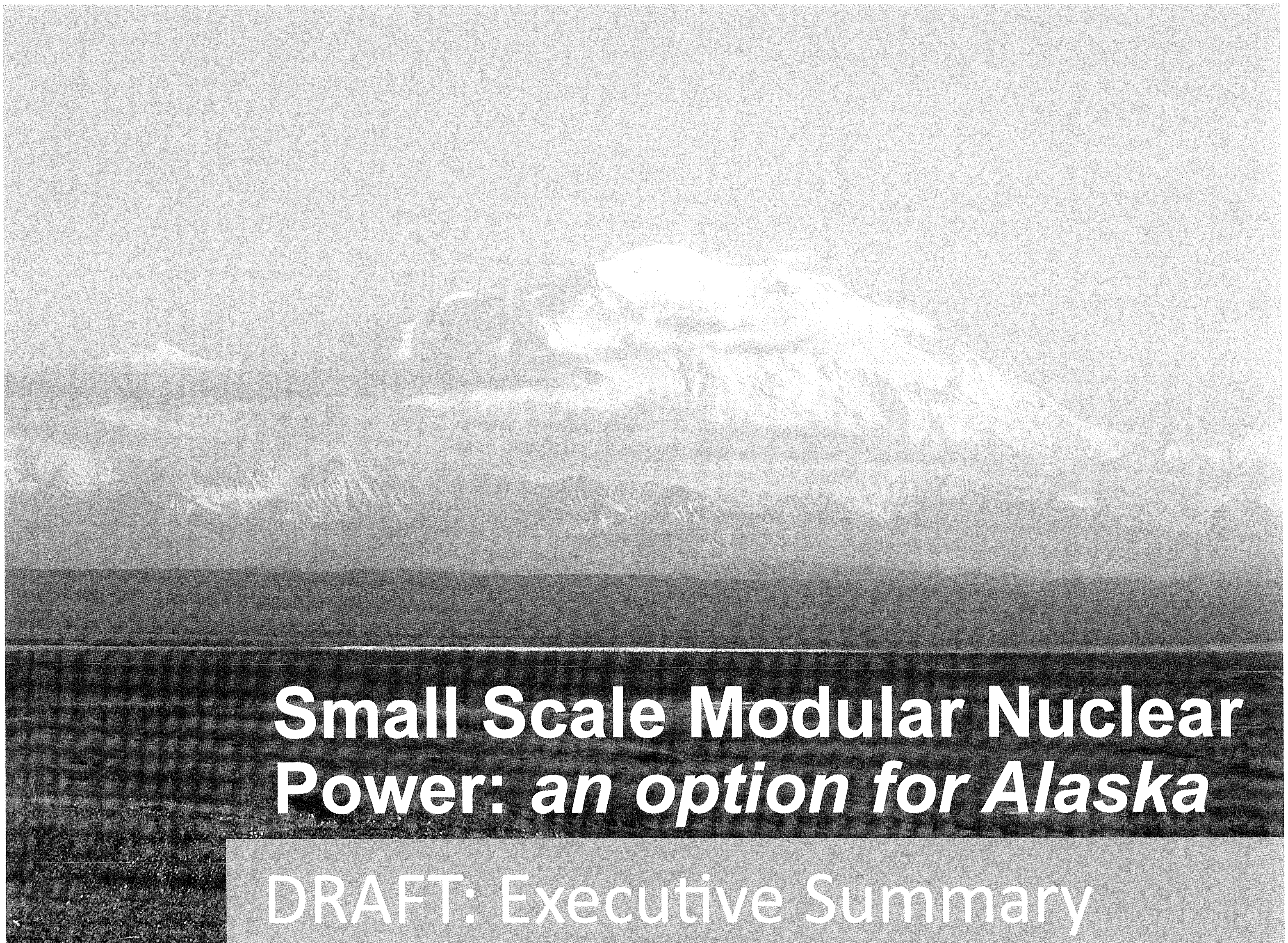

# Small Scale Modular Nuclear Power: *an option for Alaska*

## DRAFT: Executive Summary

*Prepared by the University of Alaska, Alaska Center for Energy and Power and the Institute of Social and Economic Research with funding through the Alaska Energy Authority*

# Small Scale Modular Nuclear Power: *an option for Alaska?*

EXECUTIVE SUMMARY: DRAFT March, 2011

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The Alaska Energy Authority
Project Manager Mike Harper, Deputy Director

**Prepared by:**
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**This executive summary and report have been released in draft form to allow time for public input. We anticipate a final report will be published at the end of April, 2011. Please provide comments and feedback to:**

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It should be noted that the contents of this report represent the consensus of the authors, but do not necessarily reflect the views of those listed above.

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## Photo Credits

Front Cover: Image of Denali, Jim Norman, ABS Alaskan; Image of TRIGA Research Reactor courtesy of General Atomics; Artist Rendition of Toshiba 4S Reactor courtesy of Toshiba and Marvin Yoder, MY:T Solutions.

## Executive Summary

Alaska is home to some of the most abundant supplies of fossil fuels and renewable energy resources on the planet. While the Alaska treasury benefits financially from development of these resources for export, the supply of reliable, affordable energy to small and often isolated Alaska markets remains a challenge. These conditions result in energy prices for space heating and electricity that are volatile and expensive in many areas of the state. These high energy prices are a significant burden for Alaska residents and businesses and stifle economic development.

Ways to address high energy prices are being deliberated, including the possible construction of one of several proposed natural gas pipeline projects, funding of individual projects in rural communities with access to developable resources, and consideration of a large-scale hydroelectric project to serve the Railbelt. Another possible source of energy is nuclear power.

Why discuss the nuclear option? With Alaska's abundant energy resources, this form of energy might not seem needed. However, Alaska's resources are not equitably distributed geographically, with some areas located near energy sources (for example, the gas fields of Cook Inlet that supply energy for Anchorage), and many other areas less fortunate. In particular, communities in rural Alaska face very high energy prices due to reliance on imported diesel fuel, and many do not have access to developable local resources that can appreciably reduce this dependence. To a lesser degree, the Fairbanks area also lacks low-cost, locally abundant energy resources. It is possible that the new small-scale modular nuclear power plants could lower the cost of energy in some of these locations.

Alaska was not part of the first wave of nuclear power development in the U.S., as the nation's existing commercial nuclear industry is comprised of 1000 MW reactors that are too large for any Alaska applications. However, as part of a new generation of nuclear power plants worldwide, small modular reactors (SMRs) are being developed that range in size from 10 MWe to 300 MWe. These SMRs would be manufactured in factories, allowing standardized design and fabrication, high quality control, shorter power facility construction times, and reduced finance charges during construction. In larger markets in the Lower 48, multiple SMR modules could be combined to form a single gigawatt-scale power plant, which would have several advantages over a single large reactor, including reduced downtime for maintenance and improved safety. These SMRs would also be appropriately sized for use in Alaska, making nuclear energy a viable option to consider. In addition to providing energy (heat and power) for rural communities and/or the Railbelt, other potential applications include providing energy to military bases, remote mining operations, and other industrial users.

The Toshiba 4S nuclear power plant proposed for Galena in 2003 is familiar to many Alaskans. This project initiated a serious conversation about nuclear energy throughout the state when it was incorrectly reported that Toshiba was willing to "give" a 10 MWe prototype reactor to the community of Galena. Though this project did not advance past the early conceptual phase, it influenced the national conversation about nuclear energy and brought the needs of small, remote communities to the attention of lawmakers and regulators in Washington, D.C. That conversation identified market opportunities for SMR technology, and highlighted regulatory barriers to such installations.

The purpose of this report is to explore the viability of SMR technology for meeting Alaska's current and future energy needs. We found that no small-scale nuclear reactor technology is currently approved or licensed for commercial use in the U.S. In fact, no SMR manufacturers have submitted a request for design review and certification to the Nuclear Regulatory Commission (NRC), a critical step toward development of a pilot project and a process that is expected to take several years to complete. Therefore, at least with regard to any SMR that could be installed in the U.S., this technology is still in a pre-commercial phase of development. Nonetheless, several manufacturers are actively advancing their designs, and the Department of Energy (DOE) is poised to invest $500 million in SMR technology over the next few years. The question is not whether SMRs will become commercially available, but when. In the interim, a series of questions need to be answered, some at the national level and some in Alaska. These questions include, Does the technology exist to build these small reactors? Is the technology safe? How will the fuel cycle for SMRs be managed? Are suppliers willing to sell small-scale nuclear reactors in Alaska? Who would own a project? Would this technology be cost effective? What skills are needed if Alaskans choose to adopt SMR technology as part of their energy portfolio? Should Alaska be an early adopter of this technology?

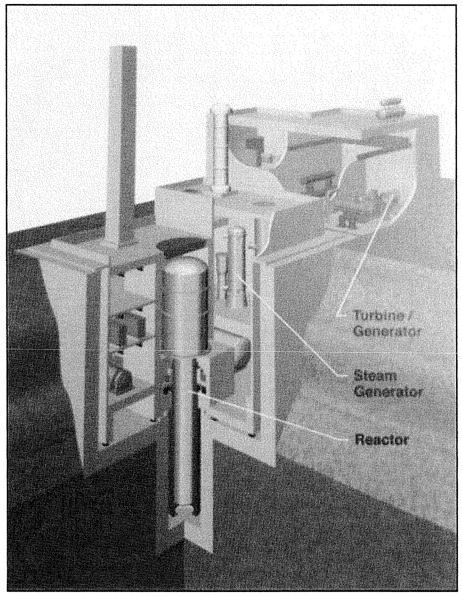

**Figure 1.** Artist rendition of the proposed Toshiba 4S 10 MW reactor proposed for Galena.

This study, conducted at the request of the Alaska Legislature and managed through the Alaska Energy Authority (AEA), addresses these questions. The scope of this report includes identification and evaluation of all currently known existing or proposed small-scale nuclear power technologies worldwide. Information contained in this report was obtained through web-based and library research, interviews with technology experts worldwide, and attendance at conferences focused on SMR technology.

In addition, many of the policy options forwarded in this report are a direct product of discussions that took place during a SMR workshop held in Anchorage involving dozens of key stakeholders from around the state, as well as representatives from the DOE Nuclear Energy Agency, the Nuclear Regulatory Commission, and other industry specialists. This workshop specifically considered Alaska applications for SMR technology, including the special challenges associated with potential deployment in Alaska. We thank those who took the time to participate and contribute to that discussion. A full transcript is available.[1]

The results of our study of current SMR technologies include the following observations:

- More than 50 nuclear reactor technologies have been proposed worldwide that are classified as small. These nuclear reactors vary in size from 1 $MW_e$ to 300 $MW_e$. Many of the newer designs are "fast reactors" as opposed to currently used "light water reactor" technology. Fast reactors are designed to allow the use of spent fuel from light water reactors, but doing so requires the development and construction of expensive fuel reprocessing plants that do not yet exist.
- No SMR systems are expected to be in service before 2020. The first systems approved by the NRC will likely be smaller-scale versions of existing light water reactor technology, such as those proposed by NuScale and Babcock and Wilcox.
- All of the current SMR designs for which NRC approval will be sought are 10 $MW_e$ or larger, a size too large for most rural communities. Radioisotope thermal generators (RTGs), used by NASA for long-term space missions or on Earth for powering critical remote communications sites, are unsuitable for village-scale power due to the high cost of radioisotope materials. Mini nuclear reactor systems that might be suitable for small communities have not been considered seriously because of the lack of an apparent U.S. market. Nuclear submarines and icebreakers use highly enriched (weapons grade) uranium that would pose safety and security issues if used for stationary power.
- Both state and federal laws require NRC approval for any project involving nuclear energy. The NRC has not reviewed any small reactor designs, although several companies have stated their intention to submit designs for review in the next year or two. The Galena Toshiba 4S project is not moving forward at this point, and no formal license application for this project has been submitted to the NRC for review. Some of the designs identified in this study are operating in other parts of the world - for example, a Russian design for a barge-mounted power plant - but cannot be permitted in the U.S. unless NRC approval is sought and given (the Russian developer, Rosenergoatom, is not considering applying for such approval).
- In addition to the reactor design review, the NRC requires a thorough review of any proposed site for a nuclear power plant. Such a review considers emergency planning, emergency zones surrounding the plant, and appropriate seismic design. Currently, there are no approved sites for commercial nuclear power plants in Alaska.
- The NRC evaluates the technical and financial capabilities of the plant owners, including the ability of the owners to finance construction of the plant; to attract, train, and retain a workforce with appropriate skills; and to construct and operate a plant that meets appropriate standards. For this reason, development of a nuclear power plant in Alaska may require partnership with a company from a location outside the state that has expertise in nuclear energy, especially when building and commissioning the first plant.

[1] http://www.uaf.edu/acep/education-outreach/events/event-archive/nuclear-energy-explorator/

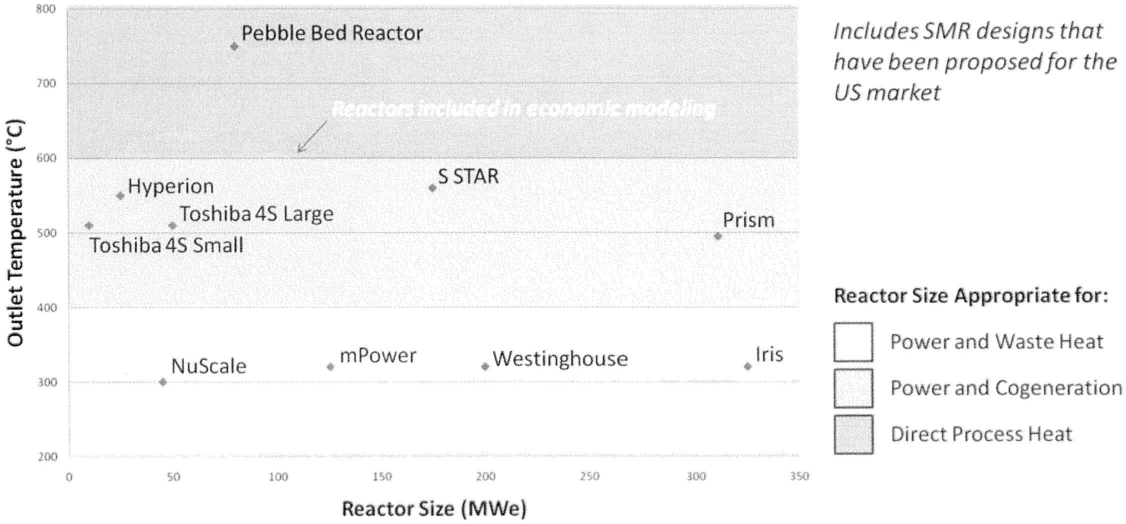


**Figure 2.** Representative small reactor designs and relative operating temperatures. Reactors with high and medium outlet temperatures are generally fast reactor technology, while designs based on more traditional light water reactor technology have lower outlet temperatures.

## Economics of Small Modular Reactors in Alaska

As part of this project, we developed an economic model to serve as an initial screening tool to determine if and where SMR technologies could be economically deployed in Alaska, when the technology become available. Since SMR technology has not been commercialized anywhere in the U.S., our analysis is subject to significant cost uncertainties. Additional analyses can easily be conducted in the future as costs become more certain, because the screening model was designed to be readily adaptable as new information becomes available.

For our economic analysis, we identified technologies currently under development that potentially could be used in Alaska settings based on the capacity of the units and the anticipated date of availability. Thus, five manufacturer designs were selected for economic viability screening: mPower, NuScale, Hyperion, Toshiba 4S large (50 $MW_e$), and Toshiba 4S small (10 $MW_e$). Capital costs per installed kW are estimated to range from $4,500 to $8,000. The combined operating license (site and technology) is estimated to cost $50 to 70 million, adding $400 to $7,000 per installed kW depending on the size of the unit. The combined operating license costs are expected to be relatively fixed so these costs would be spread across more installed kW for the larger units.

| TECHNOLOGY | Installed Capacity (MW) | CAPITAL COST AND COMBINED OPERATING LICENSE (COL) COSTS | | | | | |
|---|---|---|---|---|---|---|---|
| | | capital cost **low** [$ millions] | COL $/inst kW **low** | capital cost **med** [$ millions] | COL $/inst kW **med** | capital cost **high** [$ millions] | COL $/inst kW **high** [$] |
| Hyperion | 25 | $112.5 | $2,000 | $150.0 | $2,400 | $200.0 | $2,800 |
| mPower | 125 | $562.5 | $400 | $750.0 | $480 | $1,000.0 | $560 |
| NuScale | 45 | $202.5 | $1,110 | $270.0 | $1,330 | $360.0 | $1,560 |
| Toshiba 4S large | 50 | $225.0 | $1,000 | $300.0 | $1,200 | $400.0 | $1,400 |
| Toshiba 4S small | 10 | $45.0 | $5,000 | $60.0 | $6,000 | $80.0 | $7,000 |

**Figure 3.** Capital costs include all costs for the SMR project 'power island', which includes costs associated with buying, transporting, and installing the reactor, as well as power generation equipment, condensers, and construction of the reactor facility. It excludes costs of transmission, distribution, roads, and fuel. Combined operating license includes both NRC construction and operating license.

Communities that have at least an average annual power load close to, or larger than, 10 $MW_e$ were considered in this analysis. Eliminated from consideration were communities that meet the majority of their electrical power requirements with installed hydroelectric capacity. In addition, our analysis was limited to assessing community-based applications rather than large industrial loads, although the model could be applied to other possible users. Based on matching community electric loads with SMR unit capacity, potential economic viability was analyzed for rural hubs, including Bethel (7 $MW_e$ average annual load), Dillingham (3 $MW_e$), Galena (1 $MW_e$), Kotzebue (4 $MW_e$), Naknek (8 $MW_e$), Nome (9 $MW_e$), and Unalaska (7 $MW_e$). Galena was included in this group, despite its smaller electric load, for comparison with an analysis conducted in 2004. The other area with sufficient loads to justify considering SMRs is the Railbelt, including Anchorage (652 $MW_e$), Fairbanks (223 $MW_e$), and Tok (2 $MW_e$).

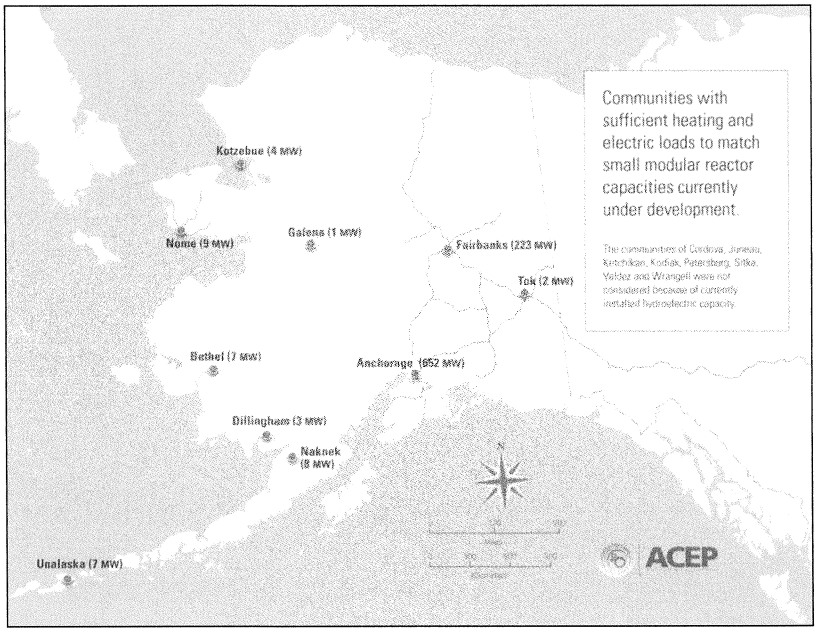


**Figure 4.** Communities analyzed for potential economic viability of SMR technology.

Economic scenarios involving assumptions of low to high price forecasts for crude oil, natural gas, and carbon, coupled with low to high costs for SMR power plant construction, fueling, and licensing, comprise 36 unique variations. We present the results of five scenarios that bracket economic viability of the alternatives based on the U.S. Energy Information Administration (EIA) crude oil and natural gas price forecasts, and the Massachusetts Institute of Technology (MIT) carbon price forecasts. In addition to EIA forecast-based scenarios, we conducted a Railbelt scenario using the natural gas price forecast of the Regional Integrated Resources Plan (RIRP).

Consistently, SMR technology is not feasible anywhere in Alaska under the current EIA low crude oil price forecast, even for the low-cost case of SMR construction and licensing. However, under the medium EIA crude oil price forecast of between \$80 and \$100 per barrel over the next 20 years, SMRs become a viable energy alternative for the Railbelt, regardless of the assumed SMR cost range used in this analysis. As would be expected, the same is true for the scenario that involves high crude oil prices projected at \$130 to \$200 per barrel over the next two decades.

In fact, four out of the five SMR power plants lower the currently projected cost of electrical power in Fairbanks as soon as or soon after the nuclear technologies are projected to become available (2020 or 2025). Most economically promising was a Fairbanks–Eielson Air Force Base scenario that utilizes excess heat from the power plant for the existing Eielson district heating system, and delivered power to the Fairbanks market. It should be noted that our analysis was based on a comparison with current generation sources only, and did not take into consideration possible changes from this baseline that would occur if a large hydroelectric or gas pipeline project developed that could serve the Fairbanks market. The analysis also did not compare the relative costs of SMR technology against a natural gas pipeline or new hydroelectric project.

Using EIA natural gas price forecasts, SMR technology did not lower the cost of energy in the Railbelt south of the Alaska Range. However, under the RIRP natural gas price forecast, the larger light water reactor designs—NuScale and mPower—could potentially provide savings for Anchorage households shortly after the designs are expected to become commercially available (2020).

The rural communities considered as part of our economic model were at a disadvantage, because despite higher energy costs, most of the SMRs were oversized for the community load, even when heating was included in the analysis. For this reason, the only rural community where SMRs would potentially lower projected future energy costs is Bethel. For Bethel, the local diesel-fuel price threshold for SMR economic feasibility is $7 per gallon (2010 dollars). More communities could benefit from nuclear energy if smaller reactors more appropriately sized for typical village-scale loads become available, but such reactors are not currently being considered in the U.S.

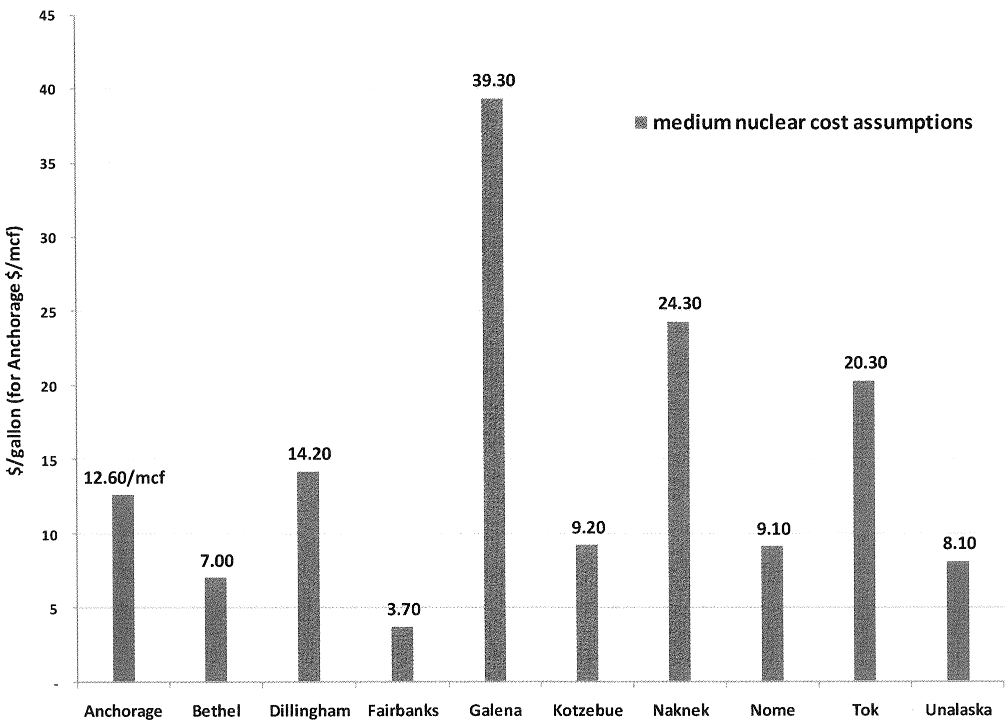


**Figure 5.** Approximate local fuel price thresholds for SMR economic feasibility (2010$, per gallon or mcf)

### Potential State Actions

While small modular nuclear reactors are not available for the Alaska market today, our findings do not preclude opportunities for SMRs to meet the energy needs of Alaska's communities and industries in the future. In fact, our economic screening analysis indicates that, were the technology available today, there would be sites in Alaska where development of a small nuclear reactor for heat and power would reduce energy costs. Furthermore, barring any unforeseen developments, we believe the chances are high that SMR technology will become commercially available sometime in the next two decades. Therefore, to explore this option further, the State of Alaska could take the following actions:

1) ***Begin a site feasibility study for two locations in Alaska.*** While much of the national focus is on technology design licensing, the site selection and permitting process will be as challenging and involves significant uncertainty. The state could fund preliminary site selection and permitting activities for two locations based on the outcome of the economic screening analysis. Leading contenders include Fairbanks and Bethel, but a final determination should be made with local community input. Moving forward to achieve a better understanding of the permitting process does not commit Alaska to installation of an SMR, or to becoming a first mover in this technology area. Instead, it provides flexibility and the ability to be an early adopter, while gaining a better understanding of the potential environmental issues associated with deployment in Alaska.

2) ***Continue research into smaller scale (<10 $MW_e$) reactor technology.*** There is virtually no market niche for mini nuclear power reactor technology in the U.S., and therefore little effort has been made to commercialize a product in this size range. However, research in this area has not been exhausted. There is no question that several small power reactors have been developed in the U.S. and other countries. For example, General Atomics has a standard design for a research reactor installed in dozens of locations around the country; it is a virtually fail-safe design with minimal NRC permitting and licensing requirements. This TRIGA reactor could be converted to a power reactor, something that was explored by the manufacturer twenty years ago but was discontinued due to a lack of apparent market potential. Alaska could seek a partnership with other groups interested in pursuing mini nuclear power, such as the Department of Defense. There is significant interest within the DoD related to nuclear energy. Applications would include providing primary power for domestic military bases to reduce vulnerability to commercial electric grid power outages, and for forward operating

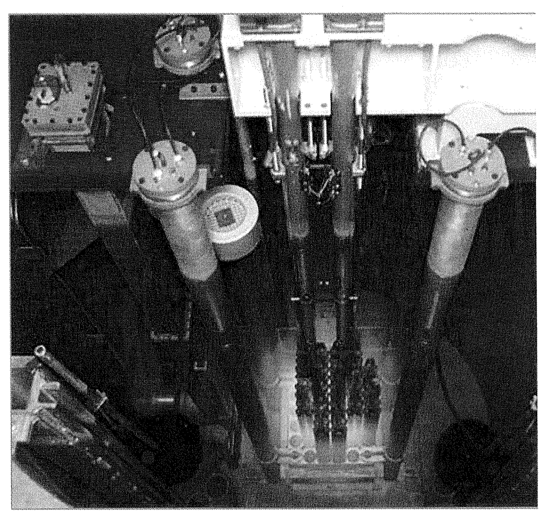

**Figure 6.** Core of a TRIGA research reactor, designed and constructed by General Atomics.

bases abroad to reduce the need for the highly vulnerable fuel convoys used to supply those operations.

3) ***Continue studies of SMR economics and technology development.*** Collaboration with the U.S. Department of Energy in reviewing their forthcoming economic analysis of SMR technologies for power plant applications in the U.S. would provide Alaska with more data for the model developed as part of this study, as well as technology and permitting insights for the most advantageous applications for Alaska.

4) ***Ask Alaska's congressional delegation to strongly support the Department of Energy FY2012* budget request called the 'Light Water Reactor Small Modular Reactor Licensing Technical Support Program'.** Through this budget request, totaling $67 million for FY2012, DOE's Office of Nuclear Energy would establish a new program to support the design certification and licensing activities for SMRs through cost-shared arrangements with industry partners. This budget item tracks legislation (Nuclear Power 2021) introduced by Senators Bingaman and Murkowski in the 111th Congress, that would authorize DOE to assist in the design and certification of two SMRs by 2021, with the goal of using public/private partnerships to build one or more demonstration projects and move the technology closer to full commercialization.

5) ***Identify a state technology lead.*** The potential for this technology in the U.S. has been recognized nationally and in Alaska. Federal licensing and permitting processes are being developed to meet the growing interest in SMR technology as a way to meet energy demands of the future. To stay abreast of these developments, the State of Alaska could identify a lead entity to follow developments by industry and federal agencies that are relevant for Alaska. Specifically, the AEA could designate a Program Manager for Nuclear Energy, who could represent a portion of the duties of an existing staff member. The AEA could also contract with the University of Alaska to follow developments and report at regular intervals, but there should be a central point of contact for the State of Alaska, and AEA is the logical choice.

6) ***Consider SMR technology as one of several alternative scenarios to a large hydro project during the next phase of the Susitna FERC permitting process.*** While SMR technology is not available commercially today, it will likely become available in the future and as such would be worth comparing to other alternatives now and in the future as a replacement for aging generation on the Railbelt. The RIRP process did consider a single Hyperion SMR module in the first stage of its screening analysis, but did not consider an array of SMRs added in increments over time to meet expected load growths. A scenario where individual modules were added over time could have the benefit of more closely matching loads and distributing costs over a longer time horizon.

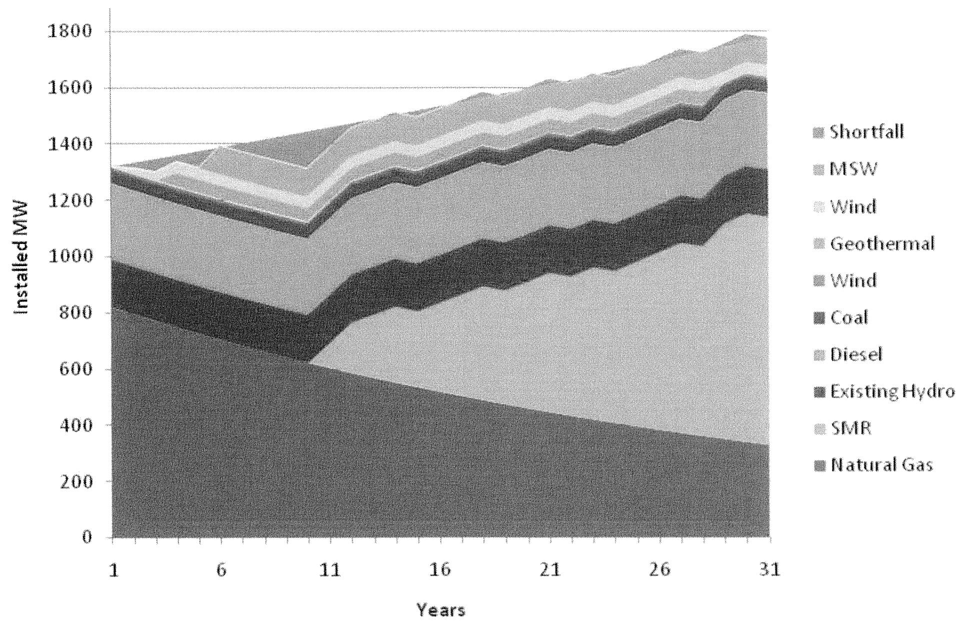


**Figure 7.** Conceptual cartoon based on RIRP model assuming 3% decline in natural gas supply per year, 1% growth in electrical demand year, and incremental additions of multiple 45 MW Nuscale SMRs beginning in 2020.

In conclusion, no immediate, large-scale actions need to be considered. Instead, the options as drawn from this study suggest smaller, prudent, measured actions that keep this technology option on the table and allow Alaska to provide some small influence over the development of SMR technology in this country.

# Appendix A:

## Small Modular Reactor Technology Screening Report

The following small modular nuclear reactor technologies were considered as part of this study.

***Commercially available, NRC reactor design approved, could be deployed in US with NRC approval of site permit and operating license.***

- No reactors identified in this category

***NRC design review application submitted, design based on previously proven technology, approval expected within 3 years.***

- No reactors identified in this category

***NRC letter of intent submitted, design based on previously proven technology, approval expected within 6 years***

- mPower 125 MW Reactor, USA, Babcock and Wilcox
- NuScale 45 MW Light Water Reactor, USA, NuScale Power company

***NRC letter of intent submitted, design includes significant items not previously approved by NRC, approval time unknown***

- Toshiba 4S Reactor, Japan, Toshiba
- Pebble Bed Reactor, South Africa, Pebble Bed Modular Reactor (Pty) Limited and Eskom
- Power Reactor Innovative Small Module (PRISM), USA, GE-Hitachi
- Hyperion Power Module, USA, Hyperion Power Generation Inc.

***New design under consideration by large nuclear development group based on previous experimental reactor experience, but NRC approval process has not begun.***

- International Reactor Innovative and Secure (IRIS), International, Westinghouse
- Secure Transportable Autonomous Reactor (STAR), USA, Argonne National Laboratory
- Small Sealed Transportable Autonomous Reactor (SSTAR), USA, Lawrence Livermore, Argonne and Los Alamos National Laboratories in collaboration with others.

***Proposed design being researched by viable company with sufficient funding, but remains in modeling stage***

- Medical Isotope Production System (MIPS), USA, Babcock and Wilcox
- Encapsulated Nuclear Heat-Source (ENHS), USA, University of California, Berkeley.
- LSPR--LBE-Cooled Long-Life Safe Simple Small Portable Proliferation-Resistant Reactor, Japan

- Liquid Fluoride Thorium Reactor (LFTR), USA, Oak Ridge
- Fuji Molten Salt Reactor (MSR), Japan, Fuji--Russian--USA
- Traveling Wave Reactor (TWR), USA, Terrapower (approaching Toshiba)
- Energy Multiplier Module (EM2), USA, General Atomics
- Advanced High Temperature Reactor (AHTR), USA, Oak Ridge National Laboratory
- Gas Turbine - Modular Helium Reactor (GT-MHR), USA--Russia--Japan, General Atomics in
- partnership with Russia's OKBM Afrikantov, supported by Fuji (Japan)
- Antares Reactor, International, Areva
- Advanced Reactor Concepts (ACR-100), USA, Advanced Reactor Concepts LLC (ARC)

***International commercial design not seeking NRC approval for licensing in US***

- NP-300, France, Technicatome (Areva TA)
- KLT-40 S Pressurized Water Reactor, Russia, OKBM
- Pressurized Heavy Water Reactors (PHWR-220) (PHWRs), India, Nuclear Fuels Complex, India

***Proposed reactor design appears viable, but not supported by funded research***

- Radix, USA, Radix Power and Energy Corporation
- TRIGA, USA, General Atomics
- Adams Engine, USA, Adams Atomic Engines

***International research design not likely to result in application for NRC license***

- ABV, Russia, OKBM Afrikantov
- Korean Fast Reactor Design (KFRD), South Korea, Korea Atomic Energy Research Institute
- BREST, Russia, RDIPE
- CAREM Pressurized Water Reactor, Argentina, CNEA & INVAP
- Pebble Bed Commercial Reactor HTR-PM, China, Institute of Nuclear & New Energy Technology (INET) at Tsinghua University north of Beijing
- Pebble Bed Demonstration HTR-10, China, Institute of Nuclear & New Energy Technology
- (INET) at Tsinghua University north of Beijing
- CNP-300 Pressurized Water Reactor, China,
- ELENA, Russia, Russian Research Centre “Kurchatov Institute” (RRC KI)
- High Temperature Test Reactor (HTTR), Japan, Japan Atomic Energy Research Institute (JAERI)
- System-integrated Modular Advanced Reactor (SMART), South Korea, KAERI
- VKT-12, Russia
- VKR-MT, Russia, Federal State Enterprises NIKIET and VNIIAM
- VK-300 Pressurized Water Reactor, Russia, Atomenergoproekt
- VBER-300, Russia, OKBM Afrikantov

- VBER-150, Russia, OKBM Afrikantov
- MRX, Japan, Japan Atomic Energy Research Institute (JAERI)
- SVBR-100, Russia, Rosatom/En+, Gidropress
- MARS, Russia, Russian Research Centre "Kurchatov Institute" (RRC KI)
- SAKHA-92, Russia, OKBM Afrikantov
- RITM-200, Russia, OKBM Afrikantov
- NHR-200, China, Tsingua University's Institute of Nuclear Energy Technology (now the Institute of Nuclear and New Energy Technology)
- Modular Transportable Small Power Nuclear Reactor (MTSPNR), Russia, N.A. Dollezhal
- Research and Development Institute of Power Engineering (NIKIET)
- UNITHERM, Russia, Federal State Enterprise NIKIET

***Obsolete reactor design unsatisfactory for commercial use due to safety, non-proliferation, or other issues,***

- SM-1A Fort Greely Reactor, USA, US Army
- EGP-6 Reactors, Russia,
- Big Rock Point, USA, Army
- PM-3A, USA, US Military
- MH-1A, USA, US Army

***Small scale designs not suitable for utility power***

- Radioisotype Thermoelectric Generator (RTG), USA, Teledyne Brown
- Rapid-L, Japan, Toshiba
- NASA Nuclear Sterling Engine for Lunar Base, USA, NASA