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Back to the Future: Small Modular Reactors, Nuclear Fantasies, and Symbolic Convergence

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Abstract

In this article, we argue that scientists and technologists associated with the nuclear industry are building support for small modular reactors (SMRs) by advancing five rhetorical visions imbued with elements of fantasy that cater to various social expectations. The five visions are as follows: a vision of risk-free energy would eliminate catastrophic accidents and meltdowns. A vision of indigenous self-energization would see SMRs empowering remote communities and developing economies. A vision of water security would see SMR-powered desalination plants satisfying the world's water needs. A vision of environmental nirvana would see SMRs providing waste-free and carbon-free electricity to preserve the earth's biosphere. A vision of space exploration would see SMRs assisting in the colonization of the moon, Mars,

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and possibly other worlds. These visions help create a symbolic convergence among promoters, serving to attract political and financial support, and erasing previous nuclear failures from public discourse. Moreover, underlying these visions is a technological utopian ideal world where SMRs would generate plentiful energy of multiple kinds (electricity and heat), offering the necessary means for a life of comfort for all people by meeting various needs (lighting, temperature control, drinking water, and provision of scarce minerals) and without any environmental externalities or cause for concern about accidents.

Keywords
energy policy, nuclear power, environmental practices, politics, power, governance

> If you want to build a ship, don't drum up the men to gather wood, divide the work and give orders. Instead, teach them to yearn for the vast and endless sea.
>
> Antoine de Saint-Exupéry, Aeronautical Explorer (Saint-Exupéry 1950, 13)

Introduction

When US President Franklin D. Roosevelt visited the Hoover Dam, he wrote "I came, I saw, and I was conquered" (Bocking 2009). Halfway across the world, Jawaharlal Nehru, the first Prime Minister of India, similarly remarked in 1954 that the Bhakra Nangal Dam Project "is something tremendous, something stupendous, something which shakes you up when you see it. Bhakra, the new temple of resurgent India, is the symbol of India's progress" (Bhakra Beas Management Board [BBMB] n.d.). These comments underscore how some technologies can elicit an almost religious feeling of sublimity (Nye 1994). They can provoke awe and wonder, capturing the imaginations and hearts of proponents in addition to their minds and pocketbooks (Khagram 2005).

In this study, we posit that many scientists and engineers are as fervent in their advocacy of the concept of small modular nuclear reactors, or small modular reactors (SMRs), as were presidents and prime ministers endorsing hydroelectric dams more than half a century ago. Talk about SMRs has become only louder after the nuclear accidents at Fukushima. After summarizing recent literature on the topic of expectations, fantasy, and technology, and utilizing symbolic convergence theory (SCT) to explain how group fantasies begin and evolve, we identify five distinct rhetorical visions of SMRs—risk-free energy, self energization, water security, environmental nirvana, and space exploration—found within the technical and scientific literature. We then show how these visions selectively recount the history of interest in SMRs, how they contradict one another, and how they differ from earlier fantasies.

The importance of our exploration is threefold. First, understanding the dynamics constraining or accelerating nuclear power reactors, as well as the epistemological assumptions underpinning the expansion of the industry, is essential to weighing its costs, benefits, and future role. Despite the Fukushima accidents, nuclear fission and new reactor designs continue to receive enormous research and development budgets in many countries. Second, our exploration of the fantasies surrounding SMRs illuminates current debates over energy security, technology, and policy—over the provision of reliable, affordable, safe, and environmentally benign energy services. Third, because no commercial SMRs have been built so far, they are almost entirely a rhetorical construction. Arguments over different kinds of SMRs therefore have much to do with contestations about visions and expectations, thus demonstrating the influence of fantasies on scientific and technical development.

Expectations, Fantasies, and Technology: Theoretical Concepts

There is a growing literature spanning several disciplines that addresses the topic of expectations, fantasy,[1] and technology. This research shows that technological fantasies will be *functional*, *utopian*, *contradictory*, and *selective*.

First, fantasies and visions are *functional* by fulfilling some perceived social need, and by enabling proponents to capture resources (Geels and Smit 2000). Expectations and promises about a new technology are thus "constitutive" and "performative" in "attracting the interest of necessary allies (various actors in innovation networks, investors, regulatory actors, users, etc.) and in defining roles and in building mutually binding obligations and agendas" (Borup et al. 2006). Such expectations serve to broker relationships between relevant social groups and create a dynamic of "promise and requirement" where actors make promissory commitments to the technology, forging a shared agenda that requires action (Borup et al. 2006). In this way, the functionality of a vision results in a "mandate" to developers and advocates: "the freedom to explore and develop combined with a societal obligation to deliver in the end."

Second, fantasies are frequently *utopian*, advancing a technology for its purported ability to bring about a society viewed as perfect (Segal 1994, 2005). These visions tend to be sharp and apolitical, presented by advocates as tools for societal enhancement rather than personal gain. Such visions involve experts tasked with constructing a particular technological world and also the imagination of appropriately behaved publics that are expected to live in it (Marvin 1988). These utopian elements of fantasies have led proponents and sponsors to exaggerate potential benefits and downplay risks of many different technologies (Corn 1988; Geels and Smit 2000; Berkhout 2006).

Third, fantasies are strategically *contradictory*. Part of this dimension relates to the manufactured ambiguity or flexibility of most fantasies: they need to be broad enough to enroll actors but vague enough to withstand criticism. Eames et al. (2006), for instance, have drawn from Van Lente (1993) to show how visions of a hydrogen economy contradicted each other. However, such contradictory elements can even be a strength: scenarios are malleable so that actors can build support from diverse quarters. This requires the avoidance of discussing all of the technical details because that may expose the contested nature of the activity. They instead focus on visions that keep boundaries and possibilities limitless, enhancing their flexibility as well as their rhetorical power (Selin 2007; Sovacool and Brossmann 2013; 2014).

Fourth, fantasies are also *selective*. That is, they choose what aspects of history to highlight and leave out potential challenges to their vision. This "rhetorical selectivity" (Peterson 1997, 34-53) extends beyond viewing a particular technological advance uncritically. It entails positioning a future transition as unique so that comparisons with previous technological transitions can be overlooked (since the impact of this particular technological utopia will be so great that prior situations have no relevance), and ignoring the paradox of relying on technology to solve problems brought about by earlier forms of technology.

Rather than being some latent or unintended side effect, much research has shown that fantasies and expectations are a key part of the process of technological innovation (Brown, Rappert, and Webster 2000; Borup et al. 2006). Fujimura's (2003) work has demonstrated how genomic scientists use "future imaginaries" to mobilize financial support for their research, and Van Lente (1993) has similarly shown that expectations of technology can motivate engineers and designers to initiate projects. Jasanoff and Kim (2009,

124) write about "socio-technical imaginaries" operating behind nuclear research in South Korea and the United States, and point out that national "imaginations can penetrate the very designs and practices of scientific research and technological development." Borup et al. (2006, 285-86) argue that expectations stimulate, steer, and coordinate action among actors as diverse as designers, managers, investors, sponsors, and politicians.

These four dimensions of technological fantasy—functionality, utopianism, contradiction, and erasure—are useful for predicting what particular visions of SMRs will say and do—and we will see examples of each of them in the analysis mentioned below. But they do not address the question of how these fantasies come to be shared. To answer this question, we turned to SCT, a general theory of communication that has its roots in psychology and the sharing of group fantasies. SCT looks at the collective sharing of fantasies and how group consciousness affects human action (Bormann 1972, 1982a; Bormann, Cragan, and Shields 1994, 2001; Cragan and Shields 1995). The theory accomplishes this goal by illustrating that fantasies have "communicative force," that is, they affect perpetually the consciousness of individuals, groups, and large publics, almost like "gravity." SCT posits that fantasy is an elemental part of being human, a force needed for humans to explain and interpret their experiences (Shields 2000). The theory holds that humans are storytellers and that when they share a dramatization of an event, they make sense out of its complexity by creating a script or narrative to account for what happened. This act of telling a narrative enables groups of people to come to a "symbolic convergence" about that part of their common experience (Vasquez 1993).

For SCT, "fantasy" refers to the way that communities of people share their social reality, a creative interpretation of events that fulfills a psychological and rhetorical need (Bormann 1982b). Fantasies, according to SCT, achieve their strength through the use of three critical elements: dramatis personae, symbolic cue, and rhetorical visions.

The first critical element, *dramatis personae*, is the set of characters who populate the narratives that form part of the shared fantasies. Unlike in real drama, these characters do not have to be humans but could also include nonhuman elements such as climate change which play key roles in constructing these fantasies.

Second, members subscribing to a particular fantasy theme will develop or reuse code words, phrases, slogans, or nonverbal signs and gestures. These *symbolic cues* trigger previously shared fantasies (Cragan and Shields 1992). The cues may refer to a geographical or imaginary place or the name of a person, and they may arouse tears or evoke anger, hatred, love, affection, laughter, and a range of other emotions. When a community comes to share a fantasy type, they will frequently respond to general statements cued by these symbols and recurring phrases.

Third, when groups share dramatis personae and symbolic cues, the result is often a larger narrative or discourse known as a *rhetorical vision*. That vision represents the consciousness of the fantasy theme's adherents, creating a rhetorical community with its own distinct worldview (Gunn 2003). Rhetorical visions can become so encompassing and compelling that they permeate a group's entire social reality (Bormann, Cragan, and Shields 1996).

Research Focus and Methods

This article explores how technological expectations and rhetorical visions are used to promote SMRs. The acronym SMR stands for two related terms. In the United States and in some other parts of the world, it stands for "small, modular reactors." The International Atomic Energy Agency (IAEA), on the other hand, uses the acronym to mean "small and medium-sized reactors." A "small" reactor is one having electrical output less than 300 MWe and a "medium" reactor is one having a power output between 300 and 700 MWe. Modular means that these reactors are to be assembled from factory fabricated modules, with each module representing a portion of a finished plant, rather than constructed on site.[2] In this article, we use SMR in both senses. SMRs in either sense have electrical power outputs substantially smaller than currently operating reactors or those under construction, with the exception of heavy water reactors that are typically smaller than light water reactors.

While the term SMR is widely used, it actually does not represent any one kind of a reactor. Rather, there are multifarious SMR designs with distinct characteristics being developed. These designs vary by power output, physical size, fuel type, enrichment level, refueling frequency, site location, and spent fuel characteristics. They are also in different levels of development, with some in the process of being constructed (e.g., the Russian KLT-40 floating power plant and the Chinese HTR-PM reactor), and others that still face major technical challenges unlikely to be overcome during the next decade. This multifariousness allows SMR advocates to claim multiple desirable characteristics for SMRs in general; these characteristics would not all be realizable in a single design (Ramana and Mian 2014).

We adopted a specific schema to analyze how SMRs are conceived and described. Because our goal was to identify the prevalence of fantasies among practicing scientists and engineers, we focused our literature review on academic and technical articles. This approach is similar to methodologies employed by McDowall and Eames (2006) and Sovacool and Brossmann (2010) to illustrate visions articulated by advocates of the hydrogen economy. For simplicity (and because both of the authors speak only English proficiently), our study was limited to English publications only.

We recorded visions of SMRs as articulated by their proponents in two sets of literature: peer-reviewed energy and nuclear power journals, and IAEA publications. We identified peer-reviewed academic studies by searching the ScienceDirect database for the phrase "small modular reactor" in a study's title, abstract, or key words published from January 2002 to September 2012. We chose ScienceDirect because it is home to most of the scientific journals dealing with nuclear power, including the *Annals of Nuclear Energy*, *Annals of Nuclear Science and Engineering*, *International Journal of Radiation Applications and Instrumentation*, *Journal of Nuclear Energy*, *Journal of Nuclear Materials*, *Nuclear Physics*, and *Progress in Nuclear Energy*, among others. Our initial search identified sixty-seven articles, of which forty-two were actually about SMRs for the power sector and thirty-four articulated some type of rhetorical vision.

To supplement these articles, we collected thirty-eight reports published from 2004 to 2012 by the IAEA. We chose the IAEA because, with more than 100 member countries and a staff of 2,300 professional personnel, it represents "the world's central intergovernmental forum for scientific and technical co-operation in the nuclear field."[3] The inclusion of IAEA documents gives our pool of studies a more "global" character representative of the multitude of countries currently pursuing SMR research.[4] Of these thirty-eight reports, twenty-six articulated some type of rhetorical vision in association with SMRs. Figure 1 depicts our sampling process.

Our final sample of sixty articles is available from the authors on request. Academic studies tended to come from the technical literature on nuclear energy, notably journals such as *Nuclear Engineering and Design* and *Progress in Nuclear Energy*. These articles were written predominately by authors affiliated with universities, energy companies, consulting firms, and government-sponsored research laboratories. While their institutional affiliations represented ten countries, 29 percent had primary authors from the United States. Multiple publications were also from institutions in France, Japan, Russia, and South Korea, implying that visions of SMRs, and

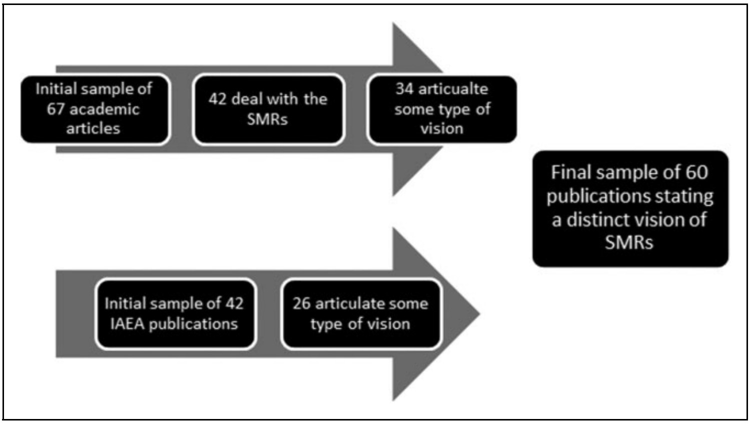

Figure 1. Literature selection process for academic and International Atomic Energy Agency (IAEA) small modular reactor (SMR) studies.

not just technology development programs, are widespread. Publications from the IAEA also featured authors from several countries.

Five Fantastic SMR Visions

Though nuclear engineers have talked about SMRs since the 1950s, the current wave of interest dates back to the early 2000s. The problem, as laid out by analysts from the IAEA's Department of Nuclear Energy, was that "quite simply, over the last 15 years, nuclear power has been losing market share badly in a growing world electricity capacity market" (Mourogov, Fukuda, and Kagramanian 2002, 286). Their diagnosis: "we, in all our doings, continue to rely on nuclear technology developed in the 1950s, which had its roots in military applications which cannot exclude absolutely the possibility of a severe accident and which has reached its limits from an economic point of view" (Mourogov, Fukuda, and Kagramanian 2002, 292). As the way forward, these analysts suggested developing innovative new reactor designs, chiefly of the SMR variety. Since then, the discourse about SMRs has moved from these characteristics being "desirable" to the claim that they will definitely be "achieved."

The idea of developing SMRs has secured support from a multitude of individuals and organizations for a variety of reasons. Our sample of SMR literature depicted diverse rhetorical visions, ranging from cost competiveness with existing sources of energy, the jobs and technological

Table 1. Five Rhetorical Visions Associated with Small Modular Reactors (SMRs).

Rhetorical Vision	Description	Dramatis Personae	Symbolic Cues
Risk-free energy ($n = 43$)	Produce energy with perfect reliability and complete safety	Improperly trained and error-prone human operators as well as terrorists and potential saboteurs seeking to cause nuclear catastrophes, natural disasters	"Passive safety," "inherently safe," "sure protection," "safety by design," and "operator free"
Indigenous self-energization ($n = 24$)	Provide energy autonomy and self-determination for remote areas and developing countries	Those without access to modern energy services, rapid population growth	"Remote village communities," "limited grids," "unsophisticated grids," and "just-in-time capacity growth"
Environmental nirvana ($n = 22$)	Deliver clean and plentiful electricity in a carbon constrained future	Climate change and environmental degradation as well as the difficulty of storing nuclear waste	"Waste-free energy," "carbon free energy," and "zero carbon energy source"
Water security ($n = 21$)	Desalinate water needed to avert global water crises	People living in water stressed and water scarce areas	"Universal access to water," "nonelectric markets," and "process heat applications"
Space exploration ($n = 2$)	Explore space and interstellar propulsion	Scientific curiosity, resource depletion	"Lunar outputs" and "Mars mission"

learning that would accompany mass production of SMR units, the ability to undertake "advanced oil recovery" through unconventional reserves such as oil shale and tar sands, large-scale hydrogen production, and the creation of process heating for chemical and manufacturing processes, among others.

In this section, we focus on the five visions that stood apart from the rest. Table 1 shows the specific elements of each of these rhetorical visions. The most popular vision concerned risk-free energy (presented in forty-three studies) followed by self-energization (24), environmental nirvana (22), water security (21), and space exploration (2).

As predicted, each of the overarching dimensions of functionality, utopianism, contradiction, and erasure appears in the visions, as well as the three elements of SCT (dramatis personae, symbolic cues, and rhetorical vision). While functionality is apparent in almost all the articles we analyzed, utopianism is an underlying ideal behind each vision. In this ideal world, SMRs would generate plentiful energy of multiple kinds (electricity and heat), providing the necessary means for a life of comfort for all people by meeting various needs (lighting, temperature control, drinking water, and scarce minerals) with no environmental externalities or cause for concern about accidents. Contradiction and erasure are not as obvious but do exist between various objectives and visions, and much history is erased through a process of "selective remembrance," which we will discuss at a later point in the article.

Risk-free Energy

By far the most prevalent rhetorical vision concerning SMRs, present in more than 60 percent of our sampled studies, relates to their ability to generate energy without risk. Dramatis personae for this vision are natural disasters, improperly trained human operators, and would-be terrorists and saboteurs. The most prominent symbolic cue of SMRs being "inherently safe" was mentioned in more than a dozen studies within our sample. Given the heightened concerns about nuclear accidents following Fukushima, the functionality of this vision is obvious.

The risk-free energy vision begins by acknowledging that existing nuclear power plants are prone to accidents from a variety of causes above and beyond those that have already occurred such as Three Mile Island (operator error), Chernobyl (a mishandled safety test), and Fukushima (an earthquake and tsunami). They can be caused by "internal events," such as rupturing pipelines, blocked valves, and malfunctioning equipment, as well as "external events," such as flooding, heatwaves, and severe storms (Kuznetsov 2007; IAEA 2006a).

Proponents of the risk-free SMR vision comment that ensuring adequate safety at these existing plants is impossible, with reactor safety and control limited by the "confined capability of the first nuclear power plant generations to withstand severe accidents" (Slessarev 2007, 884). Authorities, in other words, have been "obliged" to "compromise" safety standards due to inferior technology. SMRs, by contrast, can benefit from a "fresh safety strategy"—in essence, the functional element of the vision—that provides "sure protection against all severe accidents." SMRs focus on "eliminating by design the possibility for an accident to occur, rather than dealing with its consequences" (Filho 2011, 2332) and possess "inherent safety properties (deterministic elimination of severe accidents) that ... assure a high level of social acceptability of the nuclear plant" (Zrodnikov et al. 2008, 178).

The symbolic cue, "inherent safety" is usually justified by invoking some combination of passive safety features or multiple defensive barriers. Specifically, SMRs can feature "larger reactor surface-to-volume" ratios, operate at lower power densities, have lower fuel inventory, and can be placed underground; all these properties, it is argued, reduce the chances of an accident and contain its impacts should one occur (IAEA 2007a, 86)

This risk-free energy vision is pervasive and affirms the utopian dimension of the fantasy. Chinese researchers argue that design features in SMRs allow them to "solve" the accident problem and "make sure" that "reactors will not melt" (Zhang and Sun 2007, 2265). A Russian research team speaks of "inherent self-protection" and "passive safety," pointing to calculations indicating that "no other potentially realized scenarios of accidents which can result in hazardous consequences have been found" (Zrodnikov et al. 2011, 241). Japanese researchers assure us that their SMR design's chosen "configuration [makes] the plant system drastically simple ... eliminating accidents which cause fuel failure" (Hibi, Ono, and Kanagawa 2004, 254). A South African research team writes about "inherently safe design" which "renders obsolete the need for safety back-up systems and most aspects of the off-site emergency plans required for conventional nuclear reactors" (Wallace et al. 2006, 446). An American nuclear engineer writes that SMR designs have "eliminated accident vulnerabilities" (Ingersoll 2009, 592).

Indigenous Self-energization

The second most popular rhetorical vision among our sample espouses SMRs as a way to empower communities and emerging economies with energy autonomy and self-determination. This vision, its functionality and utopian dimensions, takes many forms: as SMRs being suitable for rapidly developing economies, such as those in Brazil, China, and South Africa; as vital for the needs of developing countries with small electrical grids and unsophisticated infrastructure, such as East Timor or Zanzibar; as key to electrifying small off-grid villages, towns, and islands like sparsely populated places such as the Aleutian Islands or Papua New Guinea; and as supplying energy to off-grid mining villages like those in Mongolia and Australia (Choi et al. 2011, 1498). Dramatis personae for this vision, independent of its variants, are those without access to modern energy services afflicted by energy poverty and rapid population growth. Symbolic cues include phrases such as "remote village communities" and "just-in-time capacity."

The best articulation of this vision comes from the IAEA itself. The organization states in their flagship *Nuclear Technology Review* that (IAEA 2007a, 93-94) "SMRs could meet the needs of these emerging energy markets where the industrial and technical infrastructure is generally poor." Vladimir Kuznetsov (2008, 2) from the IAEA's Nuclear Power Technology Development section writes:

> The role of SMRs in global nuclear energy system could then be to increase the availability of clean energy in a variety of usable forms for all regions of the world, to broaden the access to clean and affordable and diverse energy products and, in this way, to contribute to the eradication of poverty and, subsequently, to peace and stability in the world.

The IAEA states that Russian nuclear designers have even developed reactors that can be "barge-mounted, complete power plants which can be towed from the factory to a water accessible site, moored in a pre-prepared lagoon, and connected to a localized grid" (IAEA 2007b, 65). These designs, we are assured, "could support electrical needs for off-grid towns of up to several hundred thousand populations," and "are also properly sized for support of industrial operations at remote, water-accessible locations." Similar visions have been articulated by researchers from UC Berkeley (Vujić et al. 2012) and Oak Ridge National Laboratory (Ingersoll 2009).

Some engineers and manufacturers are so confident in the functionality of this vision that they are building SMRs explicitly for developing countries without well-developed electricity infrastructures. One prototype, cleverly called SUstainable Proliferation-resistance Enhanced Refined Secure Transportable Autonomous Reactor (SUPERSTAR), is "intended for international or remote deployment" and sized with smaller power levels to match the "smaller demand of towns or sites that are either off-grid or on immature local grids, being right-sized for growing economies and infrastructures of developing nations" (Bortot et al. 2011, 3021).

Environmental Nirvana

The third most frequent rhetorical vision, one of environmental nirvana, depicts SMRs as a "low-carbon" or "no-carbon" energy option that can produce energy cleanly without waste. The compelling, functional, utopian narrative behind this vision includes all of the calamities to be expected with impending climate change and the destruction of the environment, including rises in sea level and more frequent storms, as well as the difficulties of storing nuclear waste that remains hazardous for millennia. Symbolic cues for this vision include terms such as "waste-free" and "zero carbon" energy.

This vision is particularly influential because it takes two of the most common reasons for opposing nuclear power—its poor environmental record and its legacy of long-lived radioactive waste—and turns them into advantages. Studies from our sample posited that the issue of nuclear waste represented a "painful point" for the industry (Slessarev 2008, 636), and the nuclear industry's "future has been clouded" by, inter alia, the "challenges of radioactive waste disposal" (Kessides 2012, 187).

SMRs, by contrast, are claimed to offer the ability to tackle these challenges and avert environmental destruction. Academic studies stipulate that that "[SMRs] can play a very significant long-term role for meeting the world's increasing energy demands, while simultaneously addressing challenges associated with global climate and environmental impact" and that "renewed interest in SMRs is driven by low carbon" (Vujić et al. 2012, 288; Shropshire 2011, 299). The IAEA (2006b, 39) advocates using "innovative SMRs" outside the electricity sector as well because they "could help minimize not only the emissions associated with electricity generation but also those arising from the heat and motive power production by fossil fuel combustion."

Some SMRs offer the vision of waste-free energy. One study states, the "elimination of long-lived radioactive wastes" could be "quite realistic" with SMRs, leading to a "long-lived waste free strategy" (Slessarev 2008, 637). In parallel, the final report of an IAEA-coordinated research project declared that SMRs can entirely "eliminate the obligations of the user for dealing with fuel manufacture and with spent fuel and radioactive waste" (IAEA 2010, 6). These claims promote SMRs because long-lived radioactive waste is arguably the Achilles' heel of nuclear power, but as discussed below, this functionality comes at the cost of making it more difficult to meet other goals.

Water Security

The fourth most frequent rhetorical vision sees SMRs as instrumental in alleviating global water shortages for billions of people. As the IAEA (2007c, 34) succinctly states, "the desalination of seawater using nuclear energy is a feasible option to meet the growing demand for potable water." Dramatis personae for this vision are people living in water stressed or water scarce areas, and symbolic cues include phrases such as "non-electric markets" and "process heat applications" for SMRs.

The best example of this vision, again, comes from IAEA publications, which note that nuclear desalination has existed for about five decades but has not yet achieved wider application. Their hope is that SMRs will push nuclear desalination into the mainstream as *the* solution to global water scarcity. Even those outside of the IAEA have become enrolled in this vision, with one study commenting that "the continuous increase in the world's population and decrease in fresh water resources ... *dictates the necessity* to develop [SMRs] for both electricity and fresh water production. (our emphasis)" (El-Genk and Tournier 2004, 512).

Manufacturers have endorsed this vision as well, modifying SMR designs to allow for desalination as well as electricity generation. South Korea, for instance, is working on a 330 MWt reactor whose design has been recently certified (Subki 2012). Its developers market it as a small nuclear reactor for "diverse utilization" that includes not just "seawater desalination" but also "power generation, district heating, and ship propulsion" (Lim et al. 2011, 4079). In Indonesia, the IAEA (2005, 89-96) has sponsored a "technical cooperation project" to examine the "economic viability of construction of a nuclear desalination plant ... to support industrialization of the Madura Region." Russian scientists are working on an SMR to be used as a "small-to-medium power source" for "floating nuclear power plants or desalination complexes" (IAEA 2006b, 64).

Space Exploration

The final SMR vision within our sample, albeit rare, is perhaps the most fantastic. It argues that SMRs, in this particular case "fast spectrum space reactors," are needed to operate interstellar ships traveling with robots to Mars and beyond (Hatton and El-Genk 2009, 93–94). Another article describes the Refueling by All Pins Integrated Design (RAPID) sodium cooled reactor that generates 10,000 kWt (1,000 kWe), an "operator-free fast reactor concept designed for a lunar based power system" (IAEA 2007b, 469). The primary narrative and storyline relates to the human need to explore and discover the universe and to conduct scientific experiments, with terms such as "lunar outpost" and "Mars mission" serving as symbolic cues. The erection of lunar outposts is motivated as necessary for "industrial activities, such as the recovery of minerals, indigenous resources and the production of propellant for subsequent travel to Mars;" essentially tying SMR development to the colonization of other planets (Hatton and El-Genk 2009, 93).

This vision affirms the value of "compact and lightweight nuclear reactor power systems ... supplemented by photovoltaic arrays" for the energy needs of ships, space stations, and extraterrestrial outposts on places such as the Moon and Mars. One study contends that SMRs are a far better option than solar arrays since "compact nuclear reactor systems for surface power represent a significant saving in the launch cost and operate continuously, independent of the sun, for more than 10 years without refueling and with no or little maintenance." The SMRs advocated by these authors, we are guaranteed, are safe if launches do get aborted and units end up being submerged in wet sand or flooded with seawater because of various design features, thus preempting the most obvious argument against the use of nuclear reactors in space.

This rhetorical vision would see SMRs enabling the US National Aeronautics and Space Administration to achieve its "Vision for Space Exploration," calling for a lunar outpost on the moon to serve as the home for five to ten astronauts who would then perform tests on the moon's surface. At a later stage, SMRs would enable the outpost to be expanded to support more elaborate experiments, a greater number of personnel, and the beginning of industrial activity such as the mining of moon minerals and the creation of propellant for future travel to Mars. "Robotic missions to the moon" and to "Mars and beyond," the authors comment, "would require electrical and thermal powers in the order of tens of thousands of kilowatts 24/7, which can be provided using compact and lightweight nuclear reactor power systems as the primary energy source" (Hatton and El-Genk 2009, 93).

Selective Remembrance, Contradiction, and Novelty within SMR Visions

As expected from the theoretical literature, there are multiple contradictions, tensions, and trade-offs inherent in the five SMR visions mentioned previously, and the use of SMRs to achieve their diverging goals. This section points to the inherently flexible nature of rhetorical visions, perhaps strategically so. It indicates that some visions contradict others and that particular visions succeed only through the exclusion of others. It also confirms that no single rhetorical vision is universally persuasive or subscribed to by a majority of advocates.

Selective Remembrance

Even while SMRs are often described as “new” technologies, there is a long history of their development, one occasionally recounted but all too often ignored by proponents. Because SMRs have not materialized in the past despite substantial investment, it is easy to see why this history and these promises are subject to erasure, or “selective remembrance.” Indeed, in our data set, only one article, namely Ingersoll 2009, presented any discussion of the history surrounding the SMR concept. While the current literature on SMRs does, at times, mention the first wave of interest in the 1950s, and the eventual move to large reactors due to economies of scale, there is no discussion of how a second wave of enthusiasm about SMRs that was prevalent in the 1980s[5] resulted in no reactors with such designs being constructed. This erasure implies that there is little critical discussion about the challenges to successful implementation of the technology.

Moreover, SMR visions erase many problematic environmental and economic attributes of the technology. One form of selective remembrance is inherent in the vision of environmental nirvana and the use of SMRs to achieve that state. SMR advocates, and proponents of nuclear energy in general, portray climate change as the only environmental problem, paying little attention to other environmental and ecological concerns (such as the impacts of uranium mining and the loss of coastal biodiversity due to brine releases from desalination).

An additional type of erasure involves downplaying, or “erasing” and “selectively presenting,” data about the cost and economic competitiveness of SMRs. This has been a problem for nuclear power in general and is likely to be exacerbated in the case of SMRs. The most important component of the cost of generating electricity from nuclear reactors is the cost of constructing the facility itself (Ramana 2009). Current “overnight construction costs”[6] for the standard sized reactors (roughly 1,000 MWe) are in the range of US$3,000 to US$7,000 per kW of capacity. The general rule of thumb governing capital costs of production facilities is known as the 0.6

power rule (National Research Council 1996, 421). That is, the capital costs of two plants of size S_1 and S_2 are related as:

$$\frac{K_1}{K_2} = \left(\frac{S_1}{S_2}\right)^{0.6}.$$

This implies that, all else being equal, an SMR with a power capacity of 200 MW would be expected to have a construction cost in the range of US$5,700 to US$13,000 per kW of capacity. This increased price directly translates into a higher cost per unit of electricity generated. SMR proponents are forced to challenge this conclusion by claiming that differences in reactor designs invalidate any comparison with traditional reactor costs (Carelli et al. 2010; Locatelli and Mancini 2011).

Contradiction

SMR advocates regularly elide over how the technical requirements for meeting some particular visions will exclude, or make more difficult, the possibility of realizing others. For instance, the expense of investing in the safety features of SMRs (needed to meet the risk-free vision) makes it difficult to meet the vision of indigenous self-energization. Ability to pay is the main obstacle confronting governments and private companies trying to provide electricity for the hundreds of millions of people who do not currently have access to it. Low cost is, therefore, a vital consideration in trying to design electricity sources to meet their needs. The expected high cost per kWh implies that SMR generated electricity will likely be unaffordable to the target population touted in the indigenous self-energization vision.

There is a similar contradiction between the visions of indigenous self-energization and environmental nirvana. The strategy advocated by the publication that postulated SMRs as a viable route for the "elimination of long-lived radioactive wastes" is through the use of the transmutation of radionuclides with long half-lives. There are technical problems with transmutation and it is impossible to eliminate all troublesome isotopes. More to the point, however, is the enormous cost of this approach; the US National Academy of Sciences estimated that the additional cost of transmuting the nuclear waste in the United States was "likely to be no less than $50 billion and easily could be over $100 billion" (National Research Council 1996, 7). While these estimates are for a national program of transmutation, they do translate into significant increases in the cost of electricity.

The risk-free and indigenous self-energization visions also contradict in other ways. SMRs attempt to lower the risk of radioactivity release to the atmosphere from a reactor accident by constructing reactors underground, but this increases construction cost. For example, a study from Canada showed a 31 to 36 percent increase relative to an equivalent surface facility, and warned about "potentially more difficult construction and operating procedures" (Oberth and Lee 1980, 711). The SMR literature pays little attention to these problems.

Another contradiction between the risk-free energy and environmental nirvana visions results from the use of smaller reactors that have a higher ratio of surface area to volume than do larger reactors. This lowers the risk of fuel meltdown, but would cause some SMRs to use more uranium per unit of electrical energy generated than standard-sized nuclear reactors (Glaser, Hopkins, and Ramana 2013), increasing the environmental impact of uranium mining. It also implies that a greater quantity of radioactive spent fuel will be generated for the same amount of energy, achieving safety only at the expense of the "waste-free" vision.

Similarly, the uranium intensity of SMRs creates a tension between the risk-free energy and water security visions to the extent that more water is needed for uranium mining, enrichment, reprocessing, and storage. Moreover, SMR advocates overlook not only the environmental consequences of nuclear waste management and uranium mining, they seldom discuss the environmental consequences of the production of brine during nuclear desalination. The marine environment often provides food and livelihood for rural communities and the expulsion of brine into the sea threatens the flora and fauna near the those outlets for cooling cycles (Drami et al. 2011; Meerganz von Medeazza 2005).

Novelty and Hybridization

Even though they typically neglect to mention history, many of the visions for SMRs have an element of continuity with previous rhetorical visions. Despite the apparent novelty of the space exploration vision, even it existed historically. For instance, Krafft Ehricke, a German V-2 rocket scientist, told the US Joint Committee on Atomic Energy in 1960 that "the universe is run by nuclear energy. Space will be conquered only by manned nuclear-powered vehicles" (Mahaffey 2010, 277).

There are, however, three reasons why post–2000 rhetorical visions differ from their predecessors. One factor distinguishing the "new" SMR vision from the "old" is the urgency of climate change. The dire impacts of a likely increase in global temperature have led to widespread hope for some technological miracle to deliver the world from its catastrophic predicament. But nuclear power has been seen—rightly in our opinion—as expensive, susceptible to catastrophic accidents, and associated with undesirable externalities such as the production of weapons-usable fissile material and long-lived radioactive waste. In this scenario, the multiple rhetorical visions put forth by SMR designers and advocates, understandably, offer a great allure, both to themselves and a wider public.

A second "new" factor involves the vision of offering electricity to countries where significant sections of the population currently lack access. The potential role for nuclear power in these developing countries has become particularly important in the last decade or so as the contest between the industrialized and developing countries over responsibility for emissions and allocation of ecological space has driven climate negotiations to a stalemate. Many have realized the necessity of developing countries controlling their fast-growing emissions through low-carbon sources of energy. Therefore, if nuclear power is to meaningfully mitigate greenhouse gas emissions, then it must expand dramatically in these countries, many of which do not have any nuclear power capacity at the moment. SMR advocates posit that unlike traditional reactors, SMRs are capable of expanding in these countries rapidly.

A third "new" factor is the recent improvement in economic competitiveness of renewable energy technology, including tremendous decreases in the price of wind and solar power. Further, countries like the United States have seen a dramatic drop in the price of natural gas as a result of increased production through hydraulic fracturing. Research across many cultures and communities indicates that the public overwhelmingly prefers to reduce emissions by expanding renewable energy and natural gas rather than increasing nuclear power production (Pidgeon, Lorenzoni, and Poortinga 2008; Ertör-Akyazı et al. 2012). The nuclear industry is therefore in a tight spot and a new multifaceted vision, such as the one offered by SMRs, may be seen as necessary for its survival.

Other studies hybridized separate rhetorical visions into something new or gave their visions a distinct cultural twist. One IAEA report (2012, 2) combined concerns about climate change, the environment, and water desalination. Another report (2007b, 183, 479) fused the "risk-free" and in front of "self-energization" fantasies together by noting that SMRs in developing countries could be operated remotely, eliminating "human errors in the reactor operation." In Mongolia, SMR proponents merged the environment and self-energization themes when they argued that "using nuclear energy can be one of the ways to satisfy increasing energy demand and to solve the air pollution issues in Mongolia" (Sambuu and Obara 2012). In Russia, widespread uses of SMRs for electric heating were depicted as ensuring "fossil fuel and power-independence" (a vision of self energization) as well as "replacement of fossil fuel power sources" that have become obsolete due to environmental concerns (a vision of environmental nirvana; Zrodnikov et al. 2011). In the United States, SMRs are sold for their "excellent safety and performance record" (a vision of risk-free energy) and a growing concern for the "environmental impacts of fossil fuels" (a vision of environmental nirvana; Ingersoll 2009).

Conclusion

The nuclear industry and its attendant institutions, including sections of academia and the IAEA, have created a number of rhetorical visions related to SMRs, in turn propelling a symbolic convergence among promoters, political leaders, and financial investors. Practically all of the articles in our sample are about the abstruse technical details of SMRs. Yet they feature rhetorical visions promising a future replete with safe reactors, generating clean electricity and accelerating economic growth, offering universal access to drinking water, enabling a more sustainable climate and environment, and making possible the establishment of outposts on the Moon, Mars, and "beyond." Underlying these specific visions is a more general utopian fantasy, a society that requires and provides increasing and abundant quantities of energy indefinitely into the future.

The question that might—should—be asked is "why?" Why does a technical paper on, say, alkali metal thermal-to-electric static converters—electronic components that help generate electricity without rotating machinery—have to start with a statement on the energy challenges of "populations in underdeveloped countries and in small remote communities," move on to discussing the details of how some reactors may be "factory-assembled and shipped by rail or on barge" and then cover the possibility of using these reactors for desalination (El-Genk and Tournier 2004)? To explain the inclusion of sections like these, we turned to SCT. The theory explained how the elements of dramatis personae, symbolic cues, and rhetorical vision facilitate the sharing of fantasies by collections of individuals, such as the authors of the article on static converters, as well as the 111 other instances of visions we found across a sample of sixty academic and technical studies. The effectiveness of these visions is seen not just in the many instances of references to fantasies in the data set we examined, but also in the larger energy and climate debate. We see, for instance, leading climate scientists like James Hansen making a case for nuclear power on the basis of claimed advantages that are parallel to, if not exact copies of, the fantastic elements of the SMR vision.[7]

The types of fantasies associated with SMRs satisfy the human need to experience and interpret drama and enable people to feel positive about the future. They may also divert attention from the many problems confronting commercialization of the dozens of SMR concepts that have been put forward for some decades now. Though each of the five rhetorical visions identified in this study have various supporters, arguments, narratives, symbolic cues, audiences, functions, utopias, and degrees of frequency, we believe their presence nonetheless has four broader implications.

First, for SMR advocates, our study reveals that there is no common, single vision of what SMRs can accomplish. Instead, as predicted by the literature, such visions are full of contradictions, erasures, and tensions. There are competing, at times overlapping visions, not all of them consistent, some of them part of larger visions that cut across a variety of nuclear technologies. Rather than carefully or systematically analyzing the promise and perils of SMRs, most proponents view them to advance their own agendas. The complex history behind SMRs is thus "erased" in exchange for more narrow or powerful narratives that serve the vested interests of particular stakeholders.

Our second conclusion is that, for the nuclear renaissance, the visions we've identified with SMRs may accentuate why nuclear power has so much appeal for policymakers and mass publics. It suggests that challenges toward next generation reactors, including SMRs, may be severely discounted in the wake of the much more powerful and compelling fantasies associated with what nuclear technology can someday accomplish. Sponsors start to think of them in the "future tense" (Byrne and Hoffman 1996). SMRs are particularly endearing because there are so many different designs available to satisfy the public's imagination but can all be referred to with just one name. Moreover, statements about SMR commercialization present the future as a predetermined extension of current events. This has the effect of disguising a degree of social choice in energy planning, presenting an SMR future as inevitable instead of the result of strategic decisions and social practices. The fantasy thus becomes even more compelling since it involves little to no sacrifice, and minimal effort on the part of the public.

Our third conclusion is that, for scientific practice, our study affirms that scientists and engineers are not immune to drama and fantasy and that they can become "infected" with rhetorical visions—a symbolic convergence—that cause them, in their excitement, to lose their scientific precision. Most of our sampled documents were exceedingly technical, yet contained unscientific language indicating, for instance, that accidents can be "solved" and "eliminated" rather than the more accurate terminology that their probabilities can be lowered or that safety can be "enhanced" or "improved." Such claims are reminiscent of the early years of the nuclear age, such as the now infamous "too cheap to meter" prediction by US Atomic Energy Commission Chairman Lewis Strauss, which later had to be "explained away." As David Lilienthal (1963, 109-10), former chair of the US Atomic Energy Commission put it: "We were grimly determined to prove that this discovery [of atomic energy] was not just a weapon. This led, perhaps, to wishful thinking."

Fourth, for those concerned with the rhetoric of technology as well as energy planning and policymaking, our study suggests that SMR visions have such appeal because they satisfy an underlying functional need, despite their distinctive or contradictive attributes. In recent decades, it has become clear that the current economic paradigm has run up against environmental limits. For the system to continue in a business-as-usual fashion, it needs to find sources of energy that emit low quantities of carbon, are risk-free and virtually inexhaustible. In addition, as natural resources become scarcer, the possibility of exploring outer space seems the next obvious source of material abundance. The rhetoric involved in achieving the "five fantastic SMR visions" identified in this study is not intrinsically tied to SMRs themselves, but rather to different social, economic, and environmental functions that the reactors are believed to be capable of realizing. This should not be surprising, given Ernest Wrage's (1947) argument that rhetorical artifacts are not only engines, but mirrors through which society reflects its priorities. Rather than "manufacturing" the social need for inexhaustible, risk-free, environmentally benign energy, the advocates of SMRs are likely responding to it. This means that energy technologies, and indeed all types of technology, may be chosen not only because of their utility—the ability to produce kilowatt hours or desalinated water—but also because they capture imaginations, confirm an ideology, or fit with a particular blueprint about the future. Ultimately, the need to experience these types of fantasies will likely remain even if SMRs never reach commercialization and fail to spread beyond a few boutique, subsidized experiments.

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Notes

1. Our use of the term "fantasy" is very precise: it is not to be mistaken for something that is imaginary (like ghosts or aliens), pejorative (signifying someone that is insane), sexual (as in erotic fantasies), or distinct from reality (like Lord of the Rings).
2. Modularity is also used to indicate the idea that rather than constructing one large reactor, the equivalent power output will be generated using multiple smaller reactors.
3. International Atomic Energy Agency, "About Us," http://www.iaea.org/, accessed September 5, 2012.
4. As the IAEA (2009, 2) summarized, "recently, more than 50 concepts and designs of such innovative SMRs were developed in Argentina, Brazil, China, France, India, Japan, the Republic of Korea, Russian Federation, South Africa, and the USA."
5. See IAEA (1985), Department of Energy (1988), and Konstantinov and Kupitz (1988) for accounts of SMR interest during the 1980s.
6. This refers to the inherent cost of a construction project not inclusive of the interest incurred during the building process.
7. A recent letter by Hansen and colleagues offers an illustration: "We understand that today's nuclear plants are far from perfect ... Fortunately, passive safety systems and other advances can make new plants much safer. And modern nuclear technology can reduce proliferation risks and solve the waste disposal problem by burning current waste and using fuel more efficiently" (Top Climate Change Scientists' Letter to Policy Influencers 2013).

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