ESADE Case Study

Seaborg: A Nuclear Energy Start-up

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This case is intended to be used as the basis for class discussion rather than to illustrate either effective or ineffective handling of a management situation.
The case was made based on primary data and published sources.

Troels Schönfeldt, Co-founder and Chief Executive Officer of Seaborg Technologies, looked at the clock of his computer. It was almost midnight and he was still sitting in his office in Copenhagen (Denmark). Although it was only mid-January, he was already forgetting about his 2022 resolution of spending less hours in his office. Although they still had a few years of product development before they could start with the serial production of their Compact Molten Salt Reactors (CMSRs), a Generation IV type of Small Modular Reactor, they had already convinced many investors of their technology. But the cash was burning fast and they needed to convince more investors to continue developing their business. Lately, those investors started asking many questions about their foreseen business model and Schönfeldt had the feeling that they were not interested anymore in another company just selling Gen IV reactors since many similar businesses were arising and the market started to become saturated. Therefore, he was spending his night times figuring out different and innovative ways to commercialize their reactors. His attention was especially drawn to selling their generators in Southeast Asia, where more than 5 GW of coal plants per year should be retired over the next 2 decades to phase out fossil fuels.[i] It would definitely be a great market, if they could replace some of those traditional CO_2 polluting power plants by their CMSRs. Obviously, it would be very hard to enter, both legally and politically, and it would be a challenge to find the adequate customers and investors.

Seaborg's reactors were modular and reasonably small, what made Schönfeldt dream of selling floating CMSRs installed on barges. However, his co-founders did not share this dream and were against the idea of moving to Southeast Asia due to riskiness. They already had important disagreements over this and the subject was deteriorating their relationship. Time raced on, their money was vanishing very quickly and they needed to decide soon. But staring at a screen at midnight would not help him any further, so Schönfeldt closed down his computer and went home.

Seaborg's Birth

In June 2014, Troels Schönfeldt, Eirik Eide Pettersen, Esben Klinkby, Andreas Schofield and Ask Lövschall-Jensen were enjoying a self-brewed beer during one of their "Beer & Nuclear" meetups in the cellar of the Niels Bohr Institute at the University of Copenhagen, where they had followed their Master of Science in Physics. One of their biggest annoyances when discussing their passion with other people was that the public opinion kept on thinking that nuclear energy was not safe, in spite of the many rigorous studies showing that it was one of the safest energy technologies (see Annex 1). Not only that, it was one of the cleanest energy sources, with even lower greenhouse gas (GHG) emissions than photovoltaic energy (see Annex 2). Despite that, some Danes still remembered the "Atomkraft? Nej tak" ("Nuclear energy? No thanks") movement that lead in 1985 to the Danish parliament resolution of never doing nuclear in Denmark. The five of them had a high interest in the future of energy and their discussions, while they were brewing, often turned to nuclear reactors. On that summer evening of 2014, they were done complaining about the fact that nuclear energy would never be trusted by the public opinion and that their universities did not let them research nuclear. Therefore, they decided to do something about it and start a company. Schönfeldt, Klinkby, and Lövschall-Jensen had just finished, or were finishing, their PhDs and thought it was the best moment to act. However, Schofield was too busy with his PhD and Pettersen had just subscribed to the European Master in Nuclear Energy (MSc EMINE) of the EIT-InnoEnergy,[ii] and could not join at that moment. Too excited to sleep, Schönfeldt got up very earlier the next day and started to fill in the documents to incorporate their company. They decided to call it "Seaborg Technologies", after the American nuclear chemist Glenn Seaborg (who pioneered the peaceful use of nuclear energy). Their vision would be to develop safe, sustainable and cheap nuclear power. Schönfeldt baptized himself the Chief Executive Officer (CEO). However, since he did not have any experience with management, he asked his friend, Navid Samandari, to help him understand what a CEO does and how to become one.

The three of them started to work for their startup without any salary. They did not feel like entrepreneurs in the beginning, they thought they had been forced to start their own company if they wanted to continue working in nuclear energy. In the beginning, they made a living by working as consultants for other nuclear related firms, but that money went mostly to accountants and legal advisors instead of to their own pockets.

Molten Salt Reactors

The three founders shared a special interest in the newest Generation Four (Gen IV) reactors, consisting of the 6 cleaner, safer and more cost-effective nuclear reactor designs, recognized by the Generation IV International Forum (GIF)[1]. [iii] They decided to work with Molten Salt Reactors (MSRs) that were the most promising since they entailed the highest safety (they worked at atmospheric pressure and no chemical reaction or uncontrolled fission chain reaction were possible since the radioactive material was contained within the molten salt) and their waste was not useable for weapons. These reactors worked with uranium, plutonium or thorium fuel dissolved in fluoride or chloride salt as coolants, which circulated through graphite core channels (see Annex 3). Schönfeldt, Klinkby and Lövschall-Jensen started to research these reactors, that were already been investigated since 1954, and fell in love with their design, as Schönfeldt mentioned:

> *The liquid nature of the fuel meant that they could potentially build molten salt reactors that were cheap enough for poor countries to buy; compact enough to deliver on a flatbed truck; green enough to burn our existing stockpiles of nuclear waste; and safe enough to put in cities and factories.*[iv]

Moreover, using liquid salt was more sustainable since it could be reprocessed, separating uranium and plutonium from fuel for reuse, to produce waste that would only need 300 years of storage in nuclear cemeteries (instead of up to 300,000 years for long-lived nuclear waste).[v]

Regarding the costs, MSRs were expected to have a lower Levelized Cost of Electricity[2] (LCOE)[vi] than conventional light-water reactors[3] since they would not need a thick concrete wall containment unit and would function at higher temperature, leading to increased thermal efficiency.[vii]

Small Modular Reactors

Another hype in nuclear reactor design were the Small Modular Reactors (SMRs). These were advanced nuclear reactors with a power capacity of up to 300 MW per unit (small), and small enough to be factory-assembled and transported (modular).[viii]

Although nuclear reactors were typically operated at baseload mode (at maximum rated capacity), most of them were technically capable of flexible operation. However, since nuclear fuel is

[1] In 2001, 13 countries founded the GIF, an endeavor committed to perform the necessary research to test the feasibility and performance of fourth generation nuclear reactors, as successors of the functioning Gen II and III reactors, and to make them available for industrial deployment by 2030.

[2] The LCOE represents the average revenue per unit of electricity generated, required to recover the costs of building and operating a generator during an assumed financial life, and is calculated as the ratio of all discounted costs over the lifetime of a generator divided by a discounted sum of the delivered energy.

[3] Light-water reactors (LWRs) are a type of thermal-neutron reactors (the most common type of nuclear reactors) that use normal water, as opposed to heavy water, as both its coolant and neutron moderator; furthermore a solid form of fissile elements is used as fuel.

relatively cheap in comparison with the capital expenditure for conventional reactors because of the volume needed to operate, it is economically more attractive to operate them at full capacity. On the other hand, since SMRs are a lot smaller, by installing multiple SMR units within a single plant, more flexible operation could be reached.[ix]

Moreover, the thermal energy from nuclear reactors could also be used directly for heating (of cities, industrial processes, etc.), or to produce hydrogen or to desalinate water. Advanced reactors usually worked at higher temperatures and were thus even more suitable for these alternative uses.

On top of that, instead of a 5-10 years project for constructing a conventional nuclear reactor (see Annex 4), the lead time for a SMR could be reduced to only some 3-5 years. However, the total lead times were even some 3-5 years longer due to necessary licenses (nuclear design, construction, operations and decommissioning).

Seaborg's CMSR

Schönfeldt did his PhD on advanced neutron moderators at the Technical University of Denmark (DTU) and at the European Spallation Source (ESS). He thought that to lower the costs and become competitive, they should use another neutron moderator, instead of graphite (used since 1954).

After some more months of research, he discovered that liquid sodium hydroxide (NaOH) worked very well as neutron moderator, slowing them down 10 times more than graphite (and half that of water). Moreover, when using NaOH instead of graphite as a moderator, the radiation would not wear down the materials over time.[x] As a result, Seaborg's 100 MW reactor would last up to 12 years, without having to refuel or change the moderator at all, leading to an estimated LCOE of 60 US$//MWh by 2035, making it competitive with fossil fuels, although more expensive than traditional long-term operation (LTO)[4] nuclear reactors (see Annex 5).[xi]

In 2017, they finally patented their proprietary sodium hydroxide neutron moderator. Regarding the fuel, Seaborg chose to use uranium tetrafluoride. For final production they would need to do a thorough investigation of the cheapest supplier and develop a long-term agreement with them.[5] Also for the final design of the certified nuclear safety class CMSR parts, they would need to perform a thorough supplier's study as well because once decided there would be no way back since the parts were all supplier specific and new operating licenses would be needed.

Regulatory Complications

Almost more complicated than the design and testing of nuclear reactors, was the regulatory part. For any new type of reactor design, a license from the country's National Nuclear Regulator (NNR) of the customer was necessary to construct, operate and decommission the Nuclear Power Plant. For new (Gen IV) designs, it was necessary to explain the entire design to the NNR, which had expertise in Generation III reactor types, and usually only in the ones already deployed in their country, so that they would understand every detail of its functioning and could thus issue the design license. Once the license obtained, every phase of the reactor development had to be controlled and approved. This cumbersome process needed to be repeated for each country.

For any other site-specific licenses, it would be the responsibility of the customer/operator buying a nuclear reactor, being big energy generation companies, often (partially) owned by governments.

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[4] Long-term operated conventional nuclear reactors referred to those that extended their operating license and could thus operate for up to 60-80 years.

[5] Nuclear fuel was typically bought more than two years upfront and it entailed almost 50% of the total reactor cost.

Also, the decommissioning of reactors and nuclear waste management should be done locally. However, the CMSRs could allow for central decommissioning and/or fuel reprocessing in the future.

Schönfeldt's Floating Dream

Since years, Schönfeldt dreamed of creating floating power plants by installing their reactors on barges. The main advantages would be that the power plant could be built in a dedicated manufacturing facility in a shipyard, transported easily to the location and that no land or site works would be needed. Moreover, the dismantling was a lot easier with floating reactors because it could be carried out in a dedicated facility for that purpose. The fact that after the lifetime of the reactors, the client would not have to deal with the dismantling would definitely be a huge advantage.

Regarding floating nuclear power plants, there were only very few competitors. One Russian company, Rosatom, already had a floating nuclear power plant, Akademik Lomonosov (of two 35 MW SMRs), in operation, but it only had permissions to sell energy on the Russian Federation territory.[xii] Furthermore, there were some startups investigating the idea, such as the partnership of NuScale Power and Prodigy Clean Energy.[xiii] However, instead of MSRs, they used pressurized water SMRs. Also ThorCon, an Indonesian based company, was developing a "floating" MSR. However, they planned on anchoring their floating reactor to the bottom of the sea, making it legally a fixed reactor.[xiv]

Moreover, Schönfeldt saw a huge potential in selling floating reactors, in Southeast Asia, where the power demand was expected to double by 2050, with around 240 new coal power plants planned. Additionally, China foresaw 3 trillion US dollars to install new energy in Southeast Asia until 2040. Many Southeast Asian countries agreed to sever decarbonization commitments, but only had limited opportunities for hydro or geothermal power, while wind and solar offered only minimal supplies during the monsoon season. Moreover, they lacked the capabilities and expertise to install, operate and dismantle their own nuclear reactors. Lastly, there were abundant connections to the sea. However, there was a drawback: those countries lacked financing. But Schönfeldt considered the option of selling energy and heat from the reactors instead of selling the entire reactor. In that case, Seaborg could partly own and operate their own reactors, or perhaps form a consortium with an experienced nuclear power operator to operate them. In Schönfeldt's eyes, they could even add a barge constructor to the consortium and operate the floating reactors all together in different Asian ports, selling energy directly to some local generation companies, that would then take care of the legal permissions and all of the port and energy connection infrastructure.

However, his cofounders, did not share this idea. They all agreed that it would be too complicated to enter such a new market and that the risk was way too high. They simply wanted to sell reactors to generation companies as it had always been done.

How could he convince his cofounders of his idea? They were absolutely right about the high risk of entering this market and it would be very capital intensive since they would need to finance their own reactors to be able to co-operate them, and only getting revenues through operations. However, buying energy through temporary contracts instead of an entire reactor would be probably more appealing to customers and investors since the technology-risk would be minimum for them.

Seaborg's Funding

In the beginning, Schönfeldt struggled a lot to obtain funding, but his eager to make Seaborg a success, helped him go through all those difficult times. It even made him reject a job offer as the CTO of Moltex Energy UK, a competitive firm, mentioned in Annex 3.

By the end of 2016, Schönfeldt went back to his friend Navid Samandari asking him to invest 80,000 EUR, which they would use to finally pay themselves some salary and also to hire some business people. Samandari accepted and became a cofounder of Seaborg, followed quickly by Andreas Schofield. Eirik Eide Pettersen, had just finished his MSc EMINE, and had already accepted a job offer at the International Atomic Energy Agency. However, two days before starting this job, Schönfeldt called him and asked him to join the founding team. Recalling the Beer & Nuclear meetups, he couldn't reject. With Pettersen, the cofounders' team of 6 was completed, and they set up an agreement to split the company equity based on the dedication to Seaborg and their individual investment in the company. At that moment, Schofield had 3.5%, Pettersen 4.5%, Samandari 10%, Lövschall-Jensen and Klinkby both 12.5 % and Schönfeldt had almost 50%, and they also decided to keep 10% of the total shares for non-founders' future hires.

By the end of 2017 the company pockets were almost empty and they started to look for more investors. On December 22nd they reached an agreement with an investment group to invest one million euro. Schönfeldt went to sign the agreement, but the investors tried to introduce some last changes to the already agreed terms, such as lowering the company valuation to one third, which made Schönfeldt so angry that he decided not to sign it. As a consequence, Seaborg was heading to go bankrupt on January 1st, what made his cofounders so mad that they decided not to talk to him until the new year. It was the worst Christmas he ever had. After five days without sleep, he called David Helgason, an investor he had always liked. They met in a bar where they talked over Seaborg's situation. Helgason told him that he was interested to invest in Seaborg. They wrote the agreement terms on a napkin, and the next day, Helgason transferred 50,000 euro to Seaborg. Some days later, he, together with some other investors invested a total of 0.8 million euro, in exchange of 4.2% of the company equity. This private money was very important for Schönfeldt as he stated:

> *As long as nuclear energy is built by governments, it is not going to happen. Nuclear has to be built by private companies for it to grow.*

In 2019, they secured another 2.5 million euro from private investors in a second pre-seed[6] round, in which they gave away an additional 5.5% of their company equity.[xv]

Early 2020, they opened a first seed investment round, in which they secured 17.5 million euro. With this round, the new investors received a total of 24.6% of Seaborg. These investors, together with the founders and the other earlier investors, set up an investment group, that they called SeaSalt. After this round, the founders still kept a 65.4% of Seaborg, and preserved some 10% of the equity for future employees.

By the end of 2021, Seaborg obtained an EIC Accelerator prize, which supplied them with a 2.5-million-euro grant, business accelerator services, and a 15-million-euro investment (convertible equity or loan, to be negotiated). However, both the grant and the investment would be received

[6] Pre-seed financing is usually less than 250,0000 $, coming from friends and family, and is normally used for prototyping, idea origination or organizational expenses. While seed funding can go up to 2 million $, coming from venture capital or institutional investors.

gradually, based on certain milestones throughout the length of the project (2022-2024) and used for Seaborg's scale-up.

In 2022, Seaborg secured another 10 million euro from the SeaSalt investor group, that would be mainly used for lab construction and to hire new staff. This time they agreed to sign the arrangement as a convertible note[7] with a 20-million-euro valuation cap and a 35% discount rate (if the valuation cap would not be reached).[xvi] Annex 6 shows a summary of the funding.

Seaborg's Development

In the first half of 2022, Seaborg grew from 60 employees to 115. They were performing experiments in collaboration with experts from the Neutron and Muon Source at Oxford (UK) and from the European Spallation Source research center in Lund (Sweden) to understand how neutrons in modern reactors behave as to optimize their CMSR design.

By the end of 2022, Seaborg finally finished the construction of their own laboratory, so that they could continue investigating and resolving the problems of corrosivity that come hand in hand with hot molten salts. Every component that was to come into contact with the salts had to be made of a special high-tech alloy.

Schönfeldt estimated that they could have their first prototype around 2026 and their first 200 MW CMSR ready by 2028. Although he wanted to use nuclear waste to fuel their reactors and technically they could, legally they were not allowed to do this.

Seaborg's Financial Need

The future looked promising for Seaborg, but not good enough. The Danish salaries and the nuclear labs were causing a very high burn rate of Seaborg's money. If they wanted to succeed, they needed a lot more investment and lately Schönfeldt thought investors were more reluctant to a foreseen conventional business model of selling their CMSRs in Europe and USA. The problem was that the market for these new Gen IV reactors in developed countries could become saturated rapidly due to the increasing number of nuclear R&D companies.[8] Schönfeldt was using that reluctance as an argument for his floating reactors' business idea in which they would perform projects in a consortium, together with a barge constructor and a nuclear operator. These projects would consist in designing, building and operating their own reactors by selling electricity through power purchase agreements (PPAs) to local energy generators.

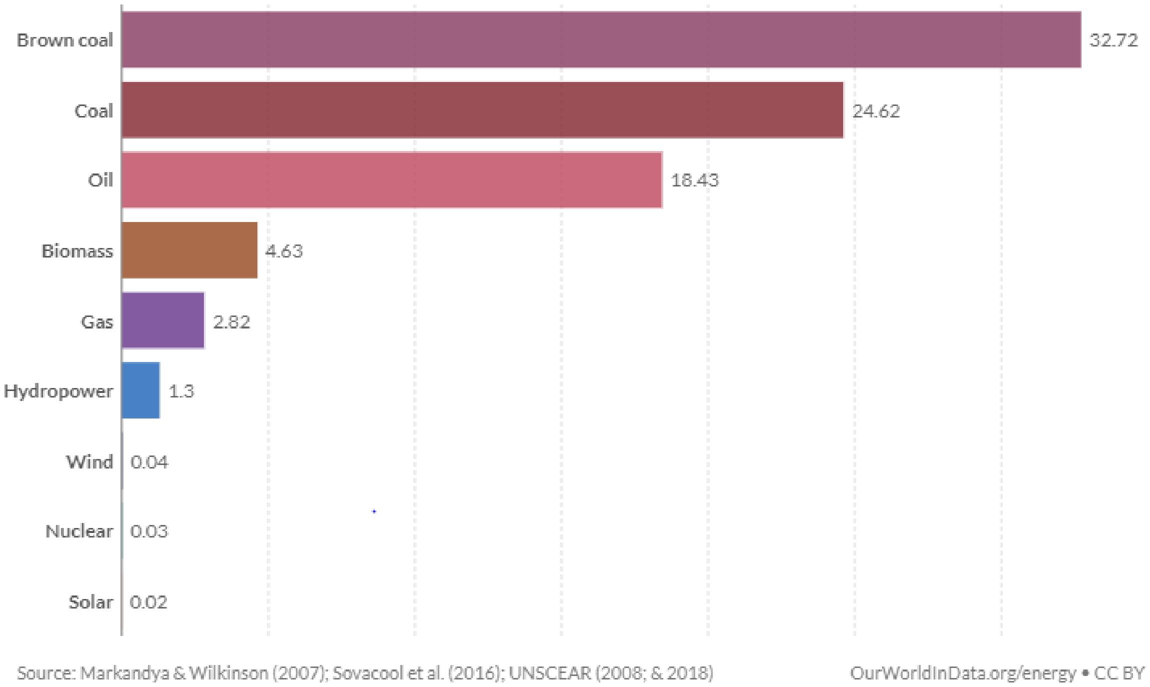
Lately, when mentioning again his idea, his cofounders got quite angry at him. So, he decided to prepare a clear value creation scheme and business model before mentioning it again. They needed more investment quickly or else they should shut down parts of their magnificent lab. Creating a dream together with his friends and cofounders was an amazing experience, but they should decide now on the strongest business model. Would their proprietary neutron moderator be sufficiently innovative to sell their reactors to countries that already had nuclear expertise? Or would they need to become more innovative and move to Southeast Asia to co-operate floating CMSRs and sell electricity within consortiums? While parking his car, Schönfeldt definitely hoped he could convince his cofounders of the latter. But, at the same time, he was really scared that if they would fail, it would be all his fault and they would stop talking to him again. He still remembered the

[7] A convertible note is a short-term debt that converts into equity, typically together with a future financing round.
[8] The global Generation IV Reactor market size was valued at USD 1010.87 million in 2022 and was expected to expand at a CAGR of 6.42% during the forecast period, reaching USD 1468.78 million by 2028.

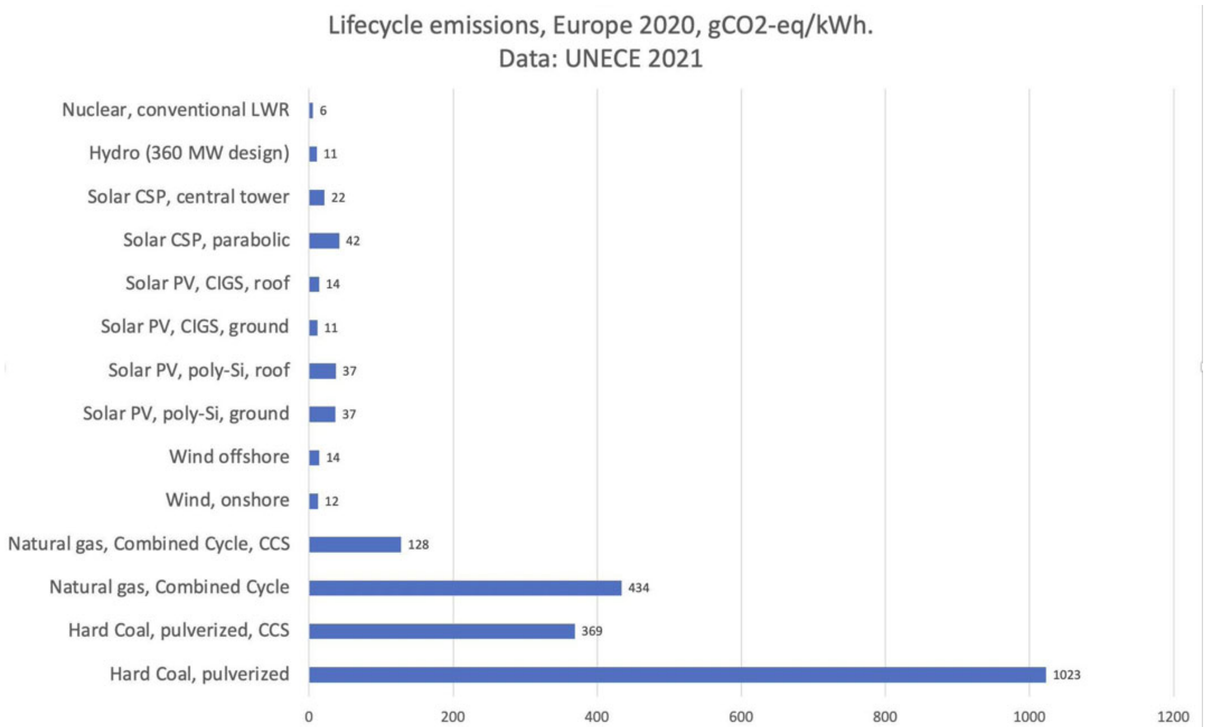
most awful Christmas of 2017. Lately, he had nightmares of his cofounders continuing doing business on their own and not talking to him ever again. While parking his car, he decided that he would study both options profoundly before making a new statement. His dream was important, but Seaborg and his co-founders were even more important.

Annex 1: Death Rates per Unit of Electricity Production (TWh) for Different Energy Sources [xvii]

(including deaths from air pollution and accidents in the supply chain)



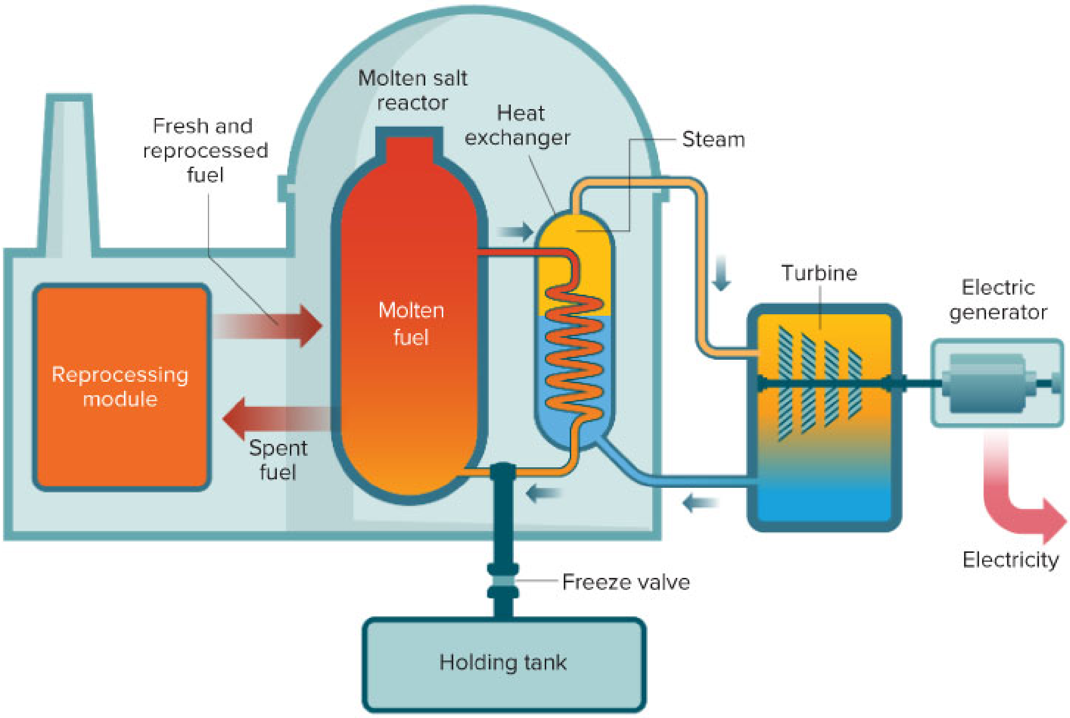
Annex 2: Lifecycle Greenhouse Gas Emissions[9] of Different Energy Sources[xviii]



[9] Measured over the full lifetime of the source, from material and fuel mining through construction to operation and waste management.

Annex 3: Molten Salt Reactors

Molten Salt Reactors (MSRs) differed from conventional nuclear reactors in many ways, starting with the fact that they used liquid nuclear fuel (molten salts) instead of solid. This had profound implications for safety since meltdowns would not be an issue: the fuel was already molten. And if temperatures in the fuel mix would get too high for any reason, a plug of frozen salt below the reactor would melt and allow everything to drain into an underground holding tank for safekeeping, as shown in the figure below.[xix]



Long-lived nuclear waste would also not be an issue since a chemical system would continuously extract reaction-slowing fission products from the molten fuel, which would allow plutonium and all the other long-half-life fissile isotopes to be completely consumed. Moreover, the high melting and boiling points of salt allow operating at high temperatures (increasing the efficiency in electricity generation) and atmospheric pressure (lowering the risk of a significant break and loss of coolant because of an accident). Molten salt can be used for thermal, epithermal and fast reactors and with a variety of fuels.

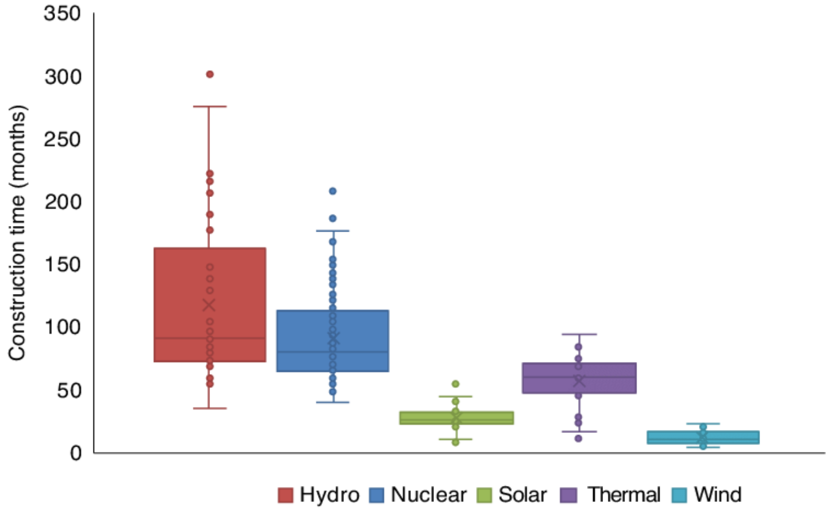
In 2015, UK company, Energy Process Developments Ltd (EPD), studied 6 MSR configurations (one of which was Seaborg's CMSR), and chose the Stable Salt Reactor (SSR) from Canadian company Moltex Energy due to its relative simplicity and low technology hurdles.[xx] Initial deployment would only be foreseen for 2030. The other studied MSR reactors were from Flibe Energy, ThorCon, Terrestrial Energy and Transatomic Power.

Another big company that was researching MSRs was Southern, a utility conglomerate headquartered in Atlanta (USA). They started a development program in collaboration with Oak Ridge and TerraPower, a nuclear research company in Washington.[xxi]

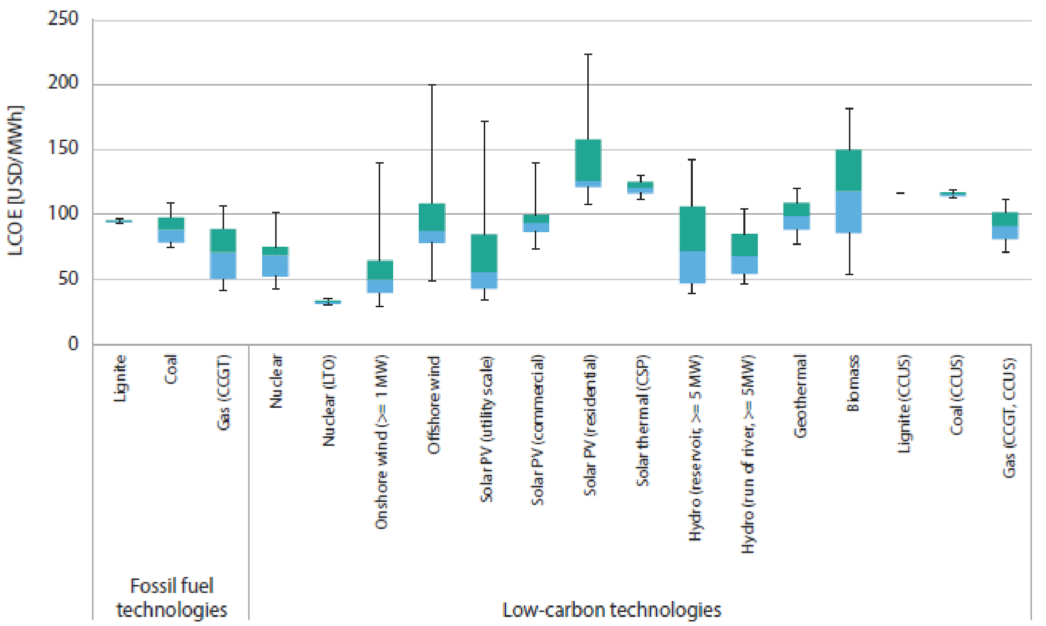
Lastly, there was another company based in Copenhagen, called Copenhagen Atomics, that foresaw to provide MSRs. They used thorium reactors and expected to have a working 1 MW prototype reactor by 2025.[xxii]

However, not any of those MSRs could reach such a small size as Seaborg's CMSR.

Annex 4: Construction Lead times for Different Energy Sources[xxiii]



Annex 5: Levelized Cost of Energy for Different Energy Sources[xxiv]



Note: Values at 7% discount rate. Box plots indicate maximum, median and minimum values. The boxes indicate the central 50% of values, i.e. the second and the third quartile.

Annex 6: Seaborg's Funding and Equity Split

Year	Round	Amount	% founders/employees	% investors
2017	Founder	500,000 €	100.0	0.0
2018	Pre-seed I	800,000 €	95.8	4.2
2019	Pre-seed II	2,500,000 €	90.3	9.7
2020	Seed round	17,500,000 €	75.4	24.6
2022	Convertible Note	10,000,000 €	-	-
2022-24	EIC Accelerator	15,000,000 €	-	-

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