerated (Ritchie and Roser, 2018). This is our focus area to reduce the landfills through increasing the amount plastic is incinerated.

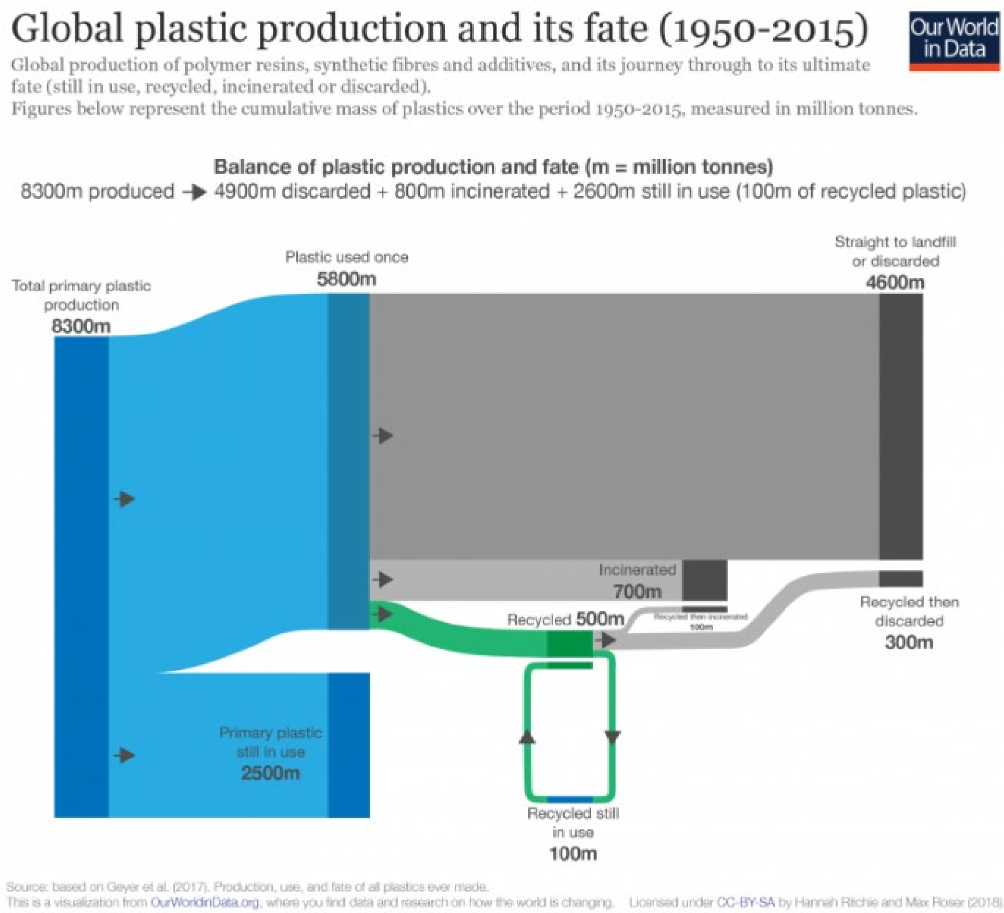


Figure 10

We are already aware of how millions of tons of plastic since its production began have ended up in the ocean and have been accumulating there since decades. Unless we find a permanent solution to this problem incineration is the best way to get rid of it. The below figure gives a glimpse of how plastics have swamped the ocean creating serious bio health hazards for our ocean life.

Figure 11

Everyone is familiar with the great pacific garbage patch but the problem is much more extensive and deeper than that. Hence the incineration cuts off the plastic pollution problem at the source; this is where the nuclear energy is so effective to dispose large amounts of plastic in a relatively small period of time.

Nuclear energy can be an effective way to safely dispose of large amounts of plastic waste, as it can produce high temperatures and pressures that can break down the plastic molecules. Nuclear energy could be used to convert plastic waste into energy, with the potential to produce electricity. The process could reduce the amount of plastic waste in the environment and reduce the emissions of greenhouse gases. Finally, nuclear energy can be used in both small and large-scale incineration operations, making it a flexible and versatile option for those looking to reduce plastic waste. Nuclear fuel is very dense and hence the energy to space consumed ratio is very high as shown in figure 5.

Plastic recycling has 6 main steps

1. Sorting: The plastic is sorted according to its type and color. This is usually done manually.

2. Washing: The next is washing to remove dirt, grime, and other contaminants. This is usually done in a hot water bath with detergents or surfactants.

3. Shredding: After the wash, it is then shredded into small pieces. This makes it easier to melt and reform into new shapes.

4. Melting: The shredded plastic is then melted in a large furnace or extruder. This process takes a few hours, depending on the type of plastic and the customized product needed.

5. Reforming: After melting, it is then reformed into pellets, sheets and blocks. This is an industrial process as per requirements.

6. Finally: The final step is to create the desired product from the reformed plastic. This could be anything from plastic bottles, containers, bags etc.

Singapore approach

Let us take the classic case study in Singapore since it the highest producer of plastic waste per capita (Statista, 2023) and uses incineration techniques to dispose of its waste (Nea.gov.sg, 2023).

Singapore is known for its efficient waste management system, including handling plastic waste. The city-state has a three-pronged approach to handling plastic waste, which includes reducing plastic usage, promoting recycling, and incinerating the remaining waste.

To reduce plastic usage, Singapore has implemented a plastic bag charge in supermarkets and retail stores since 2007. The charge encourages consumers to bring their reusable bags and reduces the use of plastic bags. Additionally, single-use plastic straws have been replaced with paper straws in many food establishments.

To promote recycling, Singapore has established a comprehensive recycling program that collects various types of plastic waste, including bottles, containers, and packaging materials. The collected waste is sorted and sent for recycling.

Finally, the remaining plastic waste that cannot be recycled is incinerated in waste-to-energy plants, which generate electricity that is used to power the city. The incineration process also reduces the volume of waste, making it easier to manage and dispose of. Singapore has built separate lake beds to store the plastic ash that it incinerates and aims that this will be enough until 2045 and beyond (Geddie, 2018)

Currently USA is the largest producer and consumer of nuclear energy and China rapidly catching up in order to meet the climate goals. To give a stat from USA, according to NEI America avoided releasing a combined amount of 16727 MMT of carbon! by the use of nuclear energy from the year 1995 to 2021.

Steps to be taken for plastic reuse and reduction

1. Education and awareness campaigns: The first step in encouraging plastic reuse and reduction is to educate the general public about the environmental impact of plastic waste. Education and awareness campaigns can be conducted through various channels such as social media, TV, radio, and billboards.
2. Promoting reusable alternatives: Encouraging the use of reusable alternatives such as reusable shopping bags, water bottles, and containers can help reduce plastic waste. Retailers can offer discounts to customers who bring their reusable bags or containers while shopping.
3. Offering incentives for recycling: Local governments can provide incentives for recycling such as tax rebates, discounts on waste disposal fees, or free recycling containers to encourage people to recycle.

4. Implementing a deposit-return system: A deposit-return system can incentivize people to return plastic bottles and containers for a refund. This system has been successful in countries such as Germany and Sweden (Deposit return in Sweden A case study, n.d.)
5. Supporting circular economy initiatives: Encouraging the use of recycled plastic and supporting companies that use recycled plastic in their products can create a market for recycled plastic and reduce the demand for new plastic.
6. Providing financial incentives: Providing financial incentives such as tax breaks, grants, or subsidies to businesses that promote plastic reduction or offer plastic-free alternatives can encourage businesses to take action.

Landfill problem

The urban municipal landfill is a very common sight in developing countries like India and it's a mixture of organic and inorganic waste like plastics. The landfills produce a huge amount of methane which is 86 times more harmful than CO_2 itself. The landfills also occupy key landfill in a dense urban area of the population and are harmful to the residents surrounding it and potential for a proper use of that land is reduced. The use of SMRs can directly eliminate the landfill and also produce much needed energy by the incineration fulfilling both needs by the proverbial burning a candle at both ends fulfilling the goal of plastic reduction and energy generation.

The most obvious effect of urban municipal landfills is the pollution it causes in terms of air, soil and portable water. The decomposition of organic waste in landfills releases harmful gases such as methane and carbon dioxide into the atmosphere, contributing to climate change. The leach ate produced from landfills contaminates water sources, leading to the pollution of rivers, lakes, and groundwater. This can cause health problems for humans and wildlife that depend on these water sources.

Furthermore, landfills also pose a threat to public health. The accumulation of waste in urban landfills provides a breeding ground for pests, such as rats and mosquitoes, which can spread diseases. Additionally, the emission of toxic gases from landfills can cause respiratory problems and other health issues for people living nearby.

Another issue with urban landfills is the space they require. As cities continue to grow, the demand for land increases, making it difficult to find suitable sites for new landfills. This has led to the expansion of existing landfills and the transportation of waste over long distances, increasing costs and contributing to carbon emissions. Even now cities and urban planners have great challenges in overcoming this problem.

One ***significant component*** of urban landfills is plastic waste. Plastic is non-biodegradable and can take hundreds of years to decompose, making it a significant problem for landfills. The accumulation of plastic waste in landfills also poses a risk to wildlife, as animals can mistake it for food, leading to ingestion and entanglement, which can cause injury or death.

Its effects in developing countries like India is more enhanced as the cattle like cows, buffaloes which give milk grazes on these landfills and consumes plastic and other toxic waste which then enters the food chain through milk and thereby harming entire bio-environment in the process.

Waste to energy angle

The rapid industrialization and continued pressure on expansion of manufactured goods have the effect of generating consumer waste which rapidly increases year on year. The problem is more pronounced in developing countries as they move upward in the social mobility. According to one estimate there are currently more than 2600 Waste-to-Energy plants worldwide disposing a collective of 460 million tons of urban waste (Ecoprog.com, 2023).

Waste-to-energy (WTE) plants are facilities that use municipal solid waste (MSW) as a fuel source to generate electricity and heat. These plants are gaining in popularity as society seeks to reduce waste and increase energy efficiency. Traditional plants had the risk of emitting toxic gases like sulphur-di-oxide, methane among others but great improvements have been made in absorption filters and polymers which ensure that quality and harmless air is emitted as a byproduct from these plants.

Firstly, WTE plants generate electricity by burning MSW at high temperatures in a combustion chamber. The heat generated from this process is used to create steam, which then powers turbines to generate electricity. The amount of energy generated depends on the size and efficiency of the WTE plant, as well as the quality and quantity of the waste used. On an average the waste to energy plant of 1MW can produce up to 8000 MWh of electricity in a year(Waste to Energy, n.d.) which is sufficient for powering around 2500 households.

In addition to generating electricity, WTE plants also produce heat, which can be used to provide heating to nearby homes and businesses. This process is called district heating, and it is particularly popular in European countries such as Denmark, Sweden, and Finland. District heating systems can significantly reduce the amount of fossil fuels needed for heating and help to reduce greenhouse gas emissions.

Moreover, WTE plants offer a range of environmental benefits. Firstly, they reduce the amount of waste that goes to landfill. When waste is sent to landfill, it decomposes and produces methane, a potent greenhouse gas that contributes to climate change. By diverting waste to WTE plants, these emissions are significantly reduced. Additionally, WTE plants help to reduce the need for new landfills, which can be difficult to find and are often located in environmentally sensitive areas. For all the plastic which needs to be transported to distant energy plants for incineration there is a tipping fee or a cost involved, hence by setting up a SMR close to the landfill saves up this cost and eventually making this place free of plastic.

Furthermore, WTE plants can also help to reduce air pollution. When MSW is burned in a WTE plant, the emissions are treated to remove harmful pollutants such as nitrogen oxides, sulfur dioxide, and particulate matter. This means that the emissions from WTE plants are often cleaner than those from other sources of energy such as coal-fired power plants. In addition, some WTE plants use advanced technologies such as gasification and pyrolysis, which can further reduce emissions. The use of advanced absorbers and filters can help further reduction in toxic gases from being let out in the atmosphere.

Why incinerate plastic at all – future of plastics

Considering all the above studies and theories, the basic question needs to be addressed, why incinerate plastic in the first place? Cant all plastic be recycled? Can plastic be eliminated for alternate materials? The answer is complicated.

Ever since the industrialization started the oil and gas use along with it's by products like petrochemicals like plastic have powered the earth for at least 4 generations. It has given us growth, prosperity and longevity as well due to improvement in medical technology, especially use of plastics in syringes, needles and masks in pandemic era. Now a sudden rollback of plastics is near impossible even if we find alternates to replace them. The reality is that most plastic waste cannot be recycled. In fact, less than 9% of all plastic waste ever produced has been recycled hence making a strong case for incineration (Oecd.org, 2022).

Rapid advances are being made and governments world over are promoting the use of green and organic materials instead of plastic for daily use. India has already banned the manufacture of single use plastic (Bhardwaj, 2022).

The biggest issue with plastic is its longevity. Unlike organic materials such as wood or paper, which can break down over time and return to the environment, plastic takes hundreds or even thousands of years to decompose. As a result, plastic waste is accumulating at an alarming rate in landfills, oceans, and other natural ecosystems.

To address this challenge research is done in the following areas exploring new materials that can replace plastic. Some promising alternatives include:

1. Bioplastics - Bioplastics are made from renewable resources such as corn starch, sugarcane, and vegetable oils. Unlike traditional plastics, bioplastics can be biodegradable, compostable, or both. While bioplastics are not a perfect solution, they represent a step in the right direction towards more sustainable materials.
2. Paper-based materials - Paper-based materials, such as molded pulp packaging, are gaining popularity as a sustainable alternative to plastic. These materials are made from recycled paper, are biodegradable, and can be recycled multiple times.
3. Natural fibers - Natural fibers, such as hemp, bamboo, and flax, are also being explored as alternatives to plastic. These materials are renewable, biodegradable, and can be used for a range of applications, from clothing and textiles to building materials.

These materials are a steadily growing industry to replace commercial plastic use. The problem of recycling is more than just in the quantity as seen below

1. Contamination - Plastic waste is often contaminated with food residue, chemicals, or other materials, making it difficult or impossible to recycle.
2. Down-cycling - Unlike materials such as glass or metal, plastic cannot be recycled indefinitely. Instead, plastic can only be down cycled, meaning it is turned into lower-grade products that are of less value and are eventually discarded.

3. Lack of infrastructure - Recycling requires specialized equipment, facilities, and transportation networks, which many communities lack. As a result, much of the plastic waste generated in these areas ends up in landfills or oceans.

Modelling the nuclear reactor for future use projections

Using all the data from above regarding the use of nuclear energy and taking into consideration all the future reactors from generation IV we get the visualisation of the data as below.

1) Landfills emitting methane is 86 times more harmful than incineration

2) Cost to build a SMR is averaged at $250 million (Science.org, 2021)

3) Waste to energy businesses across the world and how the proposed nuclear incineration plant adds to the new age green business.

Typical SMR (small modular reactor) plant stats are as follows

Plastic incinerated/day	2200 tons
Energy produced/day	1200 MWh
Tipping fee saved/year	74800$
Operating energy	20MW
Direct jobs created/reactor	700
Indirect jobs created	2800
Land recovered in eliminating 1 landfill	3.2 sq kms

Table 1

This is the base model reactor based on which a case will be made taking India as example for using of nuclear energy for plastic incineration.

Analysis and findings

Nuclear use for plastic problem in India

In the following section, the data projections are done based on the table given above. The corresponding data visualization is done using PowerBI tool and screenshots of the generated models are shared appropriately.

India, being a developing country with a large population and large urban cities has all the problems associated with them. Let’s take a brief look at those in context to our proposal

1) **Landfills**: There is no exact and official data on the total landfills but as per statista more than 3400 landfills with varying sizes and municipal waste are present in the country with an ever-growing population and hence plastic pollution also increases year on year putting pressure on land resources, affecting human and animal health, soil degradation affecting agriculture among other adverse effects.

2) **Housing crunch**: Since landfills are not regulated, most landfills are near urban centres over large commercially important land tracts which could otherwise be used for housing. The second order effects of health are already mentioned hence there is a lot of pressure on the cities.

3) **Cost of business**: Due to the pollution, degradation is air quality, wastage of public land there is a steep cost in setting up manufacturing centres in Indian cities. Lack of public awareness and government apathy has led to the situation of clogging up of not just land but also drainage and water supply systems due to plastic.

4) **High use of fossil fuels**: Due to economic reasons use of coal and fossil fuels is pervasive and government has fewer reasons to move away from them. Traditional nuclear plants occupy a large space, technically challenging to install and finally require a large capital outlay to run the plant.

5) **Energy security**: Nuclear energy can help India reduce its dependence on imported oil and gas. By diversifying its energy mix, India can achieve greater energy security and reduce the impact of global oil price fluctuations.

6) **Economic benefits**: The nuclear industry can provide high-quality jobs and economic benefits to local communities. Nuclear power plants require a skilled workforce to operate and maintain, and the industry can create jobs in areas such as construction, engineering, and manufacturing.

7) **Technological development**: Developing nuclear energy can also help India build its scientific and technological capabilities. The knowledge and expertise gained in the nuclear industry can be applied to other areas, such as medical research and environmental monitoring.

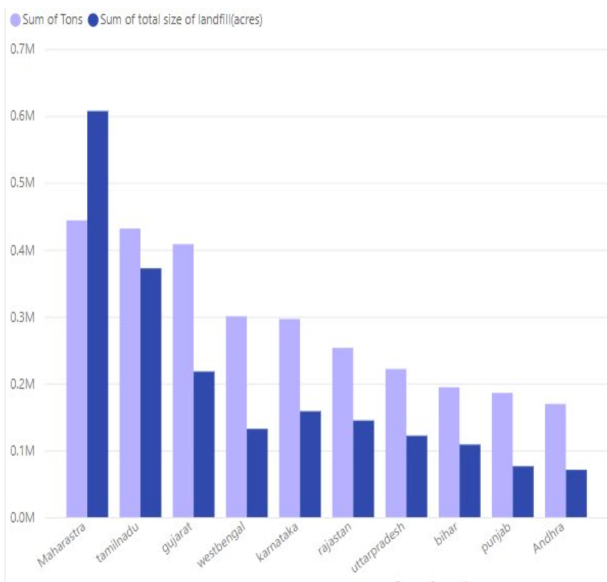
From the above it is obvious that a new approach is needed to fix this issue urgently. As per details shared earlier the SMRs are the best approach to this and India is positively inclined to use nuclear energy and has already commissioned the new generation reactors. (Pib.gov.in, 2019).

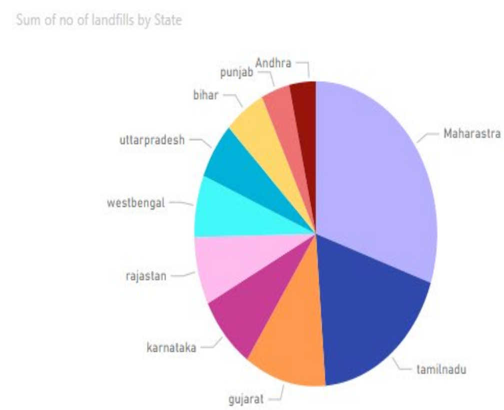
For our proposal we have used the PowerBI tool to visualize the collect data to give a picture of the current problem and how the proposal to use the SMRs will simultaneously reduce the plastic pollution, generate the much needed energy for domestic and commercial usage, and recover land for proper use by reducing dumping grounds. The added benefit is also in decarbonization and helps achieve India’s goal for 100GW of green energy.

The current look at the plastic problem in India state wise is as shown excel and below that in powerBI visualization

State	Tons
Maharastra	443724
tamilnadu	431472
gujarat	408201
westbengal	300236
karnataka	296380
rajastan	253201
uttarpradesh	221674
bihar	194312
punjab	185765
Andhra	169354

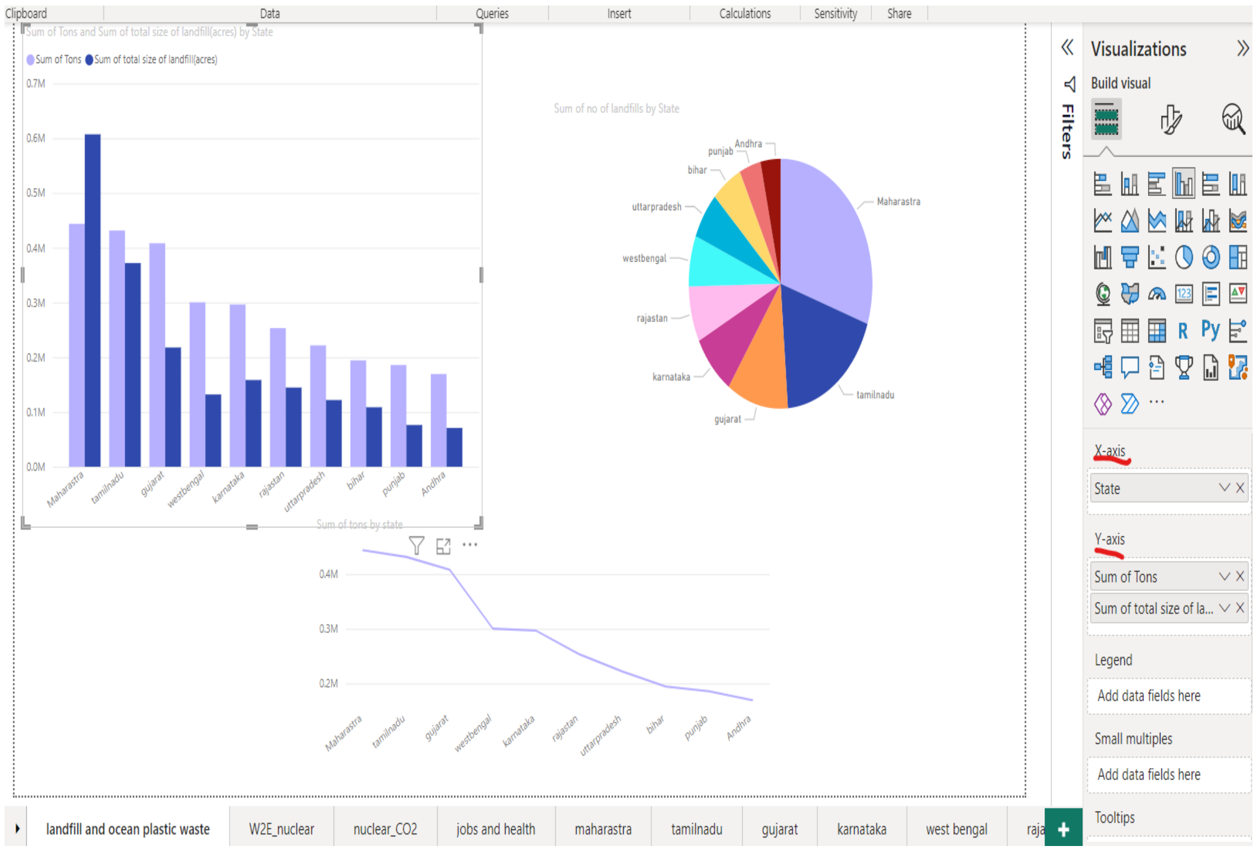
state	no of landfills	total size of landfill(acres)
Maharastra	1012	607200
tamilnadu	620	372000
gujarat	363	217800
westbengal	220	132000
karnataka	264	158400
rajastan	241	144600
uttarpradesh	203	121800
bihar	181	108600
punjab	127	76200
Andhra	118	70800





Model 2

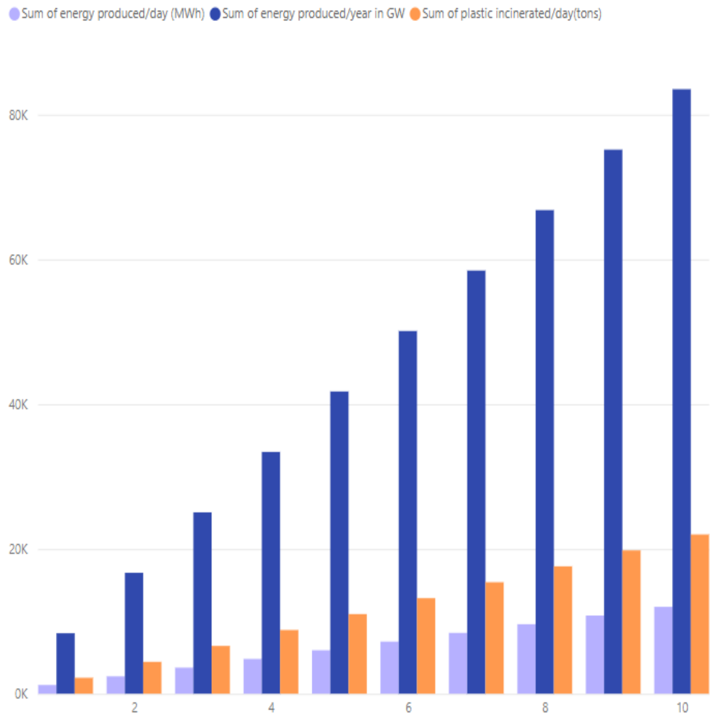
We arrive at the above model in the PowerBI using the visualisation tool using the x-axis and y-axis data after importing it from the excel file as shown in the screenshot below.

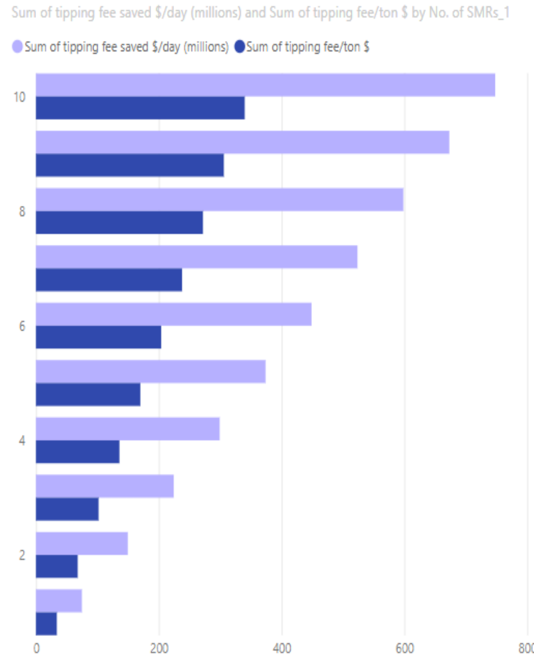


The screenshot is expanded to get a clear view, on the right the x-axis and y-axis is highlighted in red and the models used are the bar graph, pie-chart and the line chart. This is the same method used to generate all the models in this paper which can seen in the different tabs in the screenshot.

The above visualisation shows the gravity of the problem. The top industrialized states not surprisingly have the most landfills. The tonnage in each landfill is not exact from the municipal waste total is estimated based on the household collection and dumping of this in the landfill. The landfills, as shown is a great value should it be recovered from the waste or at least systematically reduced by scientific method of incineration and use of scrubbers and filters. Since the average SMR requires a small land area, it can be setup within the premise of the landfill saving the tipping cost and also ensuring continuous supply of the waste for energy generation.

Now let us look at the ***projected*** energy that can be generated, the plastic incinerated and the tipping cost saved as per the model reactor specifications given in Table 1.

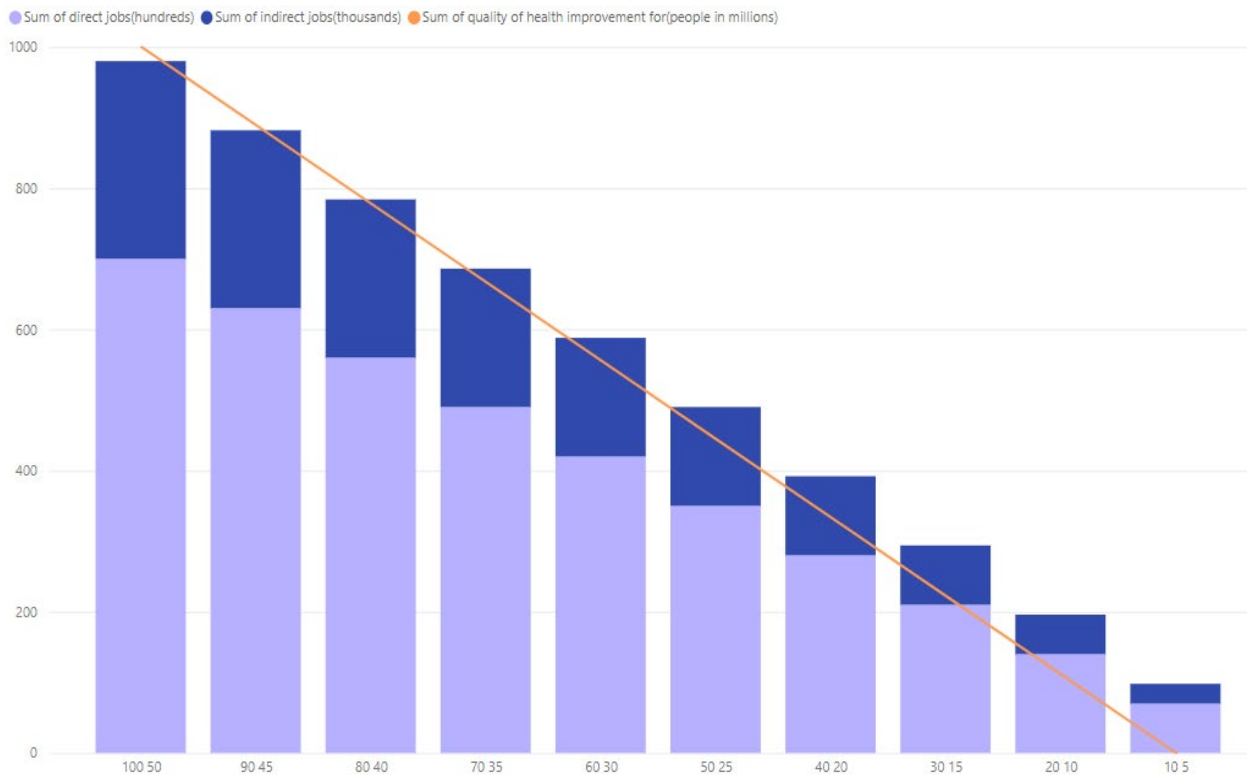




<u>Model 3</u>

The above model on the left gives the sum of energy produced in a day(MWh), the cumulative energy produced in a year(GW) and the total plastic incinerated in a day(in tonnes). The X axis is the number of SMRs used. On the right we have the model of projected savings of money (in millions $) in day and also cumulative value in a year in transporting the used plastic to distant plants instead of using the waste to incinerate in the reactor which is beside the plant. The Y axis is the number of reactors as before.

Further tangible benefits in terms of direct/indirect jobs created and the quality of the life improvements (due to reduction in hazardous landfills) is as shown below.



Model 4

The direct jobs (in hundreds) and indirect jobs (in thousands) are shown in the Y axis. The X axis is the combination of the number of plants (In decreasing order of 10 starting from 100) and the years into the future (in decreasing order of 5 years starting from 50). There is a direct correlation in the number of people whose lives have improved (in millions) and number of reactors used and number of years the reactors are running. This is marked in the orange line. This is fairly obvious due of reduction in emission of toxic gases like methane and carbon-di-oxide and also linear elimination of landfills.

State wise data projections: (top 10 states)

India being the largest country by population and having many states let's take the top 10 states to model our case for the use of nuclear reactors. In the municipal landfills the scavenging jobs are popular among poor people and they employ hundreds in each landfill or a mine in this sector with bad working conditions. So with the nuclear reactors for incineration the skilled jobs will increase but the scavenging jobs will be reduced, so an alternate livelihood for these people needs to be planned by the government. Below models give the jobs created by the reactors and also the jobs manual and the mining jobs which will be affected. The sum of the plastic incinerated is at the bottom of the model. The colour coding is as follows

Land area recovered	Light purple
No of landfills eliminated	Dark blue
Total volume of plastic incinerated	Orange

Job reduction in scavenging and mining	Maroon

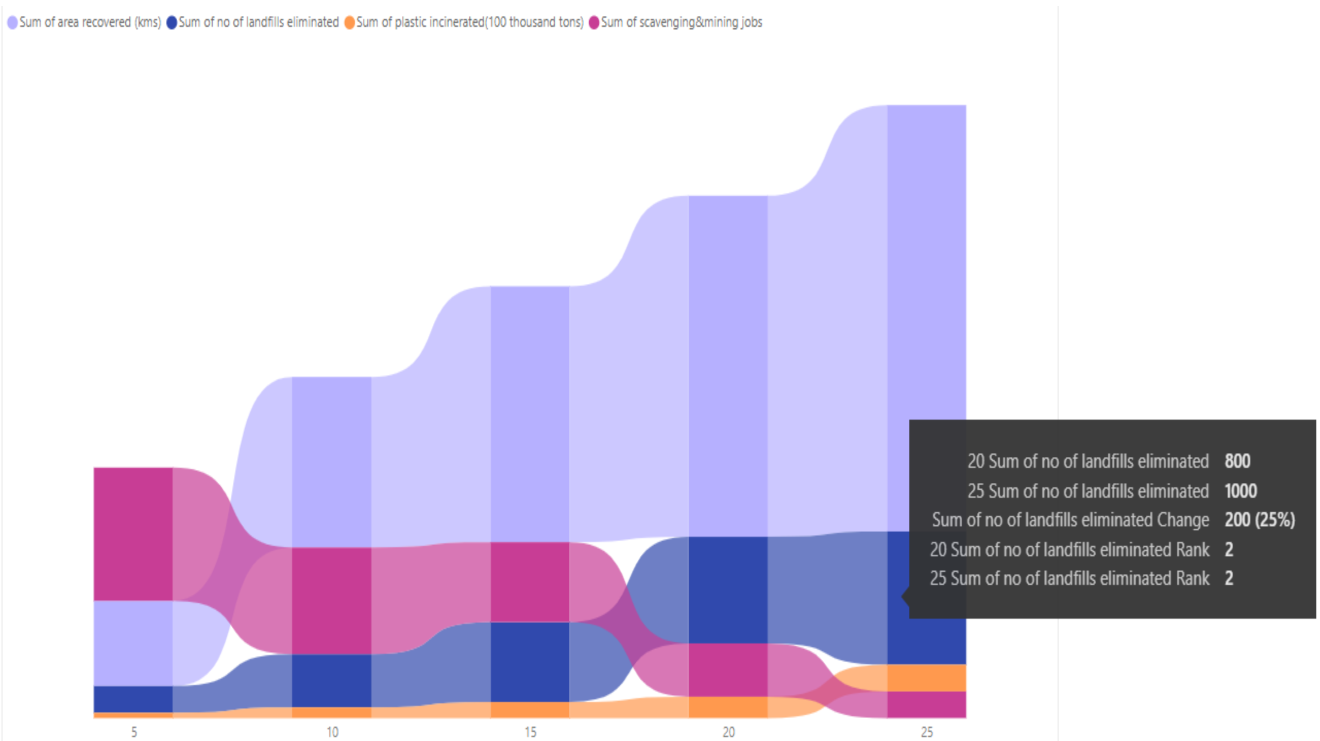
Table 2

Maharashtra

This is the financial capital of India and one of the largest states as well. The industrializations of this state have being ongoing starting from the British era and millions of people from villages and also neighbouring states come here as workers adding to the economy but also to the waste generated as well. The major industries here are related to finance and IT, chemical and pharmaceuticals are present and also there is a sizable economy in the agricultural and textiles as well. The people work in diverse fields hence represented in white-collar and blue-collar jobs. Maharashtra also has the dubious distinction of having one of the largest slums in the world. The model is based on the data below

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(100 thousand tons)	scavenging&mining jobs
200	5	640	40.15	1000
400	10	1280	80.3	800
600	15	1920	120.45	600
800	20	2560	160.6	400
1000	25	3200	200.75	200

Using the above data the PowerBI mapping model is as follows



Model 5

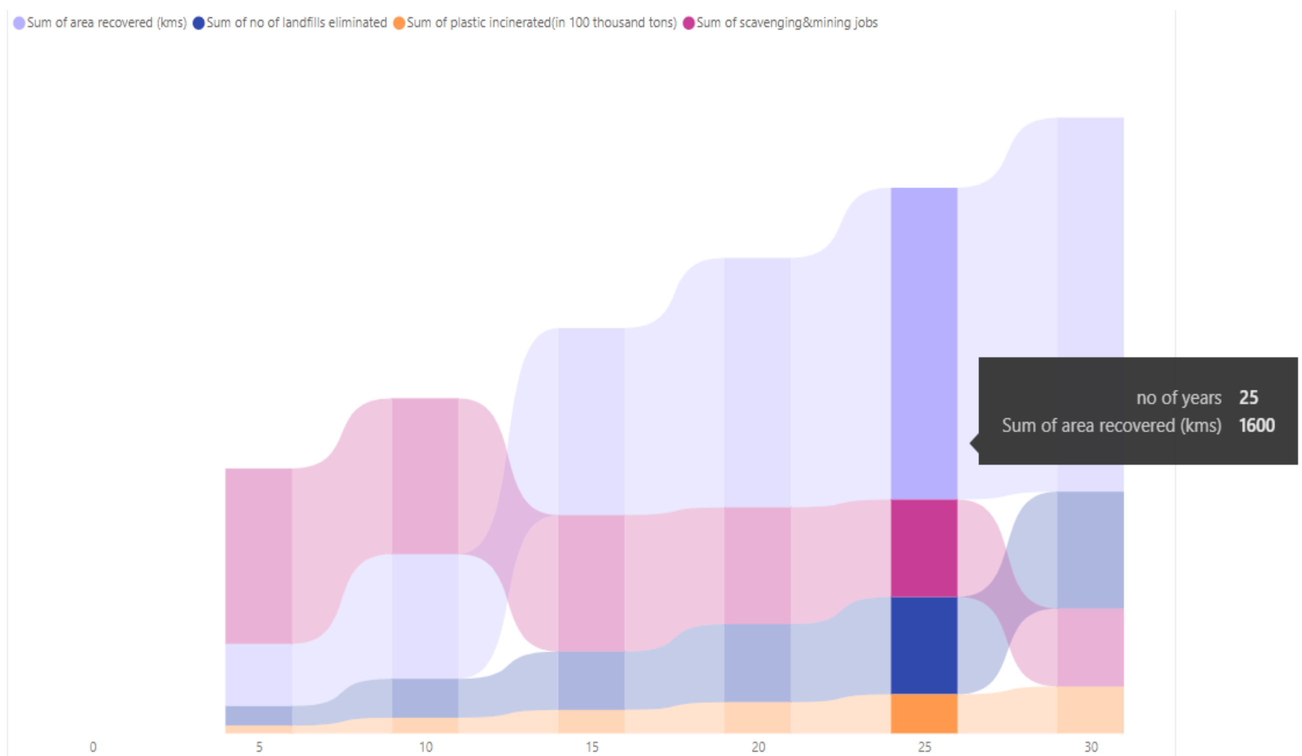
A random point on the model gives a glimpse on the projection at that point. At this point data is explained, in 20 years 800 landfills are eliminated and in the 25th year about 1000 will be eliminated which represents a 25% change/increase. We can ignore the rank data for analysis.

Tamilnadu

This is yet another large industrialised state in south India. It has a well connected road network and the region is blessed with some of the most fertile lands in India. Not surprisingly industries like sugar, paper, leather, cotton etc are produced in large quantities and there is a strong port sector as well. Since it's an agricultural economy this state has lot of one time plastic use materials like vegetable and juice covers etc. so the below table is for Tamil nadu state projections

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(in 100 thousand tons)	scavenging&mining jobs
100	5	320	40.15	900
200	10	640	80.3	800
300	15	960	120.45	700
400	20	1280	160.6	600
500	25	1600	200.75	500
600	30	1920	240.9	400

Based on the above data the PowerBI projection is as follows



Model 6

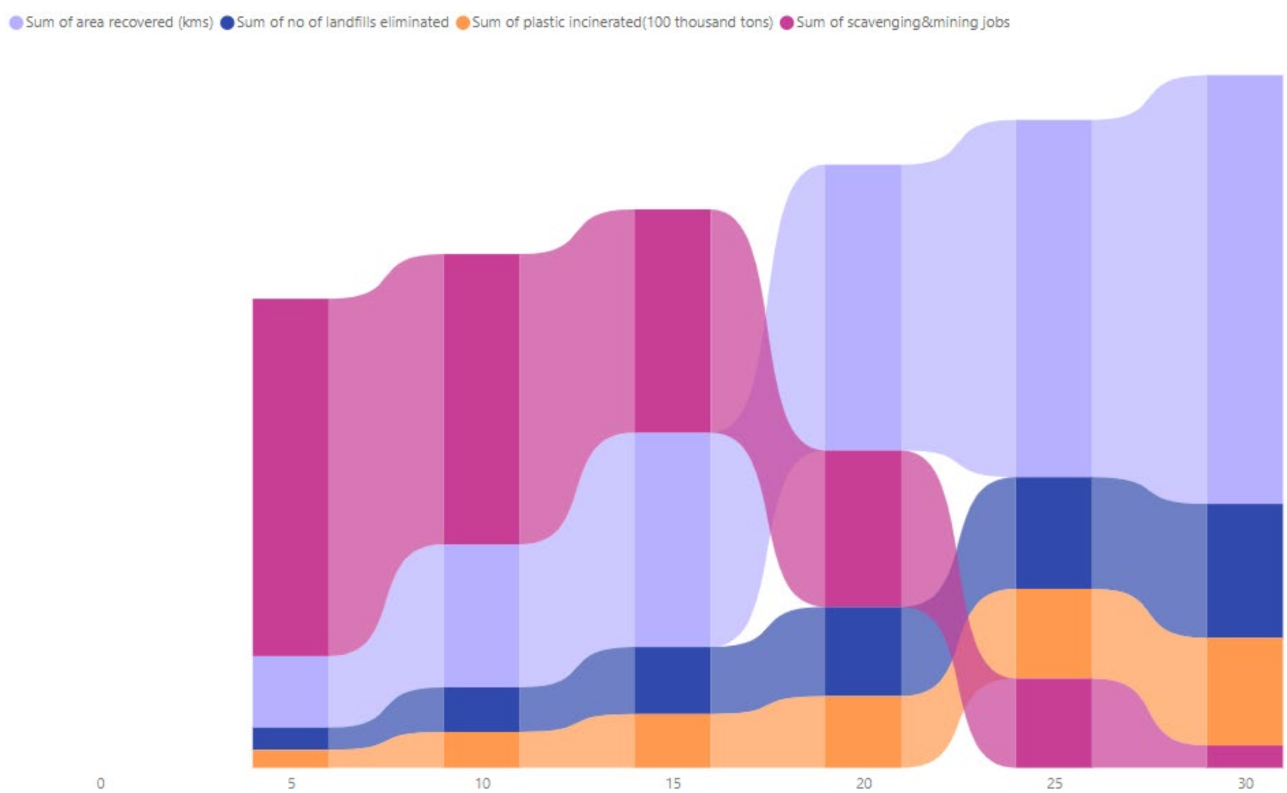
Like in the previous case the model can be used to look at specific data, in the above instance we are looking at the situation after 25 years what is total area of land recovered from the municipal waste and can be used for other useful industry or housing.

Gujarat

This is the most industrialised state and agriculture is not as prominent as the other states due to weather conditions. Lot of economic migrants come here for work and it has the largest port sector in India. Major industries include petroleum, processed diamonds and chemical industries. It has a lot of deserted areas hence the landfill sites are large in size. The projected data is as below

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(million tons)	scavenging&mining jobs
50	5	160	4.015	800
100	10	320	8.03	650
150	15	480	12.045	500
200	20	640	16.06	350
250	25	800	20.075	200
300	30	960	24.09	50

The corresponding PowerBI model is



Model 7

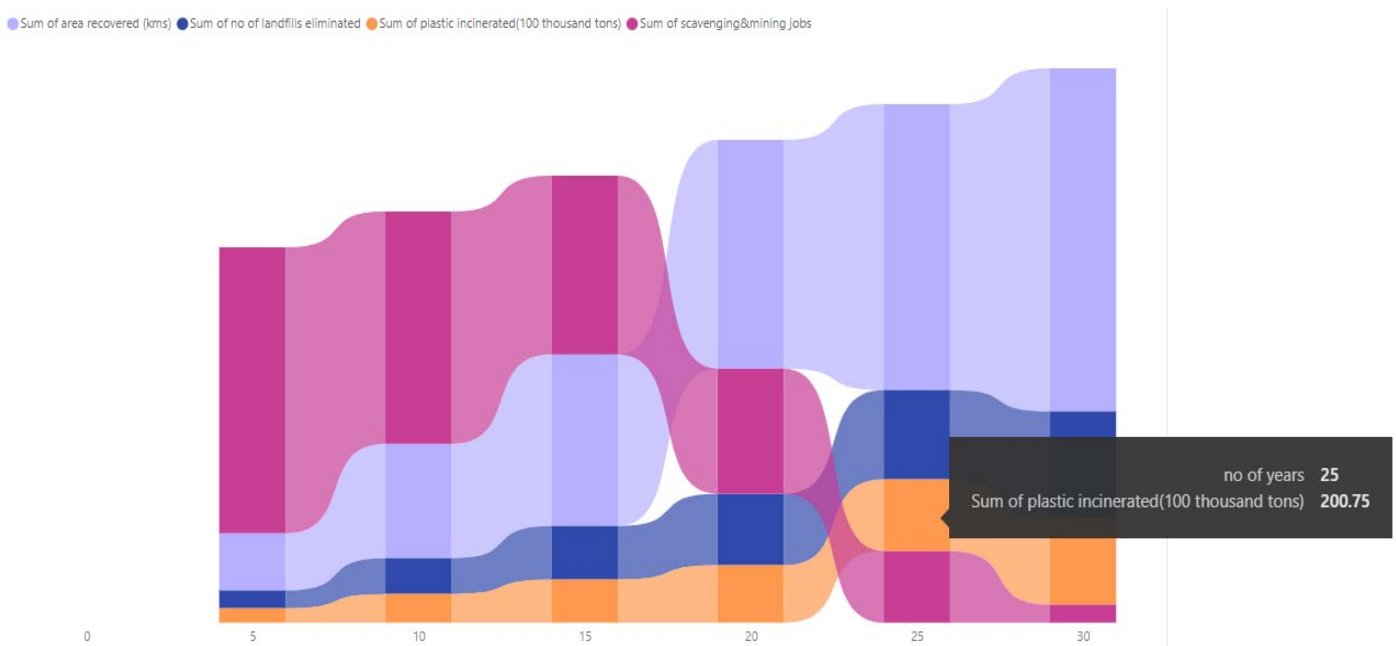
The ribbon chart shows the general flow diagram in which the amount of scavenging and mining jobs reduce over time where as the other parameters increase correspondingly.

Karnataka

This is a state that has a large coastline and shipping is one of the major employers hence lot of plastic ends up in the ocean as well apart from the landfills. The other major industries include tourism, IT sector with Bangalore being known as India's Silicon Valley. The waste generated from construction sector is also very huge. The projected data is as below

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(100 thousand tons)	scavenging&mining jobs
50	5	160	40.15	800
100	10	320	80.3	650
150	15	480	120.45	500
200	20	640	160.6	350
250	25	800	200.75	200
300	30	960	240.9	50

The corresponding PowerBI model is



Model 8

To use an example to illustrate, the above screenshot shows that in 25 years close to 20% of a million tons of plastic will be incinerated thus reducing many ill effects of the same.

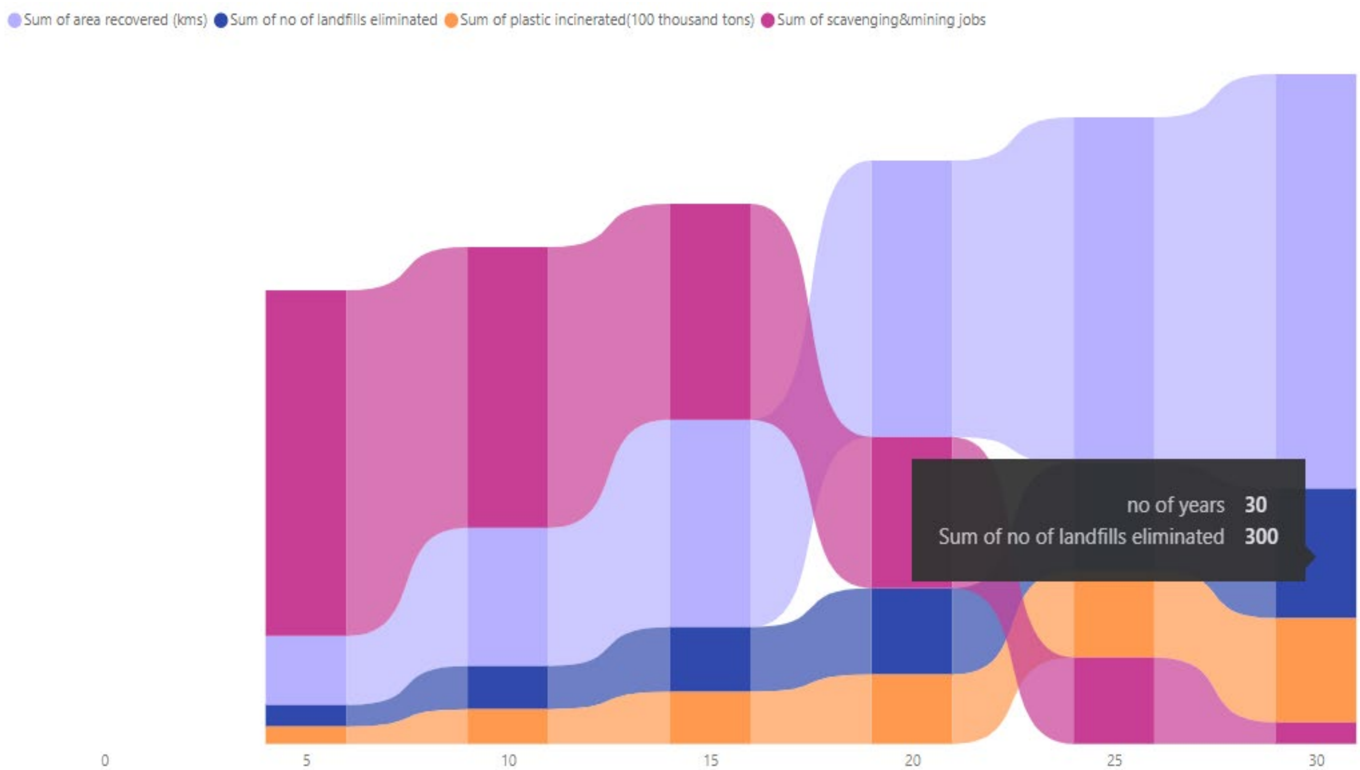
West Bengal

This is in the eastern part of India bordering Bangladesh. Availability of low cost labour and a large population has made it a regional hub and with it lot of plastic pollution as well. The region is blessed with natural resources like coal, iron ore, copper etc. In fact India's largest coal mine called Deocha Pachami is located in Bengal hence the mining sector is relatively strong.

The projected data as with the other states is given

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(100 thousand tons)	scavenging&mining jobs
50	5	160	40.15	800
100	10	320	80.3	650
150	15	480	120.45	500
200	20	640	160.6	350
250	25	800	200.75	200
300	30	960	240.9	50

The PowerBI projection for the same is



Model 9

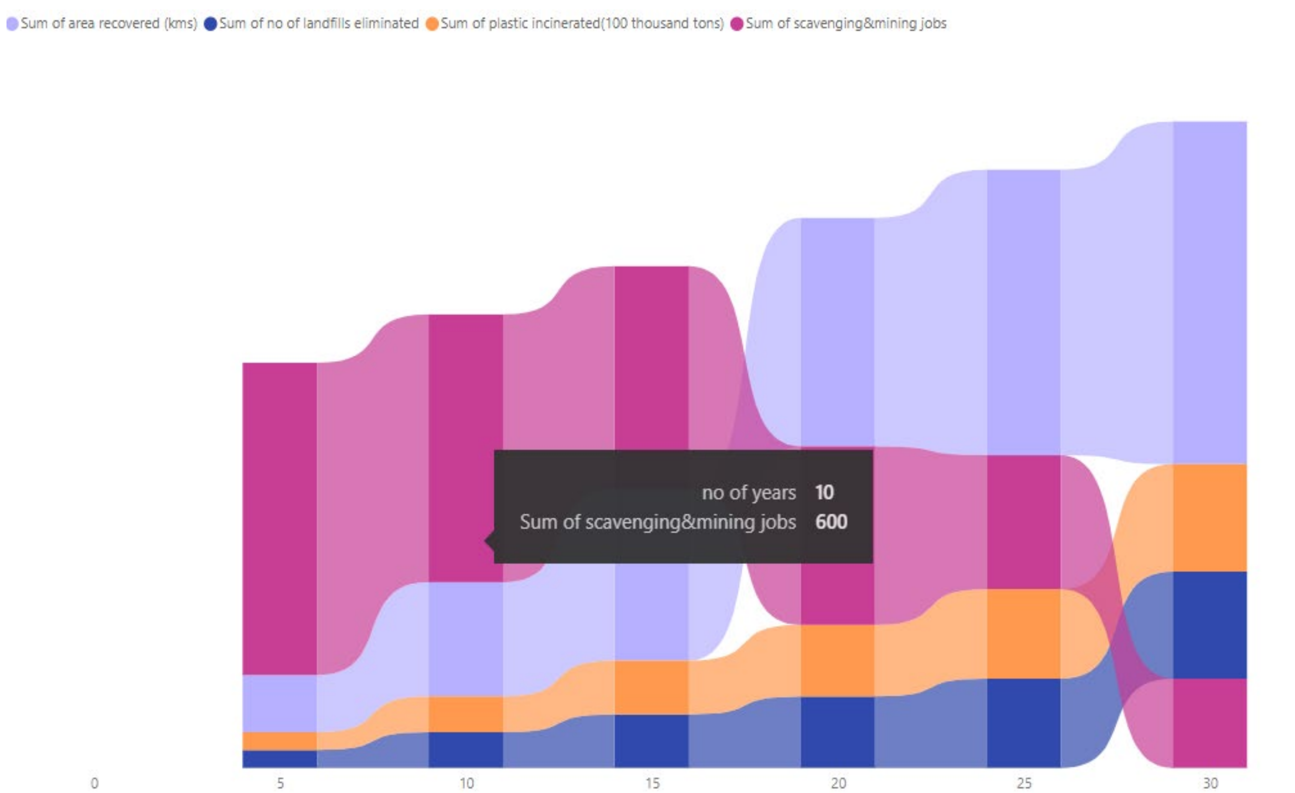
As an example the screenshot shows that in 30 years with the use of nuclear reactors about 300 landfills can be eliminated.

Rajasthan

This is one of largest states by land area and sparsely populated due to the Thar Desert. Urban areas have many landfills and it's an excellent location to set up nuclear incineration plants. The major industries located here are cement, ceramics, and textiles among others. This is the state where one of the largest limestone reserves is present in the world. The data for this state is as below

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(100 thousand tons)	scavenging&mining jobs
40	5	128	40.15	700
80	10	256	80.3	600
120	15	384	120.45	500
160	20	512	160.6	400
200	25	640	200.75	300
240	30	768	240.9	200

The PowerBI model is as shown below



Model 10

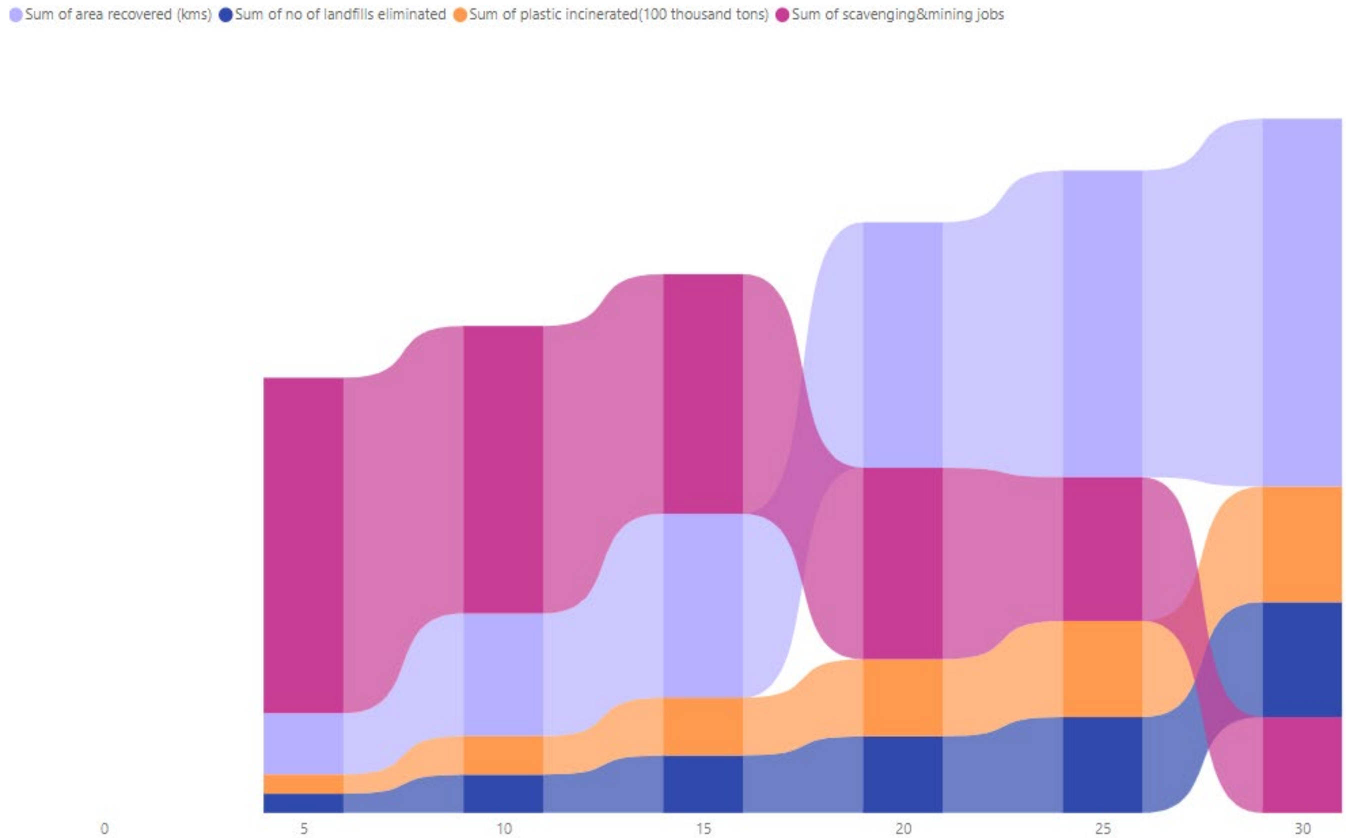
An example is shown again in the screenshot for illustration, it shows in about 10 years about 600 jobs in mining and scavenging will be eliminated.

Uttar Pradesh

This is the largest state in India by population and the general pollution is very high and many cities rank among the most polluted in the world. The Ganges River flows through the state which is the source for domestic use, fishing and industrial waste discharge. Currently the government is trying to get rid of plastic and other sources of pollution from it hence the incinerators will be of great use. The main industries here are fishing, agricultural products, and chemicals among others. The data is as shown for the landfills

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(100 thousand tons)	scavenging&mining jobs
40	5	128	40.15	700
80	10	256	80.3	600
120	15	384	120.45	500
160	20	512	160.6	400
200	25	640	200.75	300
240	30	768	240.9	200

The PowerBI model is



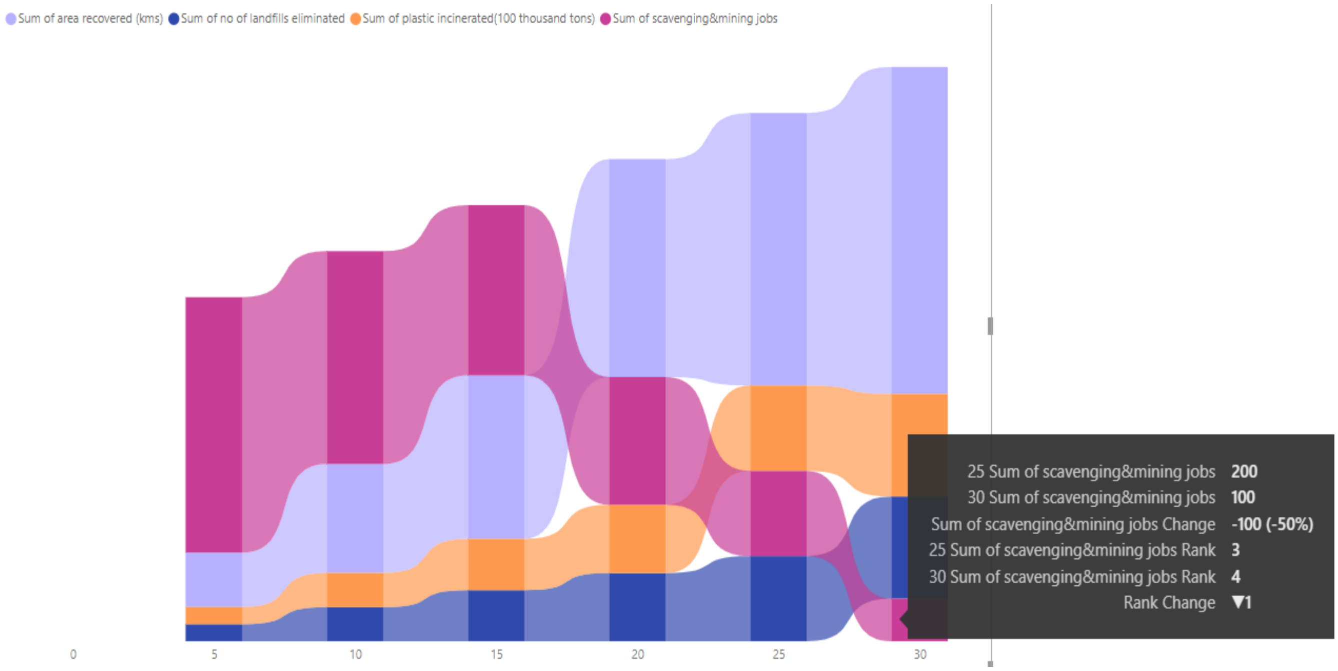
Model 11

Bihar

This is the second most populous state in the country, it's not very industrialized and the municipal waste consists of daily use plastic and agricultural waste. The main industries located in this state are sugar, jute and textiles. It is a highly polluted region and plastic wastes and landfills dominate the urban landscape.

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(100 thousand tons)	scavenging&mining jobs
40	5	128	40.15	600
80	10	256	80.3	500
120	15	384	120.45	400
160	20	512	160.6	300
200	25	640	200.75	200
240	30	768	240.9	100

The PowerBI model



Model 12

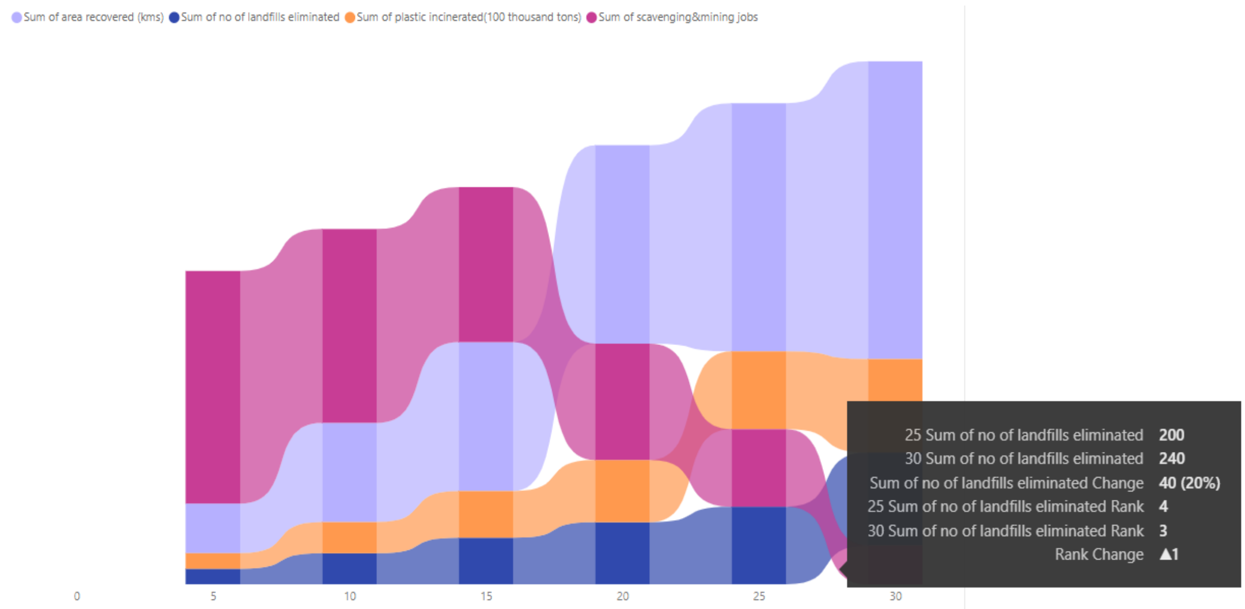
The data point in the model shows a 50% reduction in mining and scavenging jobs and the corresponding change in the job rank.

Punjab

This is a heavily agricultural dependent state and the waste consists of consumables and agricultural waste. It is the land of the five rivers and a highly fertile region. The main sectors of economic activity are cement, chemicals, agriculture, and flour mills among others.

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(100 thousand tons)	scavenging&mining jobs
40	5	128	40.15	600
80	10	256	80.3	500
120	15	384	120.45	400
160	20	512	160.6	300
200	25	640	200.75	200
240	30	768	240.9	100

The PowerBI model



Model 13

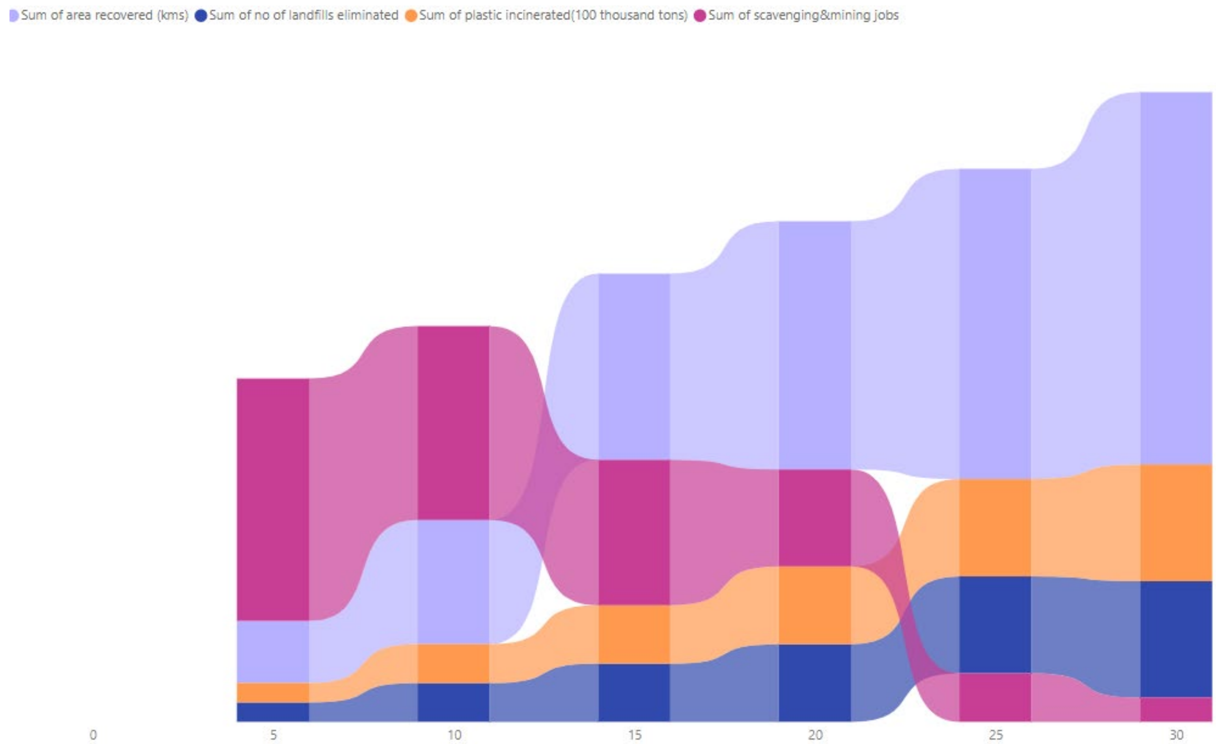
The data point in the model shows a 20% reduction in landfills and corresponding numbers.

Andhra

This state has heavy industries and also good arable land for farming hence an ideal state to setup nuclear incinerators. The major manufacturing sectors in telecom and automobiles are present in this state hence it consumes a lot of water and plastics. The combination of urban and rural economy makes the use of nuclear incinerators ideal for a long term.

no of landfills eliminated	no of years	area recovered (kms)	plastic incinerated(100 thousand tons)	scavenging&mining jobs
40	5	128	40.15	500
80	10	256	80.3	400
120	15	384	120.45	300
160	20	512	160.6	200
200	25	640	200.75	100
240	30	768	240.9	50

The PowerBI model is



Model 14

Green and renewable energy goal for India:

India being a developing country with a large majority of population yet to enter the middle class requires lot of energy in terms of growth and infrastructure has to plan its needs very methodically. Year on year the energy demand is only increasing and still India uses coal to meets its energy demands. Although India promised to phase down use of coal, they have clarified that coal will be reduced as a percentage in the overall energy matrix and in fact the mining of coal is set to cross 1 billion tons this year (Mehrotra, 2023). This means the pollution and green house gases are only set to increase with IMF declaring that it is estimated to grow at almost 6% in 2023 (IMF, 2023). Further look at this data means the middle class is set to grow more and manufactured goods will increase and with it consumption of everyday plastic as well. India has a clear and detailed plan for the use of clean and green energy as per commitments made during the COP-21 summit. They have committed to become a net zero carbon economy by 2070, so without increase in use of nuclear energy, this goal is next to impossible to achieve. Luckily the Indian government has approved 10 new indigenous nuclear plants each having a 700MW capacity in a fleet mode (Today, 2023). This is will add 7GW in the green energy bucket. The current energy matrix of India by fuel looks as follows (Akhilesh Sati, 2022)

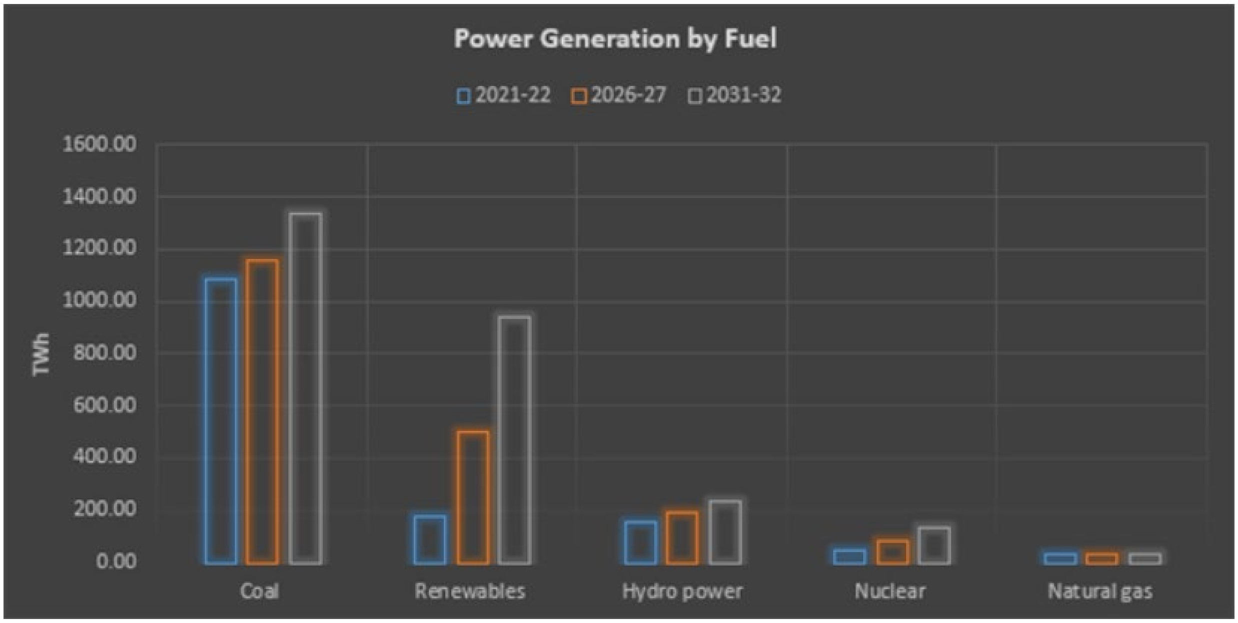


Figure 12

From the above it's clear that power by every segment is on the rise for a rising population hence it's imperative to increase the use of nuclear energy. As set out in its policy framework the following targets are set by India

1. In 2015, India set a target to achieve 175 GW of renewable energy capacity by 2022, including 100 GW of solar power, 60 GW of wind power, 10 GW of bioenergy, and 5 GW of small hydro power.
2. In 2021, India raised its renewable energy target to 450 GW by 2030, including 280 GW of solar power, 140 GW of wind power, 10 GW of bioenergy, and 5 GW of small hydro power.
3. Energy efficiency: India is also working on improving energy efficiency in various sectors, such as buildings, industry, and transport, to reduce energy consumption and greenhouse gas emissions.
4. Electric mobility: India has set a target to achieve 100% electric mobility by 2030, which includes electric vehicles for both personal and public transportation.
5. Green hydrogen: India is exploring the potential of green hydrogen as a clean energy source and has set a target to generate 5 MMT(million metric tons) annually and generate over 6 lakh jobs in this area alone (India.gov.in, 2022).

Research Gap

The research does not take into fact about the pollutants emerging from the incineration process and just focuses on reducing the other reductions in greenhouse gases like CO2, methane which are much more harmful to the ecological health of the planet. The skills required to maintain and run the plant are out of scope of this thesis. The impact on the jobs in the coal mining will be affected as a second order effect, but the study of the same is also out of scope for this paper.

Research Question

The primary question looked at in this study is the feasibility of use of a small and micro nuclear reactor in the future to incinerate large amounts of plastic generated from human activity and resulting waste in the environment. The study also aims to look at the positive environmental effect by using nuclear energy primarily in decarbonisation and pollution reduction. The business cost benefits in running the waste to energy plant using nuclear energy is also discussed. Appropriate data models using PowerBI is also given for study which would be useful for future projections with any changes in data.

Research Methodology

The primary function of a research methodology is to collect, analyze and present the data in such a way as to enable the reader to understand the findings presented. As the famous inventor, businessman and engineer Charles Kettering (Shampo, Kyle and Steensma, 2012) said “Research is an organized method for keeping you reasonably dissatisfied with what you have”. The following section shall describe the thinking behind the approach used, the data collections method, statistics used and presented in a visual format.

Philosophy

This describes the philosophy and the underlying assumptions a person makes before undertaking a research. The nature of the research can be objective or subjective or a combination of both. As the names suggest the objective research deals with the numbers and data and basically mathematical in nature. It is rigid and conclusions are precise and no room for alternate conclusions. The subjective one is related to opinions and feelings of the subjects who choose to participate in the study. Both the results of the objective and subjective data are considered to be valid with the stated assumptions and boundary of the scope chosen.

Approach and Design

Based on the assumptions stated the research approach is chosen. In this paper we have chosen a quantitative method of research as it relies on technical data and corresponding statistics. The other approach is qualitative (not used here) where in the subject's feelings and opinions are chosen and bound to change from person to person and also can change in time due to circumstances.

The design here is the quantitative and to justify this method we shall make of statistics, data from reliable sources like scientific studies, governmental data and then based on the historical data a future projection is given and the interpretation to justify our conclusions. The statistics used in this method are called descriptive statistics since they explain or describe the source data collected. Descriptive statistics are used to give uncomplicated summaries and generalizations about the sample and explain the observations that have been made. After this step the statistical analysis is made which can explain the future trajectory of the nuclear energy across the world or in specific geographies and also address in benefits of this use in plastic incineration.

Primary data source:

It is the first hand information based on the data obtained. Under the assumptions the projects stand valid and the technology is already commissioned and experimental reactors have been already demonstrated

Secondary data:

This is the data obtained from scientific papers, journals, government websites and labs across the globe. This data and analytical estimations done will be the basis for the statistical models shown.

Research limitations

This study incorporates all the latest technology and data from the field of nuclear reactor design, coolant technology, fuel rods, enrichment process etc. However the projections cannot take into account the future patents and technology (exciting new tech features can come up) and also any changes in the government policy associated with nuclear energy. The models are proposed based on the existing technology and policies.

Discussion on the analysis

From the above data and analysis we can observe and project the benefits of installing nuclear incinerators. Let us look at the benefits for India in terms of numbers and percentages based on the above proposed model.

Let's assume India sets up 100 SMRs as incineration plants, from the above projections we get and also see table given for reactor specifications.

About 2000 landfills will be eliminated in 50 years or up to 50% of all landfills. This is the land which can be then used for residential and commercial purposes. In the same time the energy generated is close to 835TW annually!, as we can see it goes a long way in helping India achieve energy independence. The plastic reduced in the 50 year period is close to 4 billion tons! Employment generation is a big part of any emerging economy hence nuclear power plants are important, they pay good salary and are technical and skilled jobs. So 100 SMRs employ 70,000 people directly and 2,80,000 people indirectly. The data for the same is projected as per following assumptions

1) 100 landfills take 2.5 years to be eliminated using 100 SMRs hence in 50 years it turns out to be 2000 landfills

2) 2200 tons of plastic is incinerated in a day (per plant) hence for 50 years = 2200x30x12x50x100 ~ 4 billion tons

3) Energy generated in year from 10 plants is 83520 GW hence it is 835 TW annually for 100 plants is 835 TW.

4) Each reactor employs 700 people directly and 2800 people indirectly, hence the number mentioned above is for 100 reactors.

Implications:

India needs further push into use of next generation reactors which can achieve overall goals of Indian policy makers in terms of energy, job creation and reduction in plastic pollution. The social and environmental conditions are improved significantly with this policy push. To put this in perspective the number of coal miners in India are numbered at 2,48,000 (Statista, 2022) and these are low skilled and hazardous jobs. The ill effects of these jobs along with the accompanying pollution related health effects are not even measured properly. The use of next generation incinerators solves these problems and also gives skill development programs a fillip to empower the next generation. Since the reactors are built in fleet mode i.e. scalable and modular, the complexity in setting up these plants is reduced and economically beneficial.

Almost everyone overlooks the skilling part of running and maintaining industrial plants. As mentioned before the nuclear plants generate a lot of high skill and highly paid jobs because they are very technical in nature. Establishing hundreds of such nuclear incinerators there will be a shift in the mindset of the population which benefits the country in the long run. By running a up skilling program there will be a cultural and a generational shift in the outlook of the people and the benefits will not just be limited to nuclear industry but will also gear India towards a better and industrial future.

To summarize, there are great benefits of using the proposed nuclear incinerators which have multidimensional benefits for the people and the country in general. To power India to a new, clean and green future now is the hour of need to setup and scale these plants at a national level in order to leave a better future for the coming generations.

Future use of SMRs

The design of the SMRs as mentioned earlier is such that it's in a plug and play mode and can be used for other uses. The versatility of the SMRs in the plug and play mode enables it to be a dependable asset for any industry or a nation. Let's look at the future of a couple of these cutting edge industries

Nuclear powered data centres

The concept is very recently gaining traction and seems like stuff from science fiction. However it's important to recognize the overpowering reasons why governments and corporations are considering this. The famous British mathematician Clive Humby said this back in 2006 "data is the new oil", for good reason. The world of commerce, innovation and development and every cutting edge discoveries rest of proper use and manipulation of data. The data centers are now the new strategic assets in national development and recognized as such in Ireland (Government Statement on the Role of Data Centers in Ireland's Enterprise Strategy, 2022). This means that nuclear energy is an excellent option for data centers that are looking to reduce their carbon footprint and meet their environmental targets. In addition, nuclear energy is highly efficient, and a single nuclear power plant can produce a significant amount of energy, making it a reliable source of power for data centers. These SMRs are highly secure power sources i.e. nuclear power plants are heavily guarded and protected, making them less vulnerable to security threats such as cyber attacks and physical sabotage. This means that data centers that rely on nuclear energy can benefit from the increased security that comes with using a highly secure power. Another aspect is that scaling up is simple for a nuclear reactor when there is a need as no new physical infrastructure needs to be built and the demand can be fairly quick for a data centre as more and more countries join the digital revolution. In fact the first nuclear powered data centre has been recently commissioned by Talen energy (World-nuclear-news.org, 2023) and lot of major players have made investments in this concept for a green future.

Nuclear powered satellites for exploration and commercial use

This is another fairly recent idea and major players like SpaceX and NASA are putting their money in this. The reasons are fairly obvious, a huge amount of energy is needed for satellites and any increase in the cryogenic fuel needed means the bigger the rocket size which has its limitations. A mini nuclear reactor can solve this problem straightaway and has been tested as a concept to take the satellites on new journeys beyond the current dimensions. An example is NASA is testing a new nuclear engine for a MARS mission (NASA, 2023). The reduction in size for the fuel chamber allows more scientific equipment and other materials to be carried in the rockets for experiments and study. The thrust power generated by a mini nuclear reactor is enormous hence the liftoff and the orbit velocity is much higher and can reduce travel time significantly. There are vast empty and dark regions of space where sunlight is not available hence a nuclear powered rocket will be a able to self-sustain for long periods of time without need for solar energy.

Environmental curing and remediation

This is one of cutting edge uses of nuclear energy. This process involves blasting the soil for example with high energy gamma radiation to ionise the water. Here the complex chemicals and harmful organic compounds in water are broken down into simpler substances and the recovery from the toxic materials is faster. The ill effects of an oil spill or industrial effluents are removed. This is particularly helpful in a developing country like India where the water and soil pollution is rampant. The aspect of nuclear radiation is that it is very accurate in identifying the pollutants to begin with using the properties of gamma radiation, this process is called neutron activation analysis and it detects contaminants in soil, such as heavy metals and radioactive isotopes. The powerful rays can penetrate deep into the soil and hence do a terra mapping without having to drill down deep inside the earth. By identifying the specific contaminants present, scientists can develop targeted remediation strategies and make the process quicker. This information is used to make a profile of the soil or water like the pH value and the contaminants it holds. The soil or water is then taken in a radiation chamber and blasted with the gamma radiation. The chemical breakdown is quicker and the soil/water is chemically pure and ready to be used. The water sterilization works similarly removing the virus, bacteria and other substances (Iaea.org, 2016). In Japan, after the Fukushima nuclear disaster, the remediation effort was launched in Japan (INTERNATIONAL ATOMIC ENERGY AGENCY, 2023) and for a 10 year period the results were studied and showed a significant improvement in people's health and improved the recovery efforts in metabolical process in the body. The patients reported improved conditions and provided valuable information on future treatments. The use of neutron activation analysis, gamma radiation and irradiation are some ways of how nuclear energy can be used to clean up contaminants in the environment. The awareness of environmental issues and de-carbonizing the planet the use of nuclear energy for environmental and soil remediation is becoming more widespread and accepted.

Manufacture of green hydrogen

Hydrogen as we have seen earlier is considered the fuel of the future. Currently hydrogen is manufactured using fossil fuels which are inefficient, not good for the environment and also very expensive. SMRs can again be a great way to manufacture clean and green hydrogen. Technically as well, since hydrogen is manufactured by splitting the water molecules into hydrogen and oxygen, it requires a high temperature which is generally not produced in a fossil fuel plants which require additional catalysts and processes. Nuclear reactors eliminate these factors thereby saving money, power and time. Since the coolants used for a nuclear plant is water there is an added benefit of using this high temperature to split the water molecules and also convert the remaining energy to generate a high pressure steam. This in turn powers a turbine to generate electricity finally completing the cycle. The generic plant is shown below for illustration purposes

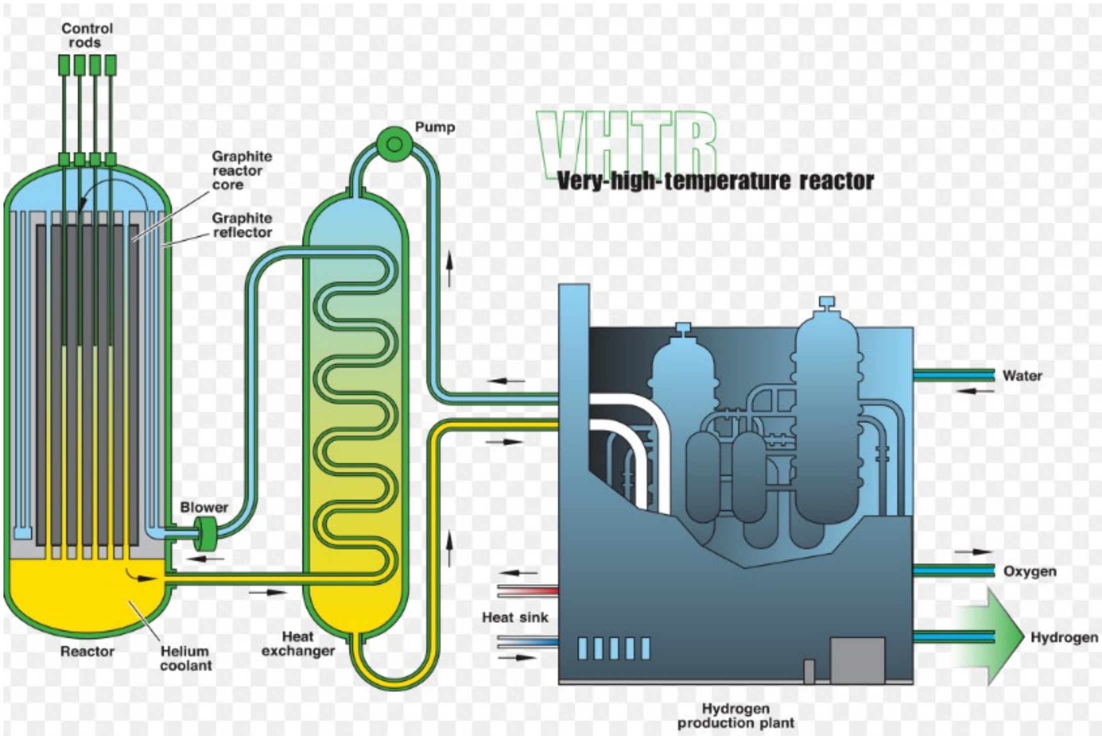


Figure 13

The department of energy in the US has already approved 4 such plants to become a leader in hydrogen manufacture across the world. The department of energy estimates that a 1000 MW plant can produce hyrogen uninterrupted at a rate of 150,000 tons in a year! (Energy.gov, 2022). India can benefit from this as well as the policy has been set for green hydrogen manufacture as seen earlier, the jobs generated will be close to 6 lakhs.

Thorium and fusion reactors

The future in nuclear energy has exciting possibilities in form of thorium and fusion reactors. Let us look at both

As the name suggests the thorium reactors use thorium as the nuclear fuel instead of traditional uranium fuel. Thorium is at least 3 times more available in the world than uranium as per the IAEA (International Atomic Energy Agency, 2018) hence extraction cost will be reduced. This is especially a great replacement for uranium as India co-incidentally seems to have the largest deposits of thorium in the world (World-nuclear.org, 2020). For the long run this is a great fuel and lasts for hundreds of thousands of years. Thorium offers greater safety, reusability and better capacity factor than uranium. This is still in the experimental stage and greater research is needed to make it commercially viable. However this is a promising area for the future.

The fusion reactor uses the fusion principle of combining atoms to release energy instead of fission. This produces tremendous amount of energy while leaving no nuclear waste and no green house gases as emission. In Germany a theoretical principal of fusion was demonstrated and the plasma state was achieved and maintained for 8 minutes which is a new record (Gieljan de Vries, 2023). The skill of the engineers at the plant is remarkable and now we are 1 step close to achieving a fusion reactor dream. Once its commercially viable the earth's energy needs will be solved for a foreseeable future.

Hence thorium reactors and fusion reactors are the future of nuclear energy, with the possibility of safer, more sustainable, and less environmentally harmful energy production. However, these technologies are still in the research and development phase and will need more investment and effort to become viable commercially.

Conclusion

In conclusion, the use of nuclear energy for plastic incineration is a promising solution for dealing with the growing problem of plastic waste. Nuclear energy has the potential to produce high temperatures and pressures that can break down plastic molecules and convert plastic waste into energy. Studies have also shown that nuclear energy is more efficient and cost-effective than other methods of plastic waste disposal. In addition, nuclear energy can reduce the emissions of hazardous substances and greenhouse gases. India's policy makers need to seriously look at scaling up use of nuclear energy for the benefit of the country and the environment in general.

Abbreviation

IAEA - International Atomic Energy Agency

NEA - National Environmental Agency

ONE – Office of Nuclear Energy

NEI – National Energy Institute

SMR - Small modular reactor

GW – Giga Watt

ASMR – Advanced Small Modular Reactor

MMt – million metric tons

MSR – Molten salt reactor

COP-Collection of parties

LED - light emitting diode

TWh - Terra Watt hour

MWh- Mega watt hour

CO_2 - Carbon dioxide

WTE - Waste to energy

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