

## ENTERING NEW MARKETS: NUCLEAR INDUSTRY CHALLENGES

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### ABSTRACT

Nuclear ship propulsion and isolated islands energy supply are unexplored markets for nuclear vendors. Carbon taxes and fuel regulations may make fossil fuels more expensive. Such markets pay more for energy because of organization and transport costs and use of small machines, which are less efficient than grid generators. The goal of this work is to find the measures the nuclear industry needs to take to get into new potential markets. This work shows the different actors and their interests and points the natural or physical constraints they face. Considering interests and constraints, this work named the most probable market niches where nuclear power may beat other power sources. After considering natural constraints, this paper analyses human-generated constraints and presents a way on how to mitigate or solve them. This study shows that nuclear industry needs to take technical, administrative, and political measures before nuclear power arrives to a wider market. This work is based on literature review and qualitative analysis and cannot point precise thresholds where nuclear power should be competitive. Future work will consist of statistical analysis to find precise thresholds to help in the decision-making process.

### 1. INTRODUCTION

Currently, except for Russian icebreakers and containership, there is no merchant ships running on nuclear power. In addition, except for Russian nuclear barge, remote locations and islands typically use fossil fuel to produce electricity. The smaller cycle efficiency, transport and maintenance elevate costs at remote places, compared with grids receiving power from large power plants. Worse, greenhouse gases emission regulations may make the use of fossil fuels yet more expensive, as shipping is an important player on sulfur, carbon and nitrogen oxides emissions [1].

Circa 95% of global commerce goes through shipping [2] and nowadays the supply chains are global, increases in tariffs due fuel costs (fuel is today the major cost driver) affect all economy sectors. This means new ship powering options need to enter play. Wind and solar power could be a choice if the average ship speed is about 10 knots (currently, container ships travel at 20 to 25 knots) and travel times may have variance. However, for baseload electricity in remote places and islands, wind and solar power become too expensive due the need of energy accumulation. Another disadvantage is the large surfaces required for renewables power sources. That means nuclear power seems to be a plausible solution to reduce greenhouse emissions due shipping because it has stable output and does not depend on the weather.

From the point of view of energy security, the issue is not if human activity is causing (or not) the climate changes, but how to secure access to energy given the changes occur. One must remember that in past this planet had periodic climate changes without human activity and such changes should continue in future. This way, both solar and wind power have a risk factor because they depend on climate, which may change over time. Fossil fuels, on the other hand, have risk and volatility on their prices because petroleum reserves concentrate in few politically

unstable countries. Nuclear fuels are present on all continents and in more countries, making its supply safer and its volatility is lower because of mining standard of long-term contracts. Further, even if nuclear fuel becomes volatile, it is not a major cost driver, as it is for fossil-fueled power plants. Because of its power density, making stocks for a long time is cheap compared with fossil fuels, which allows creation of intermediate buffers to support a supply cut.

However, nuclear power also presents problems, such lack of stable regulation, anti-nuclear sentiment on occidental countries, large capital cost, and need of expensive and complex competencies. As typically long route shipping involves two or more countries, a shipping company would need to prove nuclear safety to nuclear safety authorities of all involved countries.

This work aims at addressing all problems nuclear industry faces to get access to new markets, such as merchant ships propulsion or remote places and islands.

## **2. METHOD**

This work adopts system-engineering concepts to make analyses, like system definition [3], functional analysis [4], risk analysis and constructal law [5]. The reasoning adopts the following steps:

1. Identification of actors: it is to count the distinct organizations or groups involved in the sea transport and remote places power generation;
2. Identification of interests: for each actor, describe their needs and fears;
3. Identification of physical constraints: present physical laws that affect nuclear power and fossil fuel;
4. Identification of human risks to a nuclear project: figure out what has already created problems to nuclear power in past and may happen in future due people actions;
5. Proposition of strategies: propose technical, administrative, and political measures that nuclear industry may adopt to access more markets.

## **3. DEVELOPMENT**

This section presents the main ideas at each of the steps mentioned in methods section, focusing on small mobile nuclear power plants or nuclear barges.

### **3.1. Identification of actors**

The first actor is the nuclear vendor, which typically designs, constructs, and sells nuclear power plants to utilities. This vendor does the licensing procedures under guidance of the nuclear authorities. Utilities are enterprises that produce and distribute electrical energy. They buy nuclear power plants and fuel and sell electrical energy while manage nuclear wastes, like burnt fuel and activated parts. Society is the group of people living in a given country and benefits of services like energy supply, transport of goods and nuclear safety. It pays taxes to government and influences policy by representativeness and votes. Government is a group of people in charge of defining and setting the country policies, being nuclear policy one of them. Typically, governments delegate the technical guidance and practical realization of nuclear policy to an organization called nuclear authority because special competences are the foundations of nuclear safety. This organization gives guidance to applicants wanting to use nuclear power and assures safety to the society.

Nowadays, fossil fuel suppliers sell bunker oil to shipping companies, which also buy ships from shipyards. Figure 1 presents a graphical summary of the current situation of organization between actors.

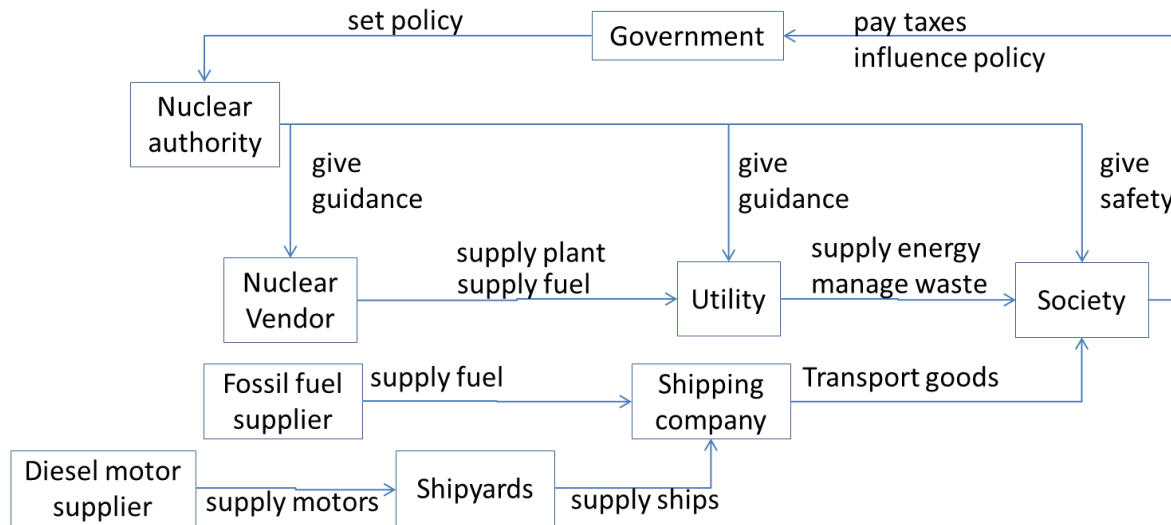


Figure 1 – Functional diagram presenting current situation

### 3.2. Identification of interests for each actor

Society desire is improvement of prosperity meaning abundance of energy and goods at low price, meaning that anything reducing costs should get public support. However, society does not want exposure to accidents (or poisoning due radiation or chemicals), which may cause deaths and diseases. Another fear is the pollution of environment, like oil spills and air pollution. Looking at society fears and historical data, well-informed society should prefer nuclear power to other power sources, since nuclear power has the best safety and environmental record [6]. From the point of desires, society should support nuclear power only when it brings savings on energy, compared to a given country available options.

Government wants improvement in taxes obtained and society support for next elections. One thing is dependent on the other, as support depend on services, which in turn depend on taxes. Government should favor the form of energy that brings down energy costs because taxes depend on economic prosperity, which depends on cheap energy and cheap transport. Besides, more than simple energy price, government must consider energy security costs because a country development needs stable prices for prolonged periods. Comparing coal, oil, gas and nuclear power on Korean case, researchers found that the best option in terms of energy security is nuclear power [7].

Nuclear authorities theoretically would want only to supply safety from nuclear radioactivity to general population and to meet government expectations, but reality is more complex. They need to justify their own existence as organization and meet political wish.

Nuclear vendors need to sell their products, obtain people at work market, obtain nuclear ores, keep their competencies, and make profit. As nuclear vendors made large investments in human capital and tools, they also want to assure a stable market to their long-term survival. Utilities want to make profit by reducing costs, including all life cycle costs. The problem is that the utility does not have all the technical capability the vendor has, so it sees nuclear energy another choice amongst others and tend to run away from nuclear power at first sight of problems.

The shipping companies want to reduce costs in a competitive market. Not only the immediate cost, but also, they need to secure access to fuel as price fluctuations may cause financial

damage. Another factor is they need access to ports. In addition, they do not want to get and keep expensive competencies, as they are a source of risk. In the same risk, issue is the cost for waste management, which currently is still an unknown for nuclear industry. Shipyards also need to reduce costs in a competitive market, and they suffer market fluctuations in demand, needing to keep a stable volume of sales. In this context, shipyards cannot afford to engage in expensive nuclear licensing activities, nor in getting nuclear competencies.

### **3.3. Identification of physical constraints**

Nuclear energy has a density (stored energy per kilogram of fuel) about one thousand times bigger than chemical energy, allowing storing large quantity of energy within a reactor. This means it is cheap to make depots to store nuclear fuel for years of normal consumption. Uranium and Thorium are more abundant than fossil fuels and more evenly distributed on the globe, making them cheap and their availability is more secure [7].

However, the process to convert nuclear energy into useful energy involves fission, which generates ionizing radiation. To allow workers near the plant, reactors need alternated layers of water and lead shielding, typically one meter thick. Additionally, fission and other types of nuclear reactions do not stop completely once the reactor goes subcritical (shutdown), requiring high reliability heat removal systems. Furthermore, nuclear reactors must not increase too much their reactivity (reach prompt criticality), which means the reactor would have uncontrolled nuclear reactions like an atomic bomb. Last, but not least, nuclear reactions generate radioactive isotopes that cause damage to human of any life form if liberated on environment. This makes all nuclear power plants to have three expensive functions: nuclear containment, reactivity control and residual heat removal, besides the one-meter thick shielding. The advantage is that nuclear power plants do not liberate the waste at atmosphere like fossil fuels, meaning the waste is more dangerous but it is under control.

Another aspect is economy scale, which is valid for any technology: larger plants are more efficient in terms of cost and their thermodynamic cycle has better efficiency. As the cost of the functions (shielding, nuclear containment, reactivity control and residual heat removal) have minor change with power increase, scale economy for nuclear power is stronger than for fossil fuels.

In conclusion, given the nuclear power plants are expensive, scale economy is strong and fuel is cheap, nuclear power is only competitive for large plants. Therefore, countries should employ nuclear power on large grid plants and use fossil fuels for smaller motors, like trucks and cars. Islands and large merchant ships could also receive help from nuclear power, but small ships should be competitive only using fossil fuel. As larger plants become nuclear, global greenhouse gases emissions should reduce and energy security would improve.

### **3.4. Identification of human risks**

As people making part of nuclear authority need to study for years the nuclear safety subject, and people are unlikely to study something they hate, they tend to have a positive bias towards nuclear energy. Besides, being a dedicated organization to assure nuclear safety, the complete ban on nuclear energy would make all personnel unemployed. That means both sympathy and conflict of interests tend to make nuclear authorities positively biased towards interests of nuclear industry, against interests of society. On the other side, wanting to meet government expectations, and being independent from other safety agencies, they may make exigencies beyond reasonable level, destroying nuclear industry. A solution to reduce risks in both senses would be to have a single general safety authority for licensing every industry, along a law imposing isonomy for risks for all industries. After this law enter into action, costs shall be

comparable, which does not happen today, except for England, where a general health and safety authority (Health and Safety Executive - HSE) defined general safety targets [8]. Based on HSE rules, nuclear authority defined acceptable risks for nuclear power [9]. Such approach led major accidents where one people die to be acceptable a  $10^{-4}$  per year while in US nuclear authority requires  $10^{-6}$  per year for containment failure affecting a single individual. While UK equalizes risk for all industries, US nuclear regulatory commission demands nuclear power to add only 0.1% of total risk incurred by individuals (about three size orders of difference) [10]. This unbalanced safety approach is harmful to everybody, as prevents a competitive technology to supply a service that affects overall prosperity, besides allowing excessive risks. It is interesting to note that nuclear power, due the physical constraints, has a large capital cost, which in turn incentives asset owners to invest in safety to assure return of capital. This means that even with equality in risk treatment, the nuclear power plant owner engagement on safety should (assuming rationality) be higher than in other industries.

Another issue is public opinion is not always coherent with facts. For instance, public opinion in most occidental countries believe nuclear power is dangerous if compared to other power sources. However, historical data indicates that in terms of deaths per mega Watts-hour, nuclear power, even counting RMBK power plants on Russia, is safer than wind, hydro, coal and oil [6]. The most dangerous power source is hydroelectric, as accidents due dam ruptures cause high number of fatalities, yet people do not mention such fact. Media exposition forges public opinion and nuclear accidents get more attention than dam ruptures, so people tend to cultivate more fear from nuclear power. A solution for such problem is to present data and facts to general public, as a simple 50 minutes presentation changed significantly the opinion of Korean students [11]. The problem is such public relations operations must happen for long time to forge informed opinions, preventing surprise manifestations like those that prevented NS Mutsu to operate [12]. The lack of scientific facts in discussions may lead the society to demand from government a political ban of nuclear power, as happened in Australia, which is a Uranium supplier [13]. Such extreme positions may have as motivation the action of syndicates fearing competition of a more economical power source, as happened in New York.

Another source of failure is the politically motivated nuclear solutions ignoring economic feasibility, like NS Savannah. Despite its technical success, it was a type of ship (mixed passenger and cargo) falling from use in favor of containerhips [14]. That means it was too expensive to keep compared with available options, so Maritime Administration decided to scrap her. A solution for this problem is to consider all market niches before starting a project and to start a project only if there is reasonable probability of being competitive against available options.

Another source of failure for projects is lack of knowledge of life cycle costs by the utility that may take decisions based on a partial set of predictable costs. As utilities do not have a large capital invested into nuclear competences, they tend to abandon nuclear power at first sight of problems, preferring more expensive but less volatile choices. A solution for this risk is to organize production in a way that the same enterprise or group that designs the nuclear power plant also run them up to disposal. This way, there are economic incentives for design to minimize life cycle costs, adding features that reduce disposal costs, like increasing life span, reusable parts and avoiding elements that become long lived radioactive isotopes.

As nuclear competences are expensive and take a long time to develop, typically new markets are not willing to adopt nuclear power. In addition, companies face the risk of losing the competences, which means that after getting (paying a high price) nuclear competences, they may also lose them. In past, on NS Savannah history, the trade union of deck officers rejected higher pay to nuclear workers, going to strike [14], which in turn, makes competence management more complicated. A solution is to have the nuclear operators working to a distinct

company from shipping, where the company running the mobile nuclear power plants sells energy to the ship. Deck officers work for the shipping company and do not need nuclear competencies, nor the ship need any nuclear quality part, being the mobile nuclear power plant autonomous in terms of safety. This way, clients only buy energy, as they would get fossil fuel. In any case, it is possible no shipping company wants to adopt nuclear power regardless of the organization and potential gain, as the competition makes this market too conservative. A solution is to make mobile nuclear power plants able to supply energy at a usual format, enabling them to sell electricity to remote places and islands.

Another risk, although not in nuclear power, is the political instability of fossil fuel suppliers, that are few and small countries. A solution is to employ nuclear power at any niche where it is competitive, as [7] proposed.

### 3.5. Proposition of Strategies

In summary, this work proposes the following strategy: creation of a general health and safety authority setting limits to every industry, following United Kingdom example; concentrating design, construction, operation and disposal of mobile nuclear power plants on a single enterprise or group; and supply energy for several types of clients (ships and islands, for instance). Figure 2 presents this summary in a graphical format.

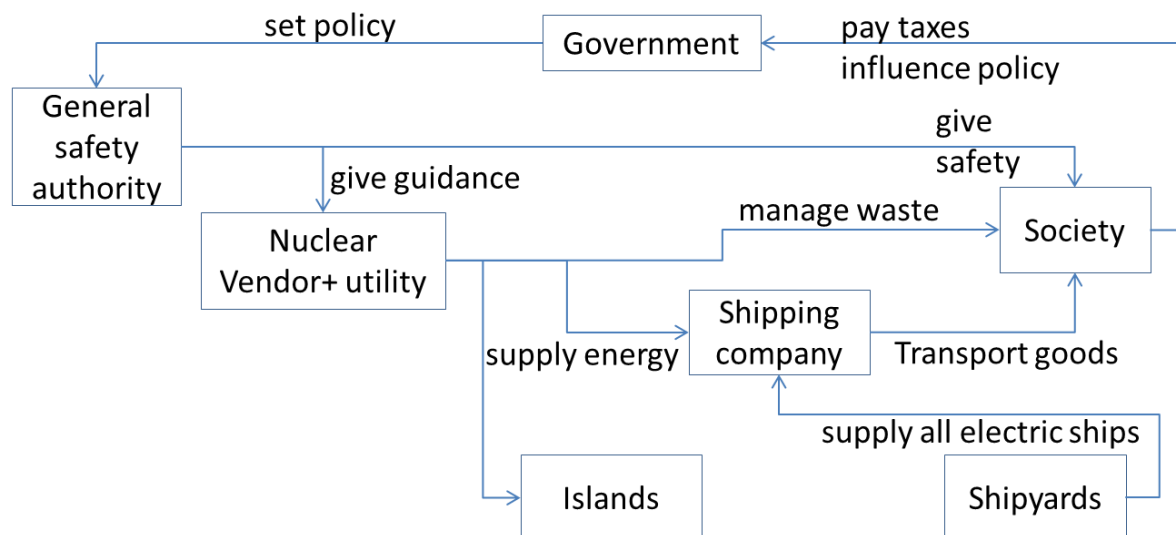


Figure 2 – Functional diagram presenting proposed objectives

#### 3.5.1. Fields for research and development

As natural laws are immutable, the general form of the curve “cost of energy unit vs. effective power” should not change, regardless of the technology adopted. However, it is possible to make this curve lower, getting access to more market niches. In previous work [15], authors proposed ship modular architecture because the mobile nuclear power plants may have a long life (about 60 years) and ships typically have shorter life (25 years). This way, detaching the plant from the ship and transferring it to another ship, the life cycle cost becomes lower. Other possibility is adoption of fourth generation reactors, like molten salt reactors, which could be cheaper, safer, and simpler. But, to make this a reality, new ways of making design, nuclear safety analysis and licensing need to take place to attract investors, and such new methods need to start at research institutions. Another measure could be the application of functional

segregation that means allocation of functions needing high reliability to small, normally in standby high-quality systems. Besides, all systems running in normal operation should be normal industrial quality. An earlier work presented an example of steam generator adopting this principle [15]. As passive safety is gaining space in land nuclear power plants, the same should occur for Mobile Nuclear Power Plants, as passive elements are more dependable and cheaper than active parts. Nevertheless, designing passive nuclear power plants at sea is more complicated because of the limited space, so this is a topic of research.

### **3.5.2. Administrative measures**

[16] proposed that utilities should raise funds to replace nuclear power plants in advance, taking profit of interest rates, instead of paying for interests. This way, the long-lived nuclear power plants have financial advantages over other power sources, being the first mobile nuclear power plants developed using R&D funds. The reason for the government to support such project is to reduce shipping costs and reach energy security, as creating jobs and getting taxes. To reduce risks for shipping companies, the nuclear vendor or group should run the mobile nuclear power plants, selling electric energy, and solving all licensing and waste disposal issues. This way, shipping companies do not need nuclear competences and get power from energy supply contracts. Nuclear vendors should aim at a large pool of clients, as diversity of clients should dilute project risks, assuming the market niches targeted allow nuclear power to be competitive. To know if a given market niche is or not competitive, nuclear industry needs to search for a cost model and associated uncertainties for mobile nuclear power plants.

### **3.5.2. Political solutions**

The first political solution is the permanent public education effort on energy sources, showing historical data on accidents and costs for the main power sources. This should be part of basic school curriculum, allowing informed decisions and judgment before reaching vote age. Also, school needs to reveal the importance of energy to human life, quality of life and jobs, along with the drawbacks and limitations of all technologies. Another political goal is to set equal risks (isonomy) policy for all industries, as United Kingdom. With a single legislation for all industries, policy needs to focus on performance-based goals (becoming technology neutral) and needs to consider human risks. Involving all industries, there should be more stability in the legislation, avoiding crescent demands like in United States, which is a local phenomenon, not representative of Korean experience, for instance [17].

## **4. DISCUSSION**

This work supplied qualitative but objective insights on the expansion of nuclear power to other markets. It assumed that small power plants could not be competitive based on current PWR costs, which may go down with fourth generation reactors. Even if new generation reactors reduce costs, they should still be in the same order of size of PWR technology due the fact that physics are the same, requiring similar functions (reactivity control, residual heat removal, nuclear containment and shielding).

Physics are immutable, but people and policy may change if educated. Media focuses on news that people give more attention, so people tend to get a disproportionate view of reality, meaning that rationality comes only after formal education efforts.

This work assumed the probability of appearance of a technological breakthrough (cold fusion, for instance) is low, so for the short and medium term, PWR reactors are the baseline for Mobile Nuclear Power Plants.

Energy and transport are permanent needs and they evolve slowly, different from software and electronics, because investments are high and there are few players in a competitive market. Moreover, they are related to people survival, as basic needs (food, water, heating) all depend on energy and shipping. Therefore, differently from other markets, government needs to take extra care and adopt measures to keep tariffs low, otherwise, social and political instability becomes expected. A fact is countries adopting uneven policies are going to lag in terms of development as risks and tariffs go up and enterprises will tend to leave the country seeking better places.

Nuclear power has constraints but has the benefit of allowing long life for plants. A long life needs careful planning to maximize the capital returns, as people who designed a 30-year-old (middle aged) plant are unlikely to be still in the market. Therefore, adoption of system engineering, model-based design and product life cycle management is fundamental to allow true organizational learning. The same is valid to the policy, which needs stability to profit of systems lasting for almost a lifetime, making nuclear power unfit for politically unstable countries.

### 3. CONCLUSIONS

Nuclear power is safer than other power sources but need to use scale economy to be competitive, fact assured by the very physics laws that allow its existence. As it has large capital costs, owners tend to invest more in safety to protect their capital than in other power sources. As current container ships are becoming larger, arriving at the 70-80MW shaft power range, they could receive help from nuclear power if travelling long routes at high speed. The same goes for isolated places and islands that need around 60 to 80MW and currently use diesel generators.

However, due the long time to recover investment and long life of nuclear power plants, nuclear industry needs to inform politicians and people to mitigate political risks. Basic school should pass such information before vote age to prevent mass media manipulation. Besides, it is important to create a general safety authority setting performance goals to all industries (as health and safety executive in United Kingdom) to prevent abusive and unreasonable demands specifically from nuclear industry.

In the administrative field, nuclear industry needs to focus correct market (markets where it may be competitive) and have redundancy of clients. Additionally, nuclear industry needs to change organization to offer energy to clients that do not need to face human capital, licensing, and waste management risks.

In the field of research and development, fourth generation reactors may become the solution for long term if governments make investments. However, for short and medium term PWR is the solution. Further research is the development of a cost model based on nuclear power experiences for ships worldwide and development of fourth generation reactor concepts.

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