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Exploring a Suitable Business Model for Nuclear Batteries

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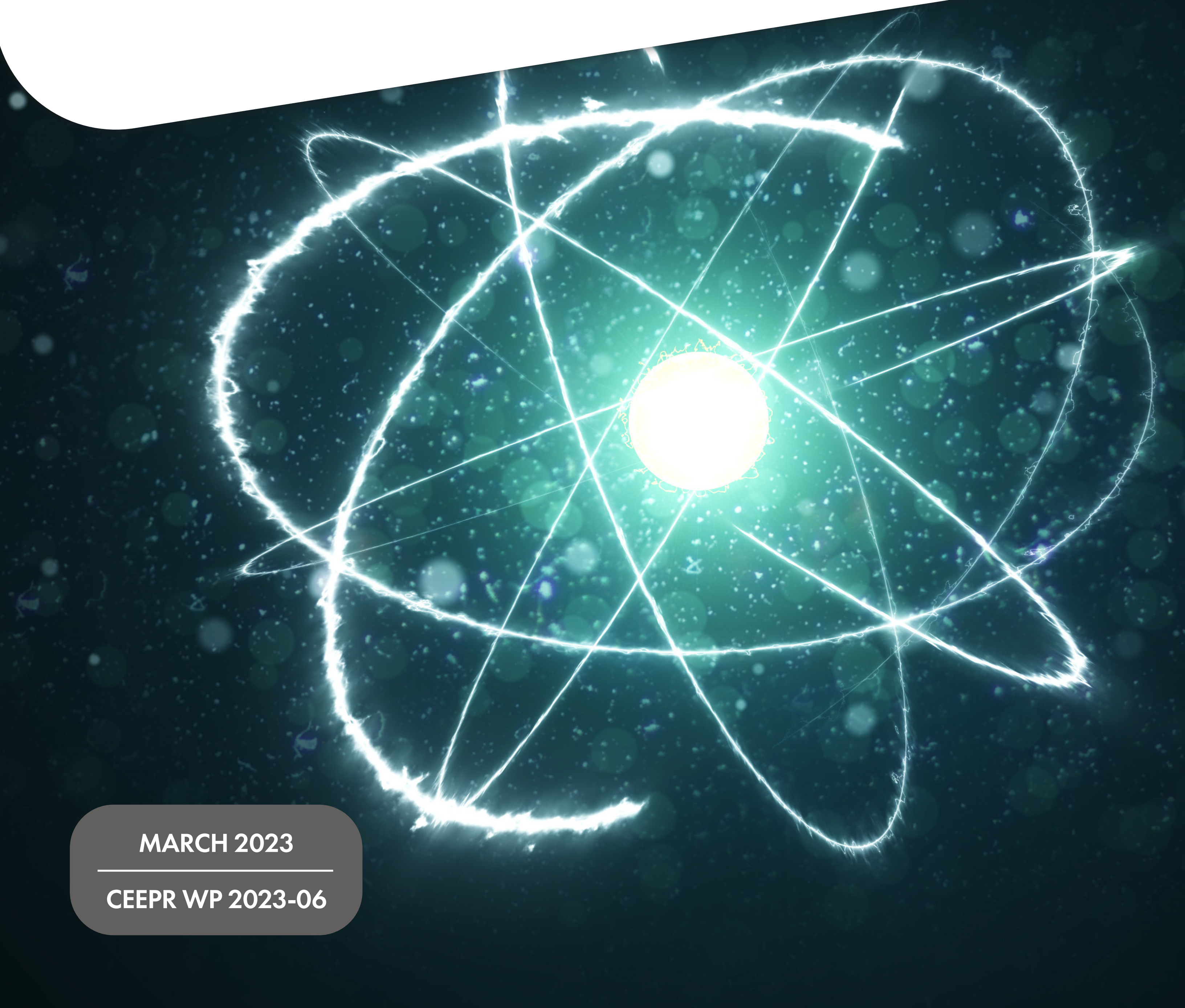

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Exploring a suitable business model for Nuclear Batteries

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Abstract

The 'nuclear battery' is a new concept for delivering nuclear powered heat and electricity. Their small scale and portability enable use off-grid. Their inherent safety and energy density make them ideal low-carbon replacements for fossil fuel-fired combined heat-and-power plants and other distributed generation co-located at industrial and commercial facilities. They can also be used as emergency energy sources where the grid has been temporarily disabled. These new use-cases require development of a new business model for nuclear, one that recognizes that the energy end-user is the customer and that the product is more differentiated than baseload electricity. We look to the existing business model for fossil fuel-fired distributed generation to identify elements that can be ported over to a model for nuclear batteries, and other elements that must be re-imagined to support the use of nuclear batteries. The value of co-location is key, and customers often purchase energy as a service as opposed to purchasing equipment. Indeed, the specialized skillset required for managing nuclear fuel and systems as compared with fossil fuel-fired systems expands the energy customer's reliance on the service provider. Finally, we put forward a Business Model Canvas for the 'Solution Provider', the entity we envision in charge of engaging with the Customer to understand their needs, create a holistic solution for them, and engage with the rest of the players in the value chain (including, Designer/Manufacturer, Developers, Regulators, Operators).

Introduction

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This research was funded by the Idaho National Laboratory as a part of the Emerging Energy Market Analysis (EMA) project. We benefitted from discussions with a number of professionals involved with the provision of energy to different industries, including Greg Jason, Joe Higgins, Steven Lanou, Aaron Reichl, Ramón Rodríguez, and Michael Cheney, and with Patrick White at the Nuclear Innovation Alliance. We also appreciate the comments and insights of a number of MIT colleagues, including Jacopo Buongiorno, Richard Lester, Michael Golay, Koroush Shirvan, Scott Kemp, Matteo Bucci, Isabel de Naranjo, Federico Antonello, Carmen Sleigh, as well as those of our EMA colleagues, David Shropshire, Steve Aumeier and Paul Kjellander.

A nuclear battery is a stand-alone, plug-and-play energy platform combining a micro-reactor of 1-20 megawatts electric and a turbine to supply electricity and heat from a very small footprint. Factory-assembled and factory-fueled, it is compact enough to fit within ISO standard shipping containers so that it is road transportable to the host site, where it can be installed and made operational in a matter of weeks or days depending upon the context. The nuclear battery is a semi-autonomous and remotely monitored system that can operate continuously for several years without fuel resupply. Once its fuel is exhausted, the complete battery can be swapped out with a fresh unit, while the used unit is shipped back to a central facility for refueling and refurbishment. Thus, there is no handling of fuel at the host site where energy is delivered (Buongiorno et al. 2021).

The nuclear battery opens up new opportunities for utilization of nuclear power. Its small size and portability enable delivery of energy off-grid, for example to remote communities or mines. Its inherent safety combined with its energy density make it an ideal low carbon replacement for on-grid fossil fuel-fired combined heat-and-power plants and other distributed generation co-located at industrial and commercial facilities.[3] It can be sited downstream of transmission congestion, expanding capacity for data centers, EV charging stations and other large load sources. Nuclear batteries can also be used as emergency energy sources where the grid has been temporarily disabled (Black et al. 2022).

Alongside the technological innovation required to realize the nuclear battery, innovation in the business model may also be required to drive deployment in these new use cases. The nuclear industry's existing business model evolved around the installation and operation of very large, light water reactors supplying on-grid electricity in bulk. This paper explores how a business model for nuclear batteries may differ from nuclear's legacy model. For inspiration, look to the business model currently used for deployment of fossil fuel-fired distributed generators which the nuclear battery may supplant. Some elements of that business model can be ported over to a business model for nuclear batteries. However, there are differences in the technologies that will force innovation in that model, too.

The Existing Business Model for Nuclear Power

Currently, approximately 400 commercial nuclear reactors supply 10% of global electricity generation. These are used almost exclusively to supply electricity onto large, regional or national grids, usually as providers of baseload. A very small number supply useful heat, whether for district heating systems or other purposes.[4]

Construction of each unit is a massive infrastructure project. Most have capacities ranging from hundreds of megawatts to more than a gigawatt. Each unit costs several billions of dollars and at least a decade to plan and construct. Once built, a unit can operate for several decades with routine maintenance. With major maintenance investments, the operating life can be extended beyond a

[3] We use distributed generation here to mean generation co-located with load, or otherwise close to load. The same term is sometimes used to mean generation located behind-the-meter or otherwise connected to the distribution grid as opposed to the transmission grid. Our usage encompasses this smaller set, but allows for generators connected directly to the transmission grid, so long as they are located close to load centers.

[4] There are a plentiful number of small, mobile military reactors, primarily used in ships.

half century. The value chain is organized around a few major milestones: construction, operation, and the eventual decommissioning along with disposal of spent fuel.

Construction of new plants involves three main participants. The plant itself is designed by a specialized nuclear engineering firm, such as Westinghouse, General Electric and Framatome. However, delivery of a completed plant involves executing a large-scale construction job with significant site-specific engineering and coordination of a large set of equipment suppliers. This puts at the center an EPC contractor specialized in project management, who negotiates and oversees the engineering, procurement, and construction (EPC) of the unit. Equipment suppliers are the third key participant. Some of the equipment supplied is specific to the design or is only produced to order.

Plants are usually commissioned, owned and operated by specialized generation companies—whether that is a state- or investor-owned-utility, or a merchant company. These generation companies usually own other generation plants. Prospective owners of a nuclear power plant evaluate a new nuclear build as one part of a larger portfolio of generators providing power and other services to the grid. Sometimes the prospective owner may also be the owner of the larger portfolio, while in other cases the nuclear power plants they own will be operated as a part of the larger portfolio serving a common grid. In considering whether to purchase a nuclear power plant, prospective owners are primarily interested in low-cost, reliable electricity. Usually that is baseload electricity. Therefore, vendors compete primarily on the prospective cost of the plant they are offering, especially the large up-front capital cost.[5]

Operation of a nuclear power plant requires a highly skilled workforce and management. The operator's capability must be certified by a regulatory authority responsible for safety. The importance of skills and experience to operation creates certain economies of scale in operating multiple plants. In a few cases, the owner may hire a specialized operating company to manage its plant. In other cases, a plant may have a consortium of owners, with one of them acting as the operator. Operators also outsource some equipment maintenance and other services to companies specializing in nuclear power plant services.

The main revenue model for the owner-operators involves levying formula retail charges on captive electricity customers as allowed under some regulations. This is true for rate-of-return regulated investor-owned utilities in the U.S. and for state-owned companies in France and China and elsewhere. The exact legal form of this pass-through of revenue requirements to retail rates can vary with each country's institutional context. For example, Finland's Mankala model used for the Olkiluoto-3 plant involves large power customers and distributors taking ownership shares of the plant. This ultimately reduces to the customers paying charges which finance the plant. The U.K. contract-for-difference used for its Hinkley Point-C plant involves fluctuating charges levied on top of the wholesale price with the end result being the same as if customers paid set charges. The Russian plants sold to Belarus, Turkey and Bangladesh all involve state companies in the host nation paying set charges for power, and it is then up to the state company to determine how those charges are passed on to customers.

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[5] Because the history of new builds has too often involved extreme delays and cost overruns, this danger is also a factor in buyers' decisions. Vendors also compete on the prospective safety and reliability of their product.

A second, less common revenue model has owners sell electricity into competitive wholesale markets, capturing revenue both for capacity and for energy. This is true for many plants in the U.S. where states forced all generation into competitive wholesale markets, and it applies for the legacy fleet in the U.K. This is a fundamentally different model: it imposes significant equity risk onto the plant owner. All the plants operating under this second competitive model were originally built under the first, regulated model and later transferred to competitive markets. No plant has ever been built under the second, competitive model, and some conjecture it would never happen (Newbury et al. 2019). However, significant investments in life extensions and power uprates have been made under this second model, although these are much smaller investments than construction of a new plant (Lei et al. 2017).

Nuclear power plants require specialized fuel, and the owner-operators maintain ongoing relationships with fuel vendors. The same company that supplied the original reactor design is often a supplier of fuel. Owner-operators typically manage their regular refueling operations, although they often supplement their capabilities with services of fuel vendors. Owner-operators typically manage the storage of spent fuel on-site for a number of years, and the handling and storage are carefully regulated to assure safety.

The ultimate storage and disposal of spent fuel is usually managed by a separate entity authorized for that purpose by the national government. The same is generally true for the decommissioning of the nuclear power plants, although in some countries such as the U.S. specialized private companies manage this. Over the decades of a plant's operation, the plant's owner makes mandated contributions to dedicated funds that will pay for the ultimate spent fuel disposal and decommissioning.

What must change from this traditional nuclear business models?

The stakeholder map across the life-cycle of a nuclear battery looks strikingly different from the traditional map of the nuclear industry. First, moving production to a factory and streamlining installation alters who the players are at the front end. What had previously been a construction project is now a manufacturing project. The role of EPC becomes subsidiary and in many essential respects standardized, but the role of manufacturer becomes significant. Second, the ultimate consumer of energy, whether electricity or heat, now enters into the picture as the customer deciding whether or not the product meets its needs. At the same time this customer is unlikely to have or want to have the specialized capabilities needed to operate and manage a nuclear asset.

Thus, the role of the Solution Provider comes to fruition. This new character will act as a service provider who will purchase the nuclear batteries from the Developer/Manufacturer and any other support systems (including those from different suppliers) to create an integrated solution for the customers. The Solution Provider can be imagined working closely with the customer to understand their particular needs in terms of energy and safety. This process will create a quote for a solution which the Customer will then decide to opt in or out, and a contract for energy services will be signed. From this point on, the Solution Provider will be responsible for operating its owned asset and delivering nuclear energy as a service (in heat or power) to the Customer. At end-of-life, the Solution Provider will also be responsible for removing the asset from the

Customer's location and transporting it back to a centralized facility for de-fueling, refurbishment, and refueling. Either the Solution Provider or the Manufacturer might take on the role of a Decommissioning and spent fuel disposal entity. The key difference between the envisioned Solution Provider and the existing service providers (such as utilities) is that of coordination. While a utility might own most of the responsibilities across the value chain to eventually offer a service, the Solution Provider, will work with different entities to provide a full-in service to a customer.

In business modeling, changes in the stakeholders' roles and responsibilities translate into different partnerships and contracts, requiring a more hands-on role for the Developer/Manufacturer and creating room for the Solution Provider entity. The way these entities may be constituted is yet undefined. The Developer/Manufacturer and Solution Provider can be part of the same company or different, and in some particular cases, the asset ownership and operation responsibility may be of interest to the Customer, e.g., if the Customer is a utility with nuclear expertise looking to leverage this technology to provide energy onto the grid or at off-grid locations.

Nuclear Batteries will require a less complex siting and acquisition process. The Emergency Preparedness Zone (EPZ) is currently expected to be at the site boundary (Christensen, INL, 2020), meaning that the land occupied by the facility will be not much larger than the space of the nuclear battery system itself. The capability of safe operation without a water body to function as a heat sink will allow this technology to be placed virtually anywhere. However, a significant challenge that site criteria will face will be those of public acceptance. Because of this, it is hypothesized that the first applications of this technology will be found in remote sites such as mining, data centers, desalination plants, and other industrial uses. Once nuclear batteries have proven to operate efficiently and safely, installing them near or within urban environments like university campuses or hospitals may be feasible.

The traditional licensing process will not promote the complete capture of nuclear battery benefits. Existing licensing can take multiple years and is exercised on a single power plant business, including the licensing of the reactor, the construction, the site, and the environmental impact. While some of these license processes are site specific (e.g., environmental) and thus will still need to exist, it is of the utmost importance to understand the key differences that Nuclear Batteries will need for success. Given the nature of serial manufacturing of Nuclear Batteries, we imagine readily assessed criteria for production and siting that will enhance the value-added from this technology. Measures that can certify the manufacturing and assembly process itself. Much like the biochemical and industrial manufacturing industry has developed, it is crucial to rely on a strict production and quality assurance process that will entitle every unit completed to a commission license. Moreover, the sites themselves challenge the fast-paced license process that we envision. It can be hypothesized that a set of criteria for a safe zone will be defined jointly by the regulator and other stakeholders to create a "standard site." This site could be found in the customer's existing land or developed with the necessary safety and infrastructure requirements (e.g., a slab of cement or an appropriate EPZ). Overcoming these two regulatory challenges can enable the supplier to match a nuclear battery licensed through the manufacturing process to a standard licensed site complying with criteria. We are leaving only to be approved from an environmental and safety lens which, with increased deployment frequency, can only be expected to become faster and more efficient. It is important to note that the regulatory entities must still ensure that the technology complies with safety, environmental and security requirements, including testing of the as-delivered nuclear batteries. This process can be completed in a streamlined fashion with readily assessed criteria.

Existing processes of traditional nuclear power plants offer baseload and rely on high headcounts to run. Nuclear battery operations may look drastically different. To keep costs low, experts in the field have proposed autonomous operation and remote monitoring as critical factors of this technology's operating profile. Independent process loosely translates into a self-regulated load following or baseload equipment that can address supply the Customer's energy demand profile. Cybersecurity factors heavily on this equation due to concerns of digitally enabled controls of nuclear power. However, isolating the operation from any external communication except for a controlled shutdown is an option under discussion, Naranjo (2022) proposes that between 1-2 operators could remotely monitor up to eight Nuclear Batteries from a monitoring center that would deliver high-quality service to customers and address extreme emergencies when needed. Ideally, this monitoring center could oversee the entire fleet with 1-2 operators per 8 reactors (assuming a 24/7 operator translates to roughly 5-6 full time employees). This monitoring center would also own the responsibility of scheduling and deploying maintenance projects according to regulation and equipment performance and is hypothesized to fall into the realm of duties of the Solution Provider.

The Existing Business Model for Fossil Fuel-fired Distributed Generation

All of the services we imagine a nuclear battery providing are currently available from fossil fuel-fired distributed generators. Off-grid locations around the globe use diesel generators. On-grid industrial installations operate co-generation facilities, whether fired by coal, natural gas, fuel oil or even diesel, as do district heating facilities. Microgrids hosting emergency and other essential services are anchored by combustion turbines fired by natural gas or fuel oil. Mobile emergency power is commonly supplied from diesel equipment. When trying to imagine a business model for nuclear batteries, it makes sense to inspect the business model already employed by fossil fuel-fired distributed generators.

The competitors and the business models vary according to size and the mode of operation. At the low end are generators with a capacity ranging between 0.2 to 3 MWe typically used for mobile or for temporary energy—for example at construction sites, at industrial or commercial facilities when the regular energy facilities are undergoing maintenance, or at special events such as music festivals. Among the companies serving this segment are Aggreko, Caterpillar, Sunbelt Rentals, APR Energy, Cummins and Altaaqa Global. These companies rely on a business model birthed from the mobile capability of the asset and the customer's use case, which is temporary energy. They provide a quote for a specific time of rental, and cover transportation of the equipment back and forth from the customer. Contracts are usually for a short term but can be extended.

Medium scale distributed generators, with a capacity ranging between 1 to 30 MW, are typically fixed on-site. They are used in marine power, agriculture, data centers, manufacturing, mining, and oil & gas, often providing just electric service and sometimes providing combined-heat and power. Among the top players in this class are Caterpillar, Cummins, Generac, Himoinsa, Kohler, and MTU Onsite Energy. As the size of the installation increases, the customer is more likely to own and operate the equipment.

The largest scale distributed generators are also fixed on-site, with capacities over 30 MW and on up to the 500 MW range. They are used as combined heat and power (CHP) installed at industrial facilities such as chemical or food processing plants, refineries, or at district energy systems, wastewater treatment facilities, or simply to provide power to the grid. Among the top players in this class are Solar Turbines a Caterpillar company, Kawasaki, Mitsubishi, Siemens, General Electric, Dongfang and Bharat. In this category, the host business generally owns and very likely operates the equipment. The vendor will supply and install the facility, and they also collaborate with the customer—and possibly external experts—to design a complete plant, including associated equipment. Maintenance and service are often included in the purchase agreement and the vendor will routinely come to service the machinery and supporting systems.

What can be leveraged from existing fossil-fueled distributed generation business models?

Co-location: Distributed generation, across each of the three Classes discussed previously, is co-located with the consumer of the energy produced by these assets. The reason for this co-location varies across customers. In many cases it is a product of simple necessity, such as the difficulty or impossibility of delivering heat over large distances, or the high cost of connecting a remote community or mine to the grid. In other cases, the consumer values the security of supply or other benefits of integration. Whatever the motivation, features such as the size of the asset are tailored to match the consumer's individual energy needs. Where an electric grid connection is feasible, the consumer also determines how to integrate its own energy production and its grid connection—for example, as a co-generator providing power to the grid, or as an islanding-capable micro-grid, or as a stand-by customer of the local wires company. Finally, even though the operation and monitoring of the nuclear battery might be autonomous and remote, having the generating asset on-site may provide Customers with a sense of higher control. If the Customer decides to train or hire talent relevant to this technology, they can extract value from it through recommendations and proposed improvements to the process.

Energy as a Service: The service facet is a valuable aspect of distributed fossil fuel generation. Not being responsible for operating the asset is attractive from a Customer's point of view who does not have the capability, expertise, or interest to do so. Paying a rate (fixed or variable) for each unit of energy consumed is the most typical way that current fossil fuel distributed generation companies work. Some additional fees might include delivery, installation, or rent. This will vary from company to company, but in the end, the important part is that the Customer does not own the responsibility. This will also be true in the case of Nuclear Batteries. They can draw from this existing business model and offer a rate for the Customer who, in their eyes, prefers to see a black box that supplies their energy needs with no other responsibility than paying the bill.

Maintenance: Fossil fuel-fired distributed generators are often serviced and maintained by the provider, which means that all responsibilities related to service, overhauls (major or minor), and spare parts are not handled by the Customer. In the case of Nuclear Batteries, this would also hold true because this is a more attractive (all-in) offering to the Customer and, more importantly, because of the hazardous nature of radiation and nuclear waste. It will always be necessary to have certified personnel and regulatory approval/oversight. While the Customer's existing talent could perform simple inspections, especially those of the power conversion unit or the instrumentation and control, when it comes to the nuclear reactor, we hypothesize that it will be the responsibility of the Solution Provider.

What elements of the business model need to be reimagined?

Fuel: Customers using existing fossil fuel-fired distributed generators often manage their own fuel purchases and handle their fueling operations. The situation is likely to be different for nuclear batteries. Expertise for navigating the nuclear fuel market is much less widespread than the expertise for navigating fossil fuel markets. Moreover, nuclear batteries only need refueling every three to five years, and refueling must be done offsite at a specialized facility outfitted to manage radiation hazards. For these reasons, we expect that customers will expect the Solution Provider to manage the provision of fuel. They, in turn, will manage their fuel needs on a fleet-wide basis much as current owners of fleets of power reactors do today. It is worth noting that, different to diesel, there is no fuel handling, transportation and storage on-site which can have benefits on space, real estate and capability costs.

Transportation: Transporting nuclear batteries is a challenge. Fossil-fueled distributed generators are shipped without fuel. Nuclear Batteries need to be delivered to the customer and back to the facility (after the fuel cycle is over) with the fuel loaded inside. This presents risks in terms of accidents, attacks, or terrorism. The logistics of moving this equipment back and forth across the globe includes the distribution optimization aspect and requires strict security and safety measures. Given that this has never been done in the past, the regulation for transporting a nuclear reactor with fuel inside it is not well-established. Transportation challenge is one of the toughest ones that Nuclear Batteries face for their successful deployment. On the other hand, the transportability of the nuclear battery poses an additional benefit of stranded investment avoidance. The capability of using the asset in different places by the same entity provides flexibility of operations. For example, when a mine is depleted/exhausted, the mining company could turn off the nuclear battery and request the Solution Provider to move it to a new location that has obtained the appropriate licenses.

Conclusion—a Business Model Canvas

We organize our discussion of business models using the Business Model Canvas of Osterwalder and Pigneur 2010. The Canvas is composed of nine different building blocks: Key Activities, Key Partners, Key Resources, Cost Structure, Value Proposition, Customer Segments, Customer Relationships, Channels, and Revenue Streams. Together, these describe "how an organization creates, delivers and captures value". The business model is the integration of all the factors that play into a company being able to create a product or service and deliver it to a customer in an economic transaction.

Anchoring on the result of the three previous questions, we draft a proposal of a business model for a nuclear battery Solution Provider company. This business model is displayed through the Business Model Canvas and is intended as a thought-generating tool for readers to reflect, critique and edit. Figure (1) provides an overview of the business model, and more detail for each building block is offered below, including their definition according to Osterwalder et al.

Key Partners: describes the network of suppliers and partners that make the business model work.

The Solution Provider and its operating model will rely heavily on partnerships with private and public entities. The Developer/Manufacturer of the nuclear battery is the single most crucial supplier, without them, the company simply does not have an asset to offer. Additionally, the fuel supplier is also a critical link to the functionality of the nuclear battery. Moreover, public entities like regulators (NRC in the US), and local, state, and, federal governments, are crucial non-technical partners that will license and permit the use of nuclear batteries. Finally, the Solution Provider will also have to prioritize its relationships with activists and lobbyists to address the hurdle for nuclear energy to achieve social capital.

Key Activities: describes the most important things a company must do to make its business model work.

This role is one of the more complex roles in the ecosystem. The Solution Provider will oversee purchasing all the equipment (including Nuclear Batteries and everything needed to operate), diagnosing and providing a solution to the Customer, siting the equipment, fueling the nuclear battery, and transporting it to the site. After this, the company still needs to install the nuclear battery, operate it for the duration of the agreed-upon timelines, with an incredibly high level of reliability and safety and provide monitoring of the asset. Finally, the Solution Provider will be responsible for replacing a depleted battery with a new one (if applicable), de-fueling the old one, and refurbishing it or disposing of it if it has reached end-of-life. These activities may be dissected in different ways depending on the responsibilities that wish to be taken on by either the Developer/Manufacturer (such as assembly) or the Customer (such as monitoring).

Key Resources: describes the most important assets required to make a business model work.

Many physical assets are needed for this business to run smoothly, including a fleet of Nuclear Batteries, a transportation fleet, and fuel contracts. However, there are also significant non-physical resources that are crucial for the company to produce value, such as nuclear licenses and software (for operation, monitoring, and safety). Furthermore, there is a requirement of Human Capital that needs to be hired to operate the business, from management to nuclear engineers and emergency response teams to truck drivers. All of this will come to the capital and operational expenditure of non-trivial dimensions, which will then, in turn demand the company to have relevant financial resources in the form of cash, debt, or equity.

Cost Structure: describes all costs incurred to operate a business model.

The costs incurred in this business fall within three categories. (1) Capital Expenditures include purchasing the nuclear battery fleet, transportation equipment, software licenses, nuclear licenses, and real state for the company's offices and operating centers. (2) Operational Expenditures which will include labor costs, fuel costs, service, and maintenance of the reactors and of the fleet and distribution costs. (3) Sales, General & Administrative which hold the rest of the costs departments needed to create a successful business such as Management, Sales, Marketing, Legal, finance, Human Resources, Customer Service, and/or Billing Services.

Value Proposition: describes how a company communicates with and reaches its Customer Segments to deliver a Value Proposition.

The key differentiator of this technology will be the carbon-free heat and power on-site. The rest of the value proposition can be almost identically ported from fossil fuel-fired distributed generation systems. These additional value propositions include an economically attractive solution that is readily deployed (plug-and-play) and that can be modularized to serve the specific Customer needs. Furthermore, it poses a safe and secure holistic solution to the Customer with an incredibly small land footprint (because of the high energy density of nuclear operations) that can improve the overall Environmental, Social, and Governance metrics of the user. Finally, it can be imagined that the Solution Provider might be able to generate energy efficiency insights than can be offered to the Customer to create additional value.

Customer Relationships: describes the types of relationships a company establishes with specific Customer Segments.

This building block shares several aspects with nuclear power plants and fossil fuel-fired distributed generators. Customer service will continue to be the most significant piece of this relationship. However, given that in the nuclear battery enterprise, the assets are not owned nor operated by the Customer but rather by the Solution Provider, some differences in the relationship they have are bound to happen.

Customer Segments: defines the different groups of people or organizations an enterprise aims to reach and serve.

As mentioned in the introduction, this technology can service a variety of customers across industries and locations. We propose a four-category approach to understand better what markets are being served and which are the expected players in each segment. (1) Off-grid Heat and Power: as the name mentions, these clients will not be connected to a grid and will need both electricity and heat to continue their operation. Industries such as mining, industrial processing, military bases, and microgrids will require these two resources to operate. They can leverage the nuclear battery as a carbon-free source of both inputs. (2) On-grid Heat and Power: These clients, such as some industrial processes, educational or corporate campuses, and hospitals, will require a primary system to provide clean electricity. Once they have the electricity provided by a nuclear battery, it will be more economically attractive to leverage the heating power instead of getting that resource from a different provider. This customer segment will have to address the challenge of having nuclear operations in urban settings. (3) Off-Grid Temporary: This segment will leverage the mobility and dispatchability of the nuclear battery only for a limited amount of time. Instances of this may include emergency relief (for example, natural disasters), energy demand spikes in remote areas, or military applications. (4) On-Grid Temporary: this customer base is expected to be the smallest of them all, with applications imagined substituting power for significant overhauls of other generation sources or large construction projects.

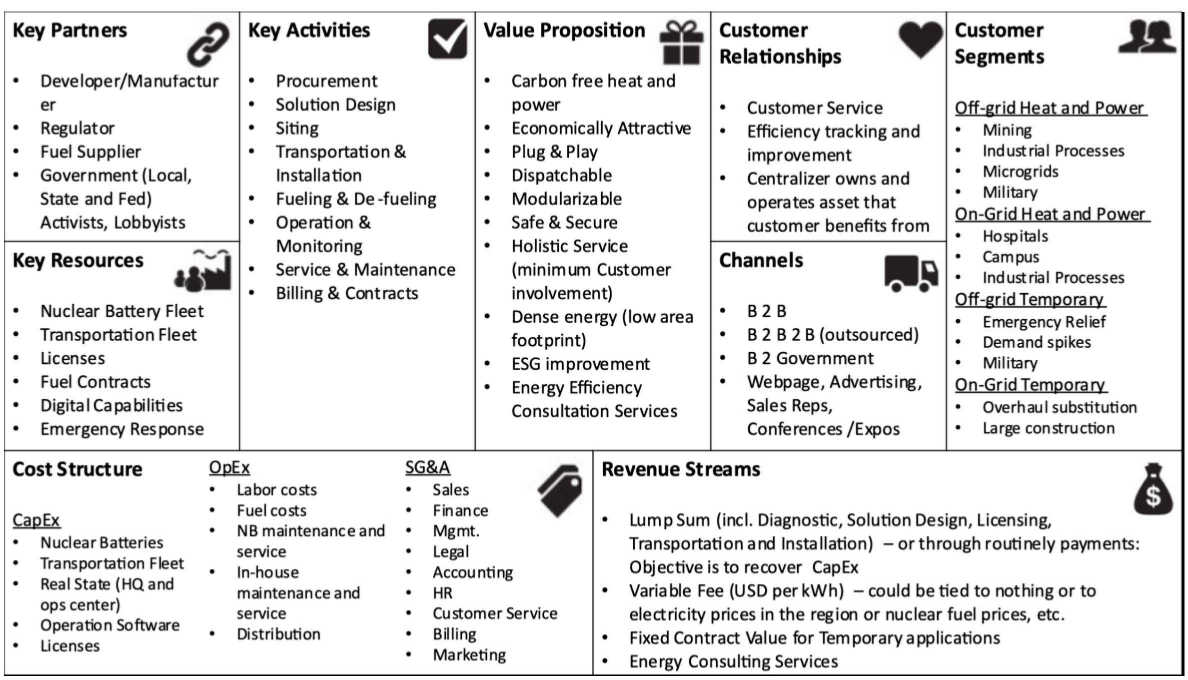
<u>Channels:</u> describes how a company communicates with and reaches its Customer Segments to deliver a Value Proposition.

Given that both NPPs and FFDGs leverage comparable channels, we expect that Nuclear Batteries will rely on similar sales channels. Business-to-Business (B2B), business-to-business-to-business (B2B2B) (outsourced), and government partnerships are imagined to be the most prominent communication channels for this player. Additionally, web services, sales representatives, advertising, and conference/expos attendance can be relevant to secure new partnerships and clients.

<u>Revenue Streams:</u> represents the cash a company generates from each Customer Segment.

The Solution Provider will generate cash in different ways depending on the type of service they provide. For example, suppose they service a mine for ten years. In that case, we can expect there to be an initial Lump Sum charged to the Customer to cover the fixed costs (i.e., the asset, transportation, installation, etc.) plus a variable rate for the energy produced, which may or may not be tied to other variables such as nuclear fuel prices or electricity prices. On the other hand, for temporary purposes, the enterprise may simply charge a contract value to the customer (i.e., a Lump Sum for the rental of carbon-free energy for a music festival). Finally, given that the Solution Provider will monitor and operate the asset, they will have the data to draw insights regarding energy efficiency and may sell those to the customer in a consultancy/advising package.

Figure 1: Proposed business model for nuclear battery Solution Provider



This model we put forward in Figure (1) is not a definitive one but rather a platform for experts in the field and in the industry to leverage as a sounding board. Many different iterations of a company that uses Nuclear Batteries to generate value can be imagined. The Solution Provider, or however it ends up being called in the future, will play a significant role in the value chain of this technology. It may be a separate or independent entity as proposed here, or it may be a subsidiary of a larger entity or even from the Developing/Manufacturer. It can even be argued that in a future where this technology is widespread, some Customers may wish to take on more responsibility as they have with fossil fuel-fired distributed generators.

It is recognized that further research and detail need to be incorporated into this exploration. Significant research and understanding need to happen on the regulation side that focuses on the licensing of serially manufactured reactors, the transportation of the technology, and the usage in urban settings (Garcia 2022). Additionally, a financial structure and economic analysis need to understand how and if this entity can be profitable in the expected markets. The Nuclear Science and Engineering department at MIT has allocated resources across different areas of expertise to better understand these elements.

The need to decarbonize our world is undisputed and Nuclear Batteries may play a significant role in reducing GHG emissions in various hard-to-decarbonize industries. For this reason, we believe that there is inherent value to the technology. It needs to be technically and economically feasible to have a place in the portfolio of energy sources that will help mitigate climate change.

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