Exploration of Micro Nuclear Reactors as a Solution to The California Energy Crisis

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Will Pfister

Fall 2022

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Kathryn A. Neeley, Associate Professor of STS, Department of Engineering and Society

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Introduction

The California power grid has a history of being unreliable dating back to the turn of the century. The power supply has struggled to keep up with the demand, resulting in the state encouraging its residents to conserve energy and threatening blackouts. According to Calmatters, the peak demand for electricity can easily pass 51,000 megawatts, which depending on conservation efforts, can be up to 3,400 megawatts greater than what the grid can support (Hoeven, 2022). With heat waves and extreme cold becoming ever more frequent, this peak demand is bound to increase. The California power grid is increasing in age and energy demands are making it a challenge to keep up. This can result in residents losing access to power during some of the most critical times of the year, mainly summer and winter when air conditioning and heat are necessities in more extreme environments. According to the US Energy Information Association, California consumes the second most energy in the US, but is only the fourth leading producer (California Profile, n.d.). The current grid is reliant on natural gas and fossil fuels to produce electricity, and is falling behind. Figure 1 below provides an overview of the state of California and their annual energy production and consumption.

CALIFORNIA STATE FACTS

State Overview
Population: 38.33 million (12% total U.S.)
Housing Units: 13.79 million (10% total U.S.)
Business Establishments: 0.86 million (12% total U.S.)

Annual Energy Consumption
Electric Power: 259.5 TWh (7% total U.S.)
Coal: 1,900 MSTN (<1% total U.S.)
Natural Gas: 2,337 Bcf (10% total U.S.)
Motor Gasoline: 337,400 Mbarrels (11% total U.S.)
Distillate Fuel: 87,200 Mbarrels (6% total U.S.)

Annual Energy Production
Electric Power Generation: 199.5 TWh (5% total U.S.)
Coal: 1.4 TWh, <1% [0.4 GW total capacity]
Petroleum: 0.3 TWh, <1% [0.5 GW total capacity]
Natural Gas: 119.7 TWh, 60% [45.6 GW total capacity]
Nuclear: 18.5 TWh, 9% [4.6 GW total capacity]
Hydro: 27.4 TWh, 14% [13.5 GW total capacity]
Other Renewable: 9.8 TWh, 5% [7.5 GW total capacity]

Coal: 0 MSTN (0% total U.S.)
Natural Gas: 250 Bcf (1% total U.S.)
Crude Oil: 197,200 Mbarrels (8% total U.S.)
Ethanol: 4,200 Mbarrels (1% total U.S.)

Figure 1: Details on California's Energy Consumption and Production (US Department of Energy, n.d.)

With the state already consuming more energy than it produces, it will be difficult to keep up with demand. There must be a change in energy production to better meet the needs of the California citizens.

This paper highlights the feasibility of solving the California energy crisis with nuclear energy, primarily through micro reactors. The social construction of technology will reveal society's role in accepting and advancing the idea of nuclear energy. We have established that there are many factors in play when it comes to the California energy crisis. There are social implications such as the perception of risk and public opinion on nuclear energy. There are also technical factors such as implementing micro reactors into the existing fossil fuel and natural gas focused power grid. Looking through the lens of a research framework can help to connect these seemingly unrelated factors.

Risk Preventing Technological Progress

Risk is a word that is often associated with nuclear power. Points such as nuclear waste, accidents, and health risks are mentioned when someone is opposed to nuclear power (Green America, 2022). Looking at deaths per unit of power produced , it is significantly safer than the top methods of producing electricity in natural gas and fossil fuels. According to 2012 data from Forbes, Nuclear energy resulted in 90 deaths per trillion kilowatt hours of energy produced, while oil and natural gas resulted in 36,000 and 4,000 deaths respectively (Conca, 2022). Mohamed Alwaeli of the Department of Technologies and Installations for Waste Management, Silesian University of Technology, argues that nuclear energy can eventually replace these older, less efficient methods (Alwaeli, 2021). According to the United States Office of Nuclear Energy, nuclear power plants produce significantly less waste than traditional fossil fuels and natural gas due to its high energy density, and do so with zero carbon emissions (Energy.gov, 2022). The first step towards the widespread implementation of nuclear energy will be to minimize apparent risk, and rid the public of preconceived notions against the fuel source.

Risk is inevitable in all things we as humans do. There is no such thing as a risk free action or event. Things as simple as going to the grocery store or making a snack at home even have risks associated with them. University of Liverpool Senior Lecturer in Sociology Gabe Mythen argues that there is always a level of uncertainty and risk associated with technological advancement. The containment of risk is also essential to maintaining progress, “structural incapacity to manage risk properly leads to institutional actors involving themselves in dramaturgical displays of risk management.” (Mythen, 2018 p.536). Essentially, it is the fear that something might go wrong, and the inability to manage the situation that hinders progress. It is easy to look back and point out famous nuclear incidents in the past such as Chernobyl in the Soviet Union, Three Mile Island in Pennsylvania, and Fukushima in Japan as scapegoats and the reason nuclear power cannot work in modern times. According to M.V. Ramana, with the Nuclear Futures Laboratory and the Program on Science and Global Security, both at Princeton University, in 2011 after the Fukushima crisis, public support for nuclear power dropped nearly 15 percent (Ramana, 2011). Going to show that just one event can have a major impact on public perception. However, with all things, especially energy sources, there is a risk involved. Professor Robert Hayes, Nuclear Engineering Department, North Carolina State University described an equation that quantifies the risk involved with any given energy source.

$$Energy\ Risk = \sum_i Consequences_i \times Probability_i$$

Equation 1: Energy Risk (Hayes 2022)

This provides a means to evaluate and compare risk, which is usually qualitative, with quantitative data. It is important to consider all aspects of energy sources before making conclusions about them. Considering nuclear energy has the fewest deaths of all major energy sources, and nuclear accidents being incredibly rare, shows there should not be such a negative perception of nuclear energy.

To reduce the public perception of risk, micro reactors can be implemented first, before larger scale nuclear power plants. Micro reactors are a recent development in the United States. They are designed to function as mobile nuclear power plants where they can be deployed anywhere in the world with ease. They are much smaller in size than a traditional nuclear power plant, which according to the Department of Energy, requires an average of one square mile to operate (US Department of Energy, n.d.), meanwhile a micro reactor will be able to fit on the back of a semi truck (seen below). These micro-reactors carry less risk than full sized nuclear power plants, and can be deployed in the areas that need them the most. They are easier to operate and can connect directly to an existing power grid. According to Idaho National Laboratory (INL, n.d.), a microreactor would be able to generate 20 megawatts of zero carbon energy to be used wherever it may be needed (Idaho National Laboratory, n.d.). For example, if a city in California is expected to be short on electricity in the coming weeks, micro-reactors would be able to be shipped in and set up in the matter of days to help keep up with power demands. To put into perspective the size of a micro-reactor, Figure 2 below from Idaho National Lab provides an example of one during transit.

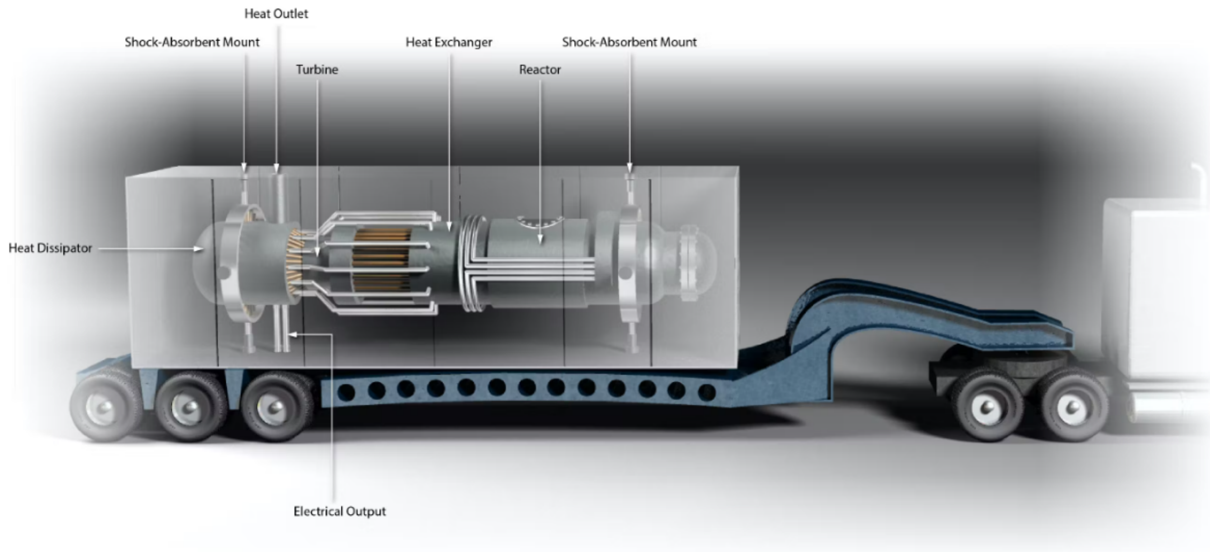

Figure 2: The Scale of a Micro Reactor (Dumond, 2021)

They are designed to easily be transported via tractor trailers, railroad, and even by plane. This versatility allows them to be moved whenever to wherever they are needed.

Micro-reactors are still in the development and prototyping phase, with the first ones expected in about two years (INL, nd). Because of this, it is unclear how exactly they will be implemented, or how much power will be able to be generated from them. Also, we must wait and see how the public will respond to widespread implementation of nuclear energy, due to pre conceived notions and lack of proper education on nuclear power. The root causes of concern must be investigated and minimized if nuclear energy is to be successful. As Mythen said, “As preindustrial cultures are succeeded by industrial society, the incidence of accidents that result from faulty human decisions rises. Nevertheless, such accidents are scattered and random rather than systemic and universal.” (Mythen, 2018) Essentially, as technology progresses, the risk associated with it also increases. The risks involved with microreactors must be considered before implementation may begin.

Positivity towards nuclear power has been seen in studies conducted in nations that have growing economies. According to a study from Mustafa Naimoğlu, it was found that nuclear energy can not only reduce carbon emissions, but also bolster a developing economy (Naimoğlu, 2022). Countries included in this study are Brazil, Argentina, Mexico, and India among others. The results indicate that the use of nuclear energy in these nations would decrease their dependency on foreign fuel, while also reducing energy costs.

It is possible to see successful use of nuclear energy without having to search as far. The United States Navy has relied on small scale nuclear reactors to propel their aircraft carriers and submarines since the 1950's. One of the most significant producers of naval nuclear fuel and components is BWX Technologies, Inc (BWXT). Headquartered in Lynchburg, Virginia, their reactors are currently powering the Navy's Ohio, Virginia, Seawolf and Los Angeles-class submarines as well as its Nimitz and Ford-class aircraft carriers (Dumond, 2022). According to the World Nuclear Organization, the United States Navy has steamed over 240 million kilometers on these reactors without any radiological incidents across 81 different nuclear powered ships (World Nuclear Organization, 2021). This bodes well as BWXT has also been contracted to produce the first micro reactors in the United States for the military (Dumond, 2022). While it is predicted that micro reactors will be 10-20 times smaller than those found in naval vessels, their proven record of success should lead to optimism with future developments in the nuclear energy industry.

The gaps in knowledge I seek to fill are the extent of general concern, risks, pros and cons of nuclear energy, and the feasibility of implementing micro-reactors on a large scale. As well as developing a plan to reduce the apparent risk of nuclear energy.

The efficiency of selected power grids need to be studied to gain an understanding of the potential impact of nuclear energy. Valid concerns of the general public and those directly impacted by this implementation will need to be taken into consideration and evaluated before work can be done.

A Blueprint For Successful Implementation

The concept of micro reactor implementation can be analyzed through the use of the social construction of technology (SCOT). SCOT first emerged in the 1980's as a study of science and technology, specifically a scientists' social responsibilities. SCOT takes great influence from the sociology of scientific knowledge (SSK) framework which has the following basis: "The sociology of knowledge, the philosophy of science, and the sociology of science. The central methodological tenets of the 'strong program' (especially its symmetry principle) seemed equally applicable to technology." (Bijker, 2015 p 135). It looks at not only changes in technology within a society, but also the relationship between society and technology (Bijker, 2015). This framework goes into how technology does not determine human action, but how human action shapes technology. It is a stark contrast to technological determinism which essentially declares that technology is an unstoppable force and the public has no choice but to embrace it. Figure 3 below from Christina Prell of the University of Sheffield provides an overview of the concepts behind SCOT.

Concept	Description
Relevant social groups	May or may not be members of same organization or institute. Key requirement is that members share similar interpretation of the artifact.
Interpretive flexibility	Notion that an artifact has numerous interpretations, thus there are as many artifacts as there are interpretations, and each RSG has their own interpretation.
Closure	When multiple interpretations cease to exist. Interpretive flexibility diminishes.
Stabilization	The development of the artifact within one relevant social group. This happens in degrees.
Technological frame	Cognitive, social and technical elements that guide or constrain meanings and behaviors relevant to an artifact. Actors have different degrees of inclusion in a frame.
Micro political power strategies	A variety of practices used to influence social groups and ultimately the production of a technological frame or semiotic structures.
Semiotic power	The extent to which meanings attributed to an artifact become reified in certain forms.
Semiotic structures	The reified meanings that constrain the extent to which actors can influence and shape an artifact.

Figure 3: Concepts of Social Construction of Technology (Pell, n.d.)

Note that in this chart, “artifact” refers to any new developments in science and technology. This provides an outline of all the people involved, and the changes that can occur along the way towards implementing any given technology.

SCOT grew throughout the STS movement of the 1970’s. During this time, there was an agenda to transform the curriculum of colleges and universities to include a scientist’s social responsibility. This led to greater thought being put into the environment, risks of nuclear weapon proliferation, and the risks of nuclear energy (Bijker). Basically, it sees these issues as neither solely technical nor solely social problems. They require a sort of democratic solution where multiple parties from individuals, corporations, and government must work together throughout the decision making process. Social values of people can have great influence on the implementation of new technologies. The idea of social construction of technology and all of the actors involved in this situation can be visualized as a solar system. In this solar system, micro reactors are at the center, like the sun, and all of the human actors are revolving around it. In this scenario, those orbiting the microreactors would be the public, the government, and also the companies involved in the production of micro reactors. All of these entities must work together to make the whole system work. If one goes astray it can disrupt all of those around it and throw off the entirety of the system. Micro reactors are the focal point of discussion amongst these groups and they must all work in unison to successfully implement them.

Social construction of technology is applicable in many scenarios, especially with the California energy crisis. The energy production methods currently in place, specifically fossil fuels and natural gas, are not cutting it and it is up to the people to make a change. To do so, the public must get on board with the idea of implementing a newer, more unknown technology in order to produce electricity. This framework closely relates to the ideas above about the fear of risk getting in the way of making progress. The state of California has the option to continue doing things the way they have been done for several decades; Or, they can take a step forward and invite new technology into their infrastructure.

Following Figure 3, the implementation of micro reactors in California can be broken down into smaller pieces. The relevant social groups include the citizens of California, the companies building these reactors, and the government officials and agencies that are responsible for regulating them. Government officials will have to communicate with the public about their goals and plans of implementation. Once agreed, the government can then bring in the companies who can begin the groundwork for deployment of the micro reactors. Interpretive flexibility refers to the uncertainty and the possibilities of implementation methods. Then, with the relevant groups working together, a method will be decided on that will allow progress to ensue. After stabilization, we will be able to see just how the solution has fared in reality versus in theory.

Results

While the current situation in California and the information on micro reactors are currently evolving, it is possible to draw some conclusions about their potential to solve the current problem. One major hurdle to widespread implementation of nuclear power is the perception of risk. Micro reactors can serve as a great means to ease into the idea of nuclear power. As far as solving major energy shortages, as of right now, it does not appear that micro reactors alone will be able to handle the extra demand statewide. This is due to their limited power production of up to 20 megawatts where the extra demand can peak at 3400 megawatts.

Problem	**Solution/Inference**
Perception of Risk	Start small, work up from there. Build trust.
Energy Shortages	Micro reactors are likely not the whole solution, but will be able to help where needed.

Given what is known about micro nuclear reactors and the power they are predicted to produce, it is unlikely that they will be a permanent solution to the current power shortages in California. While they appear to be a very promising technology, as it stands they do not produce enough power to single handedly support a large city's power grid. However, that does not mean they will not be a useful technology to have. Their versatility will allow them to still be a valuable asset as they will be able to be deployed in a variety of different situations. Also, the public can see firsthand the possibilities of nuclear energy, hopefully spurring greater use in the future.

While micro reactors will not completely bridge the gap between California's energy production and demand, they can still be valuable to the power grid. At times of extreme heat or extreme cold, they will be able to provide support for the affected areas. Per BWXT, "The reactor is designed to be safely and rapidly moved by road, rail, sea or air, and the entire reactor system is designed to be assembled on-site and operational within 72 hours. Shut down, cool down, disconnection and removal for transport is designed to take less than seven days." (Dumond, 2021, n.p.). With how portable they are, and quick setup times, they can be transported to an area in need and be running in the matter of days. Knowing that, cities can have them brought in when they are expecting heavier power usage. They will then be able to provide extra power thus reducing the overall stress on the grid. With a relatively small footprint, they will not need a large plot of land, meaning they can be placed nearly anywhere.

Similar to periods of extreme heat or cold, micro reactors could be brought in after natural disasters to aid in rescue and relief efforts. After hurricanes or earthquakes, cities can be without power for extended periods of time. This not only extends the time it takes to rescue others in need, but also to begin rebuilding. Implementing micro reactors into disaster relief efforts will provide necessary help to hospitals and relief workers to help all affected by the disaster.

Through the implementation of micro nuclear reactors, the public will be able to see first hand the benefits of nuclear energy. First, these small, portable reactors will work to reduce the perception of risk involved with nuclear energy. Once they are seen working safely, this can lead to greater use of nuclear power nationwide. This will have a massive impact not only for energy production in the United States, but also for the environment. Having nuclear energy as a viable source of energy nationwide will reduce our dependencies on natural gas and fossil fuels which emit massive amounts of carbon and are main contributors to the worldwide climate emergency. The United States could become the world's leader in nuclear power and set the standard for all nations in transitioning to a nuclear based power grid.

Micro reactors will be able to operate on their own or integrated into a power grid. This leads to a great amount of versatility as they work independently or in conjunction with existing infrastructure. While risk is necessary, the introduction of micro reactors will help minimize this risk due to their smaller scale. Once public trust is established, larger scale nuclear power plants can be put in place to support the grid. As of now, micro reactors are likely not the fix all, but provide extra support where needed. Micro reactors can provide a foundation for a future that consists of more nuclear energy.

Conclusion

Micro nuclear reactors are an exciting development that can help spur a new generation of nuclear energy. As they are still in development, there is much still to be learned about micro reactors and exactly how they will be implemented in the future. This paper explored the future impact and the potential for nuclear growth in the United States sparked by the development of micro reactors. Over the next two years or so, we will learn much more about the capabilities of these reactors and just how they may be utilized in the future. While currently it appears that they will not be a self-sustaining system on their own, they can certainly play a valuable role in future innovations in the energy industry.

References

3 reasons why nuclear is clean and sustainable. Energy.gov. (2022, June). Retrieved October 27, 2022, from https://www.energy.gov/ne/articles/3-reasons-why-nuclear-clean-and-sustainable

10 Reasons to Oppose Nuclear Energy. (n.d.). Green America. Retrieved October 10, 2022, from https://www.greenamerica.org/fight-dirty-energy/amazon-build-cleaner-cloud/10-reasons-oppose-nuclear-energy

Alwaeli, M., & Mannheim, V. (2022, June). *Investigation into the Current State of Nuclear Energy and Nuclear Waste Management—A State-of-the-Art Review*.

California State Energy Profile. California Profile. (n.d.). Retrieved October 27, 2022, from https://www.eia.gov/state/print.php?sid=CA

Conca, J. (2022, October 12). *How deadly is your kilowatt? we rank the Killer Energy Sources*. Forbes. from https://www.forbes.com/sites/jamesconca/2012/06/10/energys-deathprint-a-price-always-paid/?sh=64479c68709b

Dumond, C. (2022, April 11). *BWXT Advancing Microreactor Design Project*. BWX Technologies, Inc. Retrieved October 27, 2022, from https://www.bwxt.com/news/2022/04/11/BWXT-Advancing-Microreactor-Design-Project

Hayes, R. (2022). Nuclear energy myths versus facts support its;k expanded use—A review. *Cleaner Energy Systems*, *2*, 100009. https://doi.org/10.1016/j.cles.2022.100009

Hoeven, E. (2022, September 6). *A do-or-die day for California's power grid*. CalMatters. Retrieved October 10, 2022, from https://calmatters.org/newsletters/whatmatters/2022/09/california-power-grid-blackouts/

Idaho National Laboratory. (n.d.). *Microreactors*. https://inl.gov/trending-topic/microreactors/

Longden, T., Beck, F. J., Jotzo, F., Andrews, R., & Prasad, M. (2022). 'Clean' hydrogen? – Comparing the emissions and costs of fossil fuel versus renewable electricity based hydrogen. *Applied Energy*, *306*, 118145. https://doi.org/10.1016/j.apenergy.2021.118145

Mythen, G. (2018). The critical theory of world risk society: A retrospective analysis. *Risk Analysis*, *41*(3), 533–543. https://doi.org/10.1111/risa.13159

Naimoğlu, M. (2022). The impact of nuclear energy use, energy prices and energy imports on CO2 emissions: Evidence from energy importer emerging economies which use nuclear energy. *Journal of Cleaner Production*, *373*, 133937. https://doi.org/10.1016/j.jclepro.2022.133937

Naval Nuclear Propulsion. BWX Technologies, Inc. (n.d.). Retrieved October 27, 2022, from https://www.bwxt.com/what-we-do/naval-nuclear-propulsion

Nuclear power and the environment - U.S. Energy Information Administration (EIA). (n.d.). Retrieved October 10, 2022, from https://www.eia.gov/energyexplained/nuclear/nuclear-power-and-the-environment.php

Nuclear-Powered Ships. World Nuclear Organization. (2021, November). Retrieved October 27, 2022, from https://world-nuclear.org/information-library/non-power-nuclear-applications/transport/nuclear-powered-ships.aspx

OECD. (2010). *Public Attitudes to Nuclear Power*. OECD. https://doi.org/10.1787/9789264097933-en

Pell, C. (n.d.). *Rethinking the Social Construction of Technology*. Christina Prell: Rethinking the Social Construction of Technology Through 'following the Actors'. from https://www.socresonline.org.uk/14/2/4.html

Ramana, M. V. (2011, August). *The nuclear energy issue nuclear power and the public*.

Shirizadeh, B., & Quirion, P. (2021). Low-carbon options for the French power sector: What role for renewables, nuclear energy and carbon capture and storage? *Energy Economics*, *95*, 105004. https://doi.org/10.1016/j.eneco.2020.105004

Technology, Social Construction of | Elsevier Enhanced Reader. (n.d.). https://doi.org/10.1016/B978-0-08-097086-8.85038-2

US Department of Energy. (n.d.). *Ultimate Fast Facts Guide - Department of Energy*. Retrieved December 12, 2022, from https://www.energy.gov/sites/prod/files/2019/01/f58/Ultimate%20Fast%20Facts%20Guide-ebook_1.pdf