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Before the Subcommittee on Energy
U.S. House of Representatives Committee on Science, Space and Technology
May 13, 2015

Thank you, Chairman Weber, Ranking Member Grayson, and other Members of this Subcommittee, for holding this hearing on this important subject. I believe, as many others do, that it is important to the future national security, energy security, and environmental quality of the United States (U.S.) that ample supplies of competitively priced nuclear energy are available.

Unfortunately, it appears that nuclear energy is dying in the U.S.: there are few new plants being built, several have closed recently, and most of the 99 existing plants will be closed down within the next 40 years. To place this in context, last year nuclear energy consumed by our citizens represented 20% of U.S. electricity supply worth $80B. It also appears that the few plants being built require special regulatory arrangements because they cannot compete head-to-head on the numbers with other energy sources.

We believe this future scenario can be avoided, but it will require active involvement and investment by the U.S. Government. Why? The energy market is indicating that existing nuclear power technology (Light Water Reactors [LWRs]) is not commercially viable. For nuclear power to play any future role, the U.S. will need new nuclear power technologies that will produce significantly cheaper electricity, while ensuring public safety.

However, the private sector will not be able to develop these on its own. The investments required are very large, they are risky, and in any event will take more than a decade before they might yield any revenue from electricity production, and even longer to yield any profit. As these new technology options are developed, and private firms begin to see their way to risk reduction and making profits, private investment will increase, the government will be able to withdraw, and the market will decide which would be commercially viable.

Let me now discuss General Atomics' interest in a new advanced test reactor. We have a new reactor concept we call Energy Multiplier Module (EM^2). We specifically designed it to address the four most prominent concerns with nuclear power—its cost, its waste, its proliferation risk, and the post-Fukushima safety risk. We believe that EM^2 can significantly reduce the cost of nuclear power, and dramatically reduce the amount of waste a plant produces, while at the same time doing it safely with less proliferation risk. We believe it is a potential breakthrough technology for the U.S.; however, research is required to realize it.

To develop EM^2, a compact gas-cooled fast reactor, we looked at what physics indicates we must do: 1) go to high power densities through a compact reactor core utilizing fast neutrons; and 2) go to higher temperatures so a higher percentage of the heat produced is turned into electricity (efficiency). By doing this we can make the same amount of electricity in a much smaller reactor—small enough that it could be made in a factory and shipped by truck to a site for deployment. There are a number of prominent companies that are also advocating the use of fast neutrons and going to higher temperatures albeit with different advanced reactor designs. These also require research.

We believe we could increase the efficiency of electricity production from the lower 30s percentages in LWRs to the lower 50s – so a new reactor would only have to produce two thirds of the heat produced by a LWR to produce the same power output. We believe we could reduce the cost of electricity by up to 40% below that of existing nuclear reactors, and reduce the waste to be disposed of by up to 80%.

But to do this, we have to develop NEW materials that will be able to endure the much higher temperatures, AND endure the more energetic and neutron rich radiation environment inside the reactor. We need a new testing facility with high performance characteristics in which to do this research work.

But this is also true of all other firms and national laboratories that have other ideas and designs: all of them also need a new testing facility that could conduct tests in, say, three years that would represent what happens to these materials in an actual advanced reactor for a period of 30 years. This type of facility would dramatically increase research productivity and hence dramatically accelerate the development of new advanced nuclear technologies.

It would not make business sense for any company, or even all interested companies together, to pay for the capital costs to construct such a facility, given the large investment, the risks and the long lead times involved for return on investment.

Currently, there is no U.S. facility with the requisite high performance characteristics to do this type of research. The best we have are the Advanced Test Reactor in Idaho National Laboratory, and the High Flux Isotope Reactor in Oak Ridge National Laboratory, but neither is appropriate for a number of reasons. The best in the world is in Russia (BOR-60), but this is being shut down soon for other reasons. In any event, it would seem odd to develop such a national security technology in Russia.

Therefore, we suggest that you consider building such a facility in the U.S. It could be called the Versatile Advanced Test Reactor (VATR). It would be a highly neutron rich fast reactor capable of also providing thermal neutrons. We like “versatile” because it should be designed in a way that it could be used to test all new reactor concepts whether they involve a molten salt reactor, a liquid sodium reactor, a liquid lead bismuth reactor, a gas reactor (such as EM^2), or even LWR technology such as those reactors used in U.S. nuclear submarines. The VATR would be a user facility in the same way that the DOE Office of Science manages other highly successful user facilities. It would contribute to the public good by providing the development of future nuclear energy options. This is an excellent example of what the government should do, because industry cannot or will not do it.

The U.S. has a great opportunity to give nuclear power its best chance to become economically viable, and lead the world in this endeavor. In fact, other countries would have to seek permission from the U.S. Department of Energy to use the VATR. This Committee could start by enacting law calling for a study to be done, with industry participation, to determine a design for such a VATR, what its capabilities should be, and what it might cost.

We believe that if the U.S. were to build such a test facility, advanced reactor research and development could lead to the development of nuclear reactors that: will have much improved economics; would have improved safety through the use of high temperature materials that are also radiation resistant; will produce much less waste, and; reduce proliferation risk. This could lead to a true renaissance of nuclear power in the U.S. Thank you for inviting me to share our views, and for your interest in finding ways to sustain an extremely important future energy source for our nation.

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Appendix 1

GENERAL ATOMICS

U.S. Versatile Advanced Test Reactor (VATR) Facility

The United States (U.S.) needs a viable indigenous nuclear industry for its long-term energy security. Unfortunately, the U.S. is on a path to lose its position of world leadership in nuclear power and related technologies. And if this continues, it could present a significant national security risk to our nation. Despite the U.S.'s enviable position on fossil energy reserves, energy is a global commodity, and energy demand growth is driven by the global economy. Meeting future world energy demand will require a diverse energy mix with nuclear as a major component.

Status of the U.S. Nuclear Industry

The U.S. nuclear industry is struggling. Despite the brief stirring of a Nuclear Renaissance at the turn of the century, the industry is faced with the following bleak reality in 2015:

- Only five plants are under construction despite plans for up to 30 in 2009[i]. There are no other firm commitments for construction.
- Large nuclear plants are not economically competitive with coal and natural gas[ii]. This is due to a combination of low U.S. fossil fuel costs and the higher financing costs of nuclear plants.
- Four nuclear plants have been retired prematurely due to economic pressure and cost of repairs[iii]. Ten to 12 other plants face risk of early retirement[iv]. Five nuclear plant power upgrades have been cancelled due to economic considerations[v].
- The aging U.S. nuclear generating capacity is at the start of a steep decline based on current licenses, see Fig. 1.
- The DOE's SMR initiative is threatened by lack of market, high projected power costs and a lack of investors.

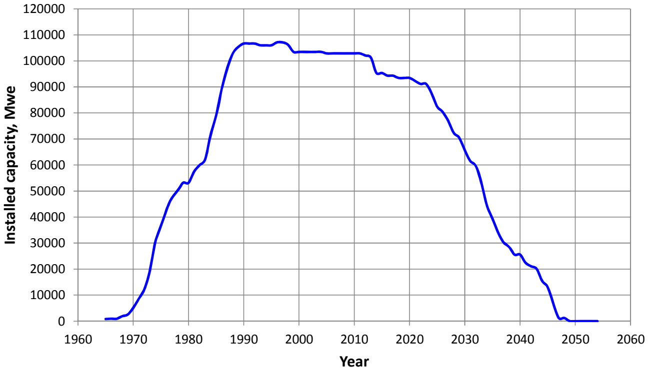

Fig. 1 U.S. licensed nuclear plant generating capacity

Global opportunities for the U.S. nuclear industry are likewise diminished due to foreign competition. With strong government support and strong indigenous markets, Asian suppliers will dominate future nuclear construction, particularly China, which has 30 LWRs under construction and plans for over 100 new LWRs by 2030. Three Chinese nuclear firms are now looking to export their nuclear plants[vi].

Many arguments can be made for preserving the U.S. nuclear industry, among the more prominent are its contribution to long-term energy security, and that it produces zero-carbon electricity. It is not likely that U.S. nuclear suppliers can compete with government supported Asian LWR vendors based on economic competitiveness. To compete, future "would-be" U.S. nuclear suppliers must rely on a unique U.S. resource -- innovation. These innovations will have to improve the new plants' safety and resource utilization while reducing the cost of electricity. These innovations will have to be bold, and will have to include new high-performance materials, higher operating temperatures for higher efficiencies, and substantially better fuel cycles to more efficiently utilize fuel resources and reduce waste production.

Nuclear R&D is Needed

Innovation requires R&D, but nuclear R&D is very expensive and its payoffs are at least a decade or more away. Countries that require nuclear power as part of their long-term energy security must be prepared to underwrite the necessary R&D efforts. Commercial companies cannot sustain a very expensive R&D effort where the payoff is likely decades in the future.

An essential nuclear R&D component is a new high-performance advanced test reactor to validate performance of fuels, materials and new high performance technologies. The U.S. has only three such reactors that can support nuclear power research: Idaho National Lab's ATR, Oak Ridge National Lab's HFIR and MIT's MITR. All three are pool-type thermal reactors. Only the ATR can support testing of larger fuel components. Only HFIR has a fast-flux region capable of testing small material samples, and only MITR can simulate LWR coolant conditions. The ages of ATR, HFIR and MITR are 57, 59 and 65 years, respectively. Due to their limited availability and capability, none is suitable for the type of innovative R&D required to stimulate and sustain a viable future U.S. nuclear industry.

The global availability of suitable test reactors is also dismal. Among fast reactors, only the Chinese 65 MWt CEFR, Russian 60 MWt BOR-60 and Indian 40MWt FBTR are operational. The CEFR is primarily a prototype reactor with limited testing capabilities. BOR-60 is scheduled to be shut down in 2015 and the FBTR is restricted to Indian military use. It is possible that no capable reactors will be available world-wide for testing fuels and materials essential to development of high-performance advanced reactors.

Among thermal test reactors, only a handful of reactors in Japan, Russia, China, Sweden and Argentina can support low-temperature nuclear fuel and materials testing. Most of these reactors are old, and some are scheduled to be shut down. An exception is the Jules Horowitz test reactor in France which went into operation in 2014 to provide fuel, materials and isotope production for the EU, but it is a thermal spectrum reactor and therefore of limited value for the necessary advanced reactor testing.

A New U.S. Test Reactor is Needed to Support Innovative R&D

To support the innovative R&D required to revive a competitive U.S. nuclear industry, a new test reactor is required **with capabilities that far exceed those of the few remaining test reactors**. This new test reactor must be an outstanding example of U.S. technical innovation. The test facility would be funded by the U.S. government and located at a national laboratory, which in turn would operate the reactor as a national user facility. Irradiation would be free to U.S. users, who would be responsible for providing test articles and support equipment. Suggested capabilities are:

Power:	500 MWt
Peak temperature:	1000^{o}C or greater
Peak fast flux:	1x10^{16} n/cm^{2}-s or greater
Reactivity:	Sufficient to support tests of 6 months or longer
Experimental:	Core and reflector spaces for materials and fuel testing; loops for fuel testing in different coolants; beam lines; full pre- and post-irradiation examination capability

A cooperative effort by U.S. industry, national labs and universities is required to achieve this new test reactor. A group of top U.S. nuclear experts from each sector should be convened to establish the functional requirements for this vital new test reactor. In addition to technical work, political and financial support will be needed to complete this project. A separate committee should be formed to plan and execute a strategy that would lead to a revitalized U.S. nuclear energy program.

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[i] Vogtle Units 3 & 4, V.C. Summer Units 2 & 3, Watts Bar Unit 3

[ii] DOE-EIA 2014 Annual Energy Outlook

[iii] San Onofre Units 2&3, Crystal River Unit 1, Kewaunee Unit 1

[iv] Cooper, Mark, "Renaissance in Reverse", Institute for Energy and Environment Report, July 18, 2013

[v] Prairie Island Unit 1, LaSalle units 1&2, Limerick Units 1&2.

[vi] Ng, Eric, "3 Chinese state firms looking to build nuclear plants abroad", South China Morning Post, April 2, 2014

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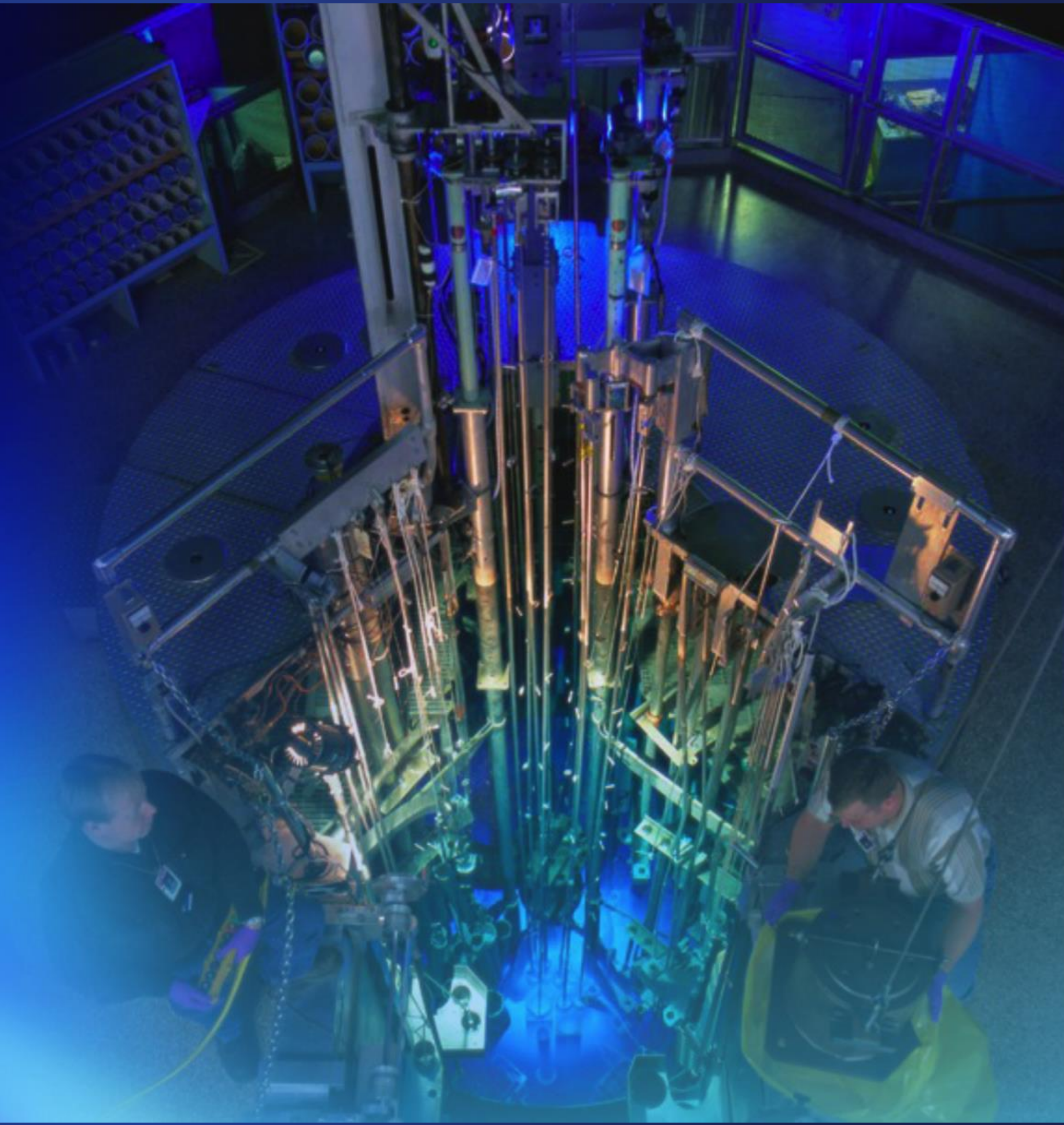
Appendix 2

Need for Versatile Advanced Test Reactor



By

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Parmentola Testimony

Appendix 2

Nuclear Energy Is a National Security Issue

- New nuclear power plants are not competitive in the U.S. energy marketplace
- U.S. leadership role in nuclear energy is eroding
- U.S. must take a bold step to maintain leadership in nuclear technology, safety and standards

Some Key Advanced Reactor Performance Parameters

Improve economics:

- **Higher power density**
  - Enables more compact designs, which reduces capital costs
- **Higher efficiency**
  - Lowers the levelized cost of electricity (LCOE)
  - increases revenue stream over reactor life
  - Improves fuel utilization
- **Higher burn-up**
  - Longer burn times reduce O&M costs and Improve fuel utilization

Other potential implications:

- **Improved safety**
  - Radiation-resistant materials and higher temperature materials can improve safety margins
- **Reduced waste streams**
  - Through higher burn-up and higher efficiency

Bold Step – Versatile Advanced Test Reactor (VATR)

Advanced Reactor Concepts (ARCs) require:

- Higher operating temperatures
- Fuel and material R&D
- Component development and testing
- Model development, verification and validation
- Risk reduction

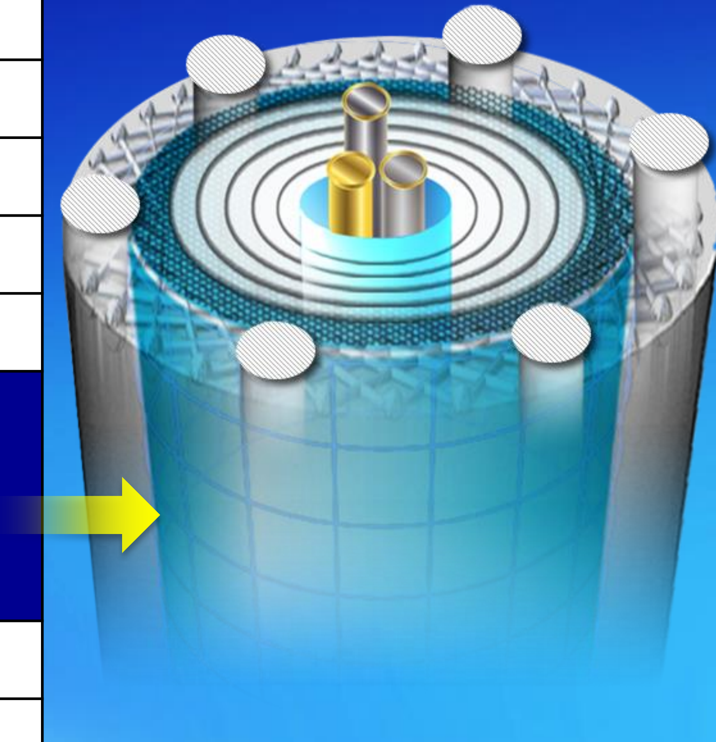
General characteristics of VATR:

- Broad neutron energy spectrum
- High fast neutron flux to accelerate DPA (displacement per atom) of materials for radiation-resistant R&D
- Higher temperature test range, max ~1000ªC
- User facility that provides testing capabilities for ARCs

Suggested Peak VATR Specifications

An Industry Perspective

Power, MWt	500
Coolant	Liquid metal
Fuel	MOX
Fuel element	Plate
Peak fast flux, n/cm^2-s	10^{16}
Active core diameter, m	1.1
Active core height, m	1.1
Central test diameter, m	0.2
High-flux test loops	**Helium Molten salt Liquid metal Light water**
Max test loop temps	~1000°C
Test duration capability	6 months



VATR Is a National Project

Approach to proceed with VATR:

- Must include participation by ARC proponents in determining general user facility requirements
- Incorporate requirements into a FOA solicitation to design, develop, build and license VATR
- Select an industry-led team to proceed in collaboration with NRC and an oversight board of customers, users and stakeholders to monitor progress

VATR Serves National Security Goals

- Creates nuclear energy options that will enable the U.S. to adapt to an uncertain energy future

- Builds a new R&D base that allows the U.S. to train the next generation of gifted and talented people to carry forward bold new nuclear energy options

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Appendix 3

Improving the Economics and Long-Term Sustainability of Nuclear Power

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***Abstract*-The fraction of global power demand supplied by nuclear power has been decreasing steadily in recent decades, in part because the cost of electricity from Light Water Reactors (LWRs) has risen to the point that it exceeds that from available fossil fuel sources. This paper examines the economics of two alternatives to gigawatt-scale LWRs: small modular LWRs (SMRs) and the Energy Multiplier Module (EM^2), a compact, gas-cooled, direct drive, fast reactor. No economic advantage over LWRs is found for SMRs, but the capital cost of EM^2 is predicted to be significantly lower owing to improved thermal efficiency, a substantial reduction in materials required, and higher fuel utilization. The waste disposal burden is also materially reduced (by 80% without recycling, up to 97% with recycling). In addition, the economics of recycling the spent fuel are found to be the reverse of that applicable to LWRs, allowing the power cost to be further improved with recycling. The improvement in fuel utilization and the possibility of multi-pass operation also increase the sustainability of nuclear power, allowing known uranium reserves to power the world economy far longer than possible with known fossil fuel reserves.**

Keywords*- *Nuclear Power; Cost Optimization; Small Modular Reactors; Nuclear Fuel Recycling

I. INTRODUCTION

As shown in Figure 1, the share of global electricity production from nuclear energy has been declining since the 1990s [1]. Present plans for new construction and plant retirements indicate that this trend will persist. Energy policy decisions are complex undertakings involving many considerations, but it is interesting to note that this trend continues despite increasing concern over fossil fuel-induced climate change and the rising cost of fossil fuel, the dominant component of fossil fuel-based power cost. This is also depicted in Figure 1, using coal as a proxy for fossil fuels in general [2].

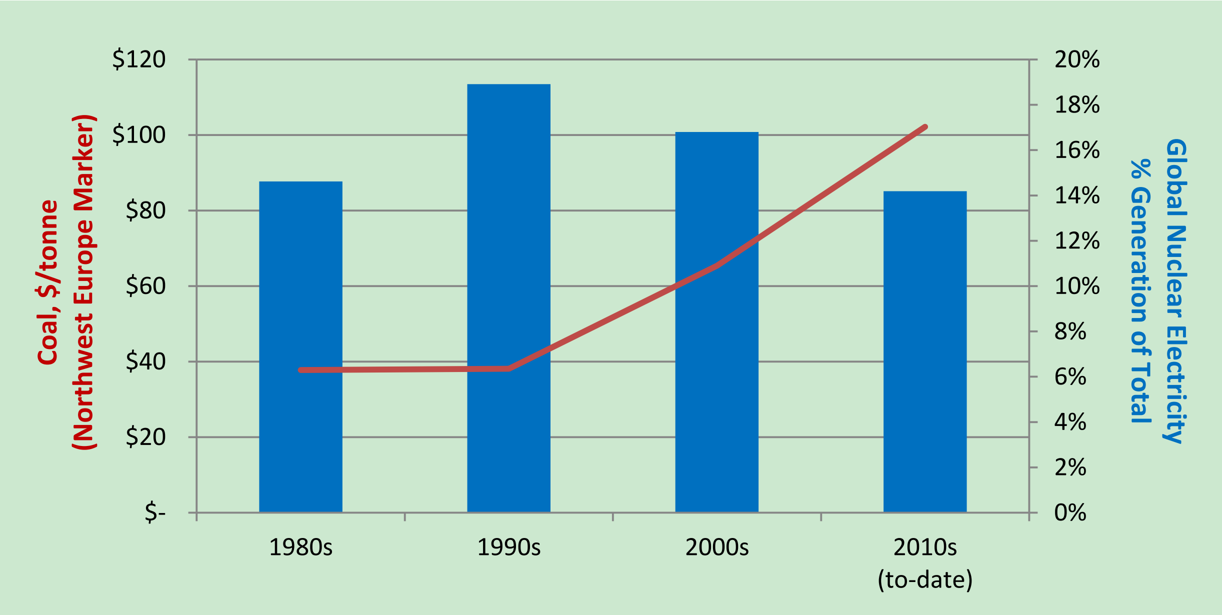

Fig. 1 Price of coal and global electricity from nuclear as a % of total electricity

Factors such as public safety and waste disposal have adversely affected the nuclear industry in some markets, but economics remains the dominant consideration in many countries and representative data in Figure 2 indicate that the capital cost of nuclear plants has been rising at a rate much greater than that of inflation[1]. These cost increases are attributable in part to increased regulatory requirements, which have had a twofold effect on costs: adding expensive safety features and extending the time required for licensing and construction. The response of regulatory bodies in the aftermath of the Fukushima event makes it clear that yet more stringent safety standards are likely to be applied to future nuclear plants. This expectation should sharpen the focus of the nuclear energy design community on developing approaches that improve the underlying economics through fundamentally new inventions and innovations. It is noted that the nuclear power industry does not have a strong tradition of making the type of R&D investments needed to maintain economic and performance competitiveness; rather, the industry has been in a largely reactive mode to regulatory mandates.

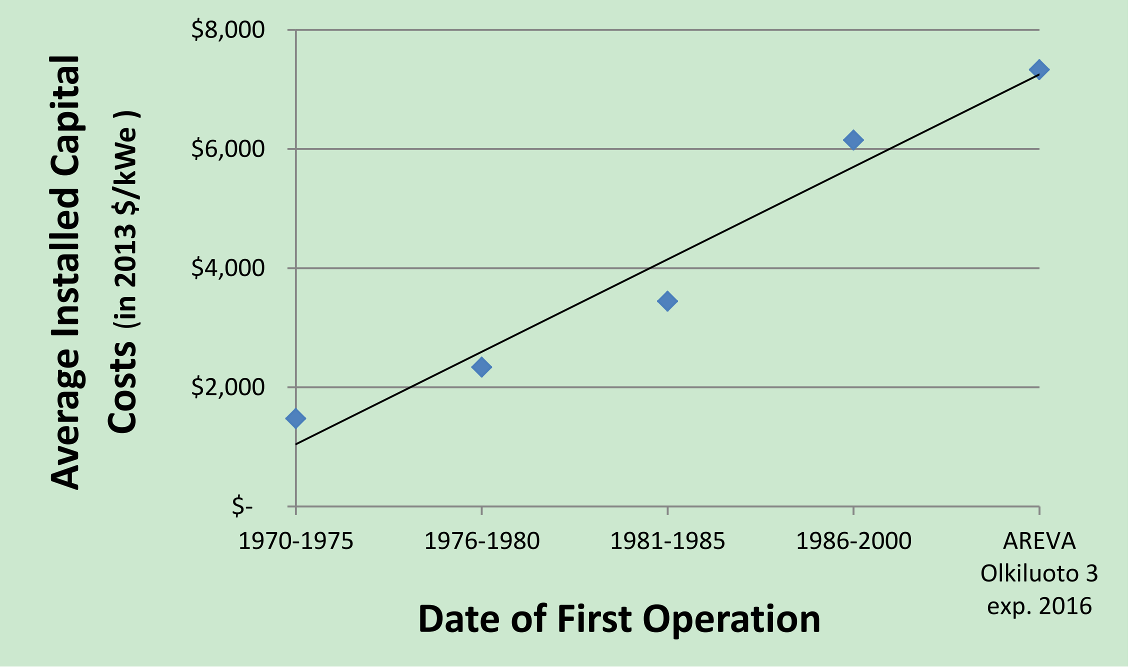

Fig. 2 Historical escalation of nuclear power capital cost; data drawn from references [3,4]

Nuclear power is unlikely to become a dominant player in the energy marketplace unless a more attractive economic model is offered. Because light water reactor (LWR) technology, which forms the basis for almost all the nuclear-based electricity generation in the world, is so mature, technical innovations that materially improve the economics are regarded as highly unlikely. This is especially true in a market where financial risk dominates investment decisions. However, in principle, a fundamental change in the approach to manufacturing and construction could make a difference to the economics. Such a change, involving a shift to smaller, lower power units, is now under serious consideration in several countries. Termed small modular reactors (SMRs), the notion is to reduce the physical size to a point that permits factory fabrication, providing economies of production and compacting the construction schedule. Such an approach clearly reduces the capital outlay required to build a power plant, but it is questionable whether the resultant cost of electricity will be lowered. Section II addresses this possibility.

Among the alternatives to LWRs under consideration are convert-and-burn reactors, which embody a number of attributes that are suggestive of a more economical price point. Two groups in the United States are developing an alternative to LWRs in the form of convert-and-burn reactors, featuring long lived reactor cores in which fertile fuel is converted to fissile fuel and then burned in-situ. One is the Traveling Wave Reactor (TWR), a gigawatt-scale sodium-cooled reactor [5] and the other is the Energy Multiplier Module (EM^2), a compact, lower power, helium-cooled reactor [6]. Such reactors offer the prospect for advances in both economics and sustainability through improved utilization of the energy stored in uranium and higher thermal conversion efficiencies. The implications for capital and operating cost are examined in the case of EM^2 in Section IV and the sustainability issue is discussed in Section V.

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[1] *The data in Figure 2 is shown for illustrative purposes only. The nature of nuclear power economics is complex with the potential for a multitude of factors to cause substantial variation. Among these factors, geographic location, regulatory environment and access to financing should be considered.*

II. ECONOMICS OF SMRS

The construction of commercial nuclear reactors in the western world is regarded apprehensively due to high initial capital costs and a legacy of cost overruns associated with uncertainty in licensing and construction delays. Apprehension drives perceived risk and increases the required rate of return for pursuing new projects. The past three decades have shown that reactors with large initial capital outlays and high required rates of return are not achieving a secure market foothold in the western world.

SMRs may be a viable option for nuclear power revival. They aim to reduce financial exposure and achieve a competitive power cost through factory fabrication, shorter construction duration and simplicity in design. However, due to scaling laws, systems are generally penalized in cost as size is reduced. SMRs will only make economic sense if the savings associated with size reduction exceed the economies of scale penalty. In addressing this issue, we follow common parlance in defining SMRs as having an electrical power output of no greater than 300 MW. In practice, the more pertinent figure of merit is physical size, with the upper bound being the largest unit whose major subsystems can be built in a factory setting and transported over land to the construction site.

The analysis begins by examining individual (single module) plants. Scaling laws can be used as an approximation for determining the relationship between the cost and power rating of systems that are otherwise identical. The cost per unit output generally decreases with increasing scale due to the economies of raw materials and spreading of fixed costs among more units of output. The economy of scale, or scaling law, used in nuclear power plants to calculate the capital cost when decreasing in unit size from P0 to P1 is

$$Cost\ (P1) = Cost(P0)\ \left(\frac{P1}{P0}\right)^{n}, \tag{1}$$

where

Cost (P1) = Cost of power plant for unit size P1,
Cost (P0) = Cost of power plant for unit size P0, and
n = Scaling factor.

The scaling law can be used as an approximation for determining the relationship between power plants of differing sizes by using the cost data for a large nuclear plant as input and calculating the cost of an SMR. The most compelling data set comes from the French nuclear program, in which a number of replicated plants were produced over a substantial range of power levels. The scaling factor derived from plants with unit power from 300 to 1300 MWe is in the range of 0.4 to 0.7 [7]; in the analysis that follows, it is assumed that n=0.5. (It is acknowledged that extracting a scaling factor is not without controversy because building units at different times often means that different regulatory constraints were in effect.) If the cost of a large 1118 MWe reactor (the rating of an AP-1000 unit) is normalized at 1.0, the specific capital cost of varying power plant sizes (P1) are plotted in Figure 3 as "Base @ Nominal Efficiency" (the uppermost curve), which implies that electricity from a single 300 MWe power plant is expected to be 90% more expensive than that from a single 1118 MWe unit of the same general design, all other factors being equal. The unit power levels on the abscissa correspond to proposed SMR power levels and to the nominal 1118 MWe AP-1000 rating.

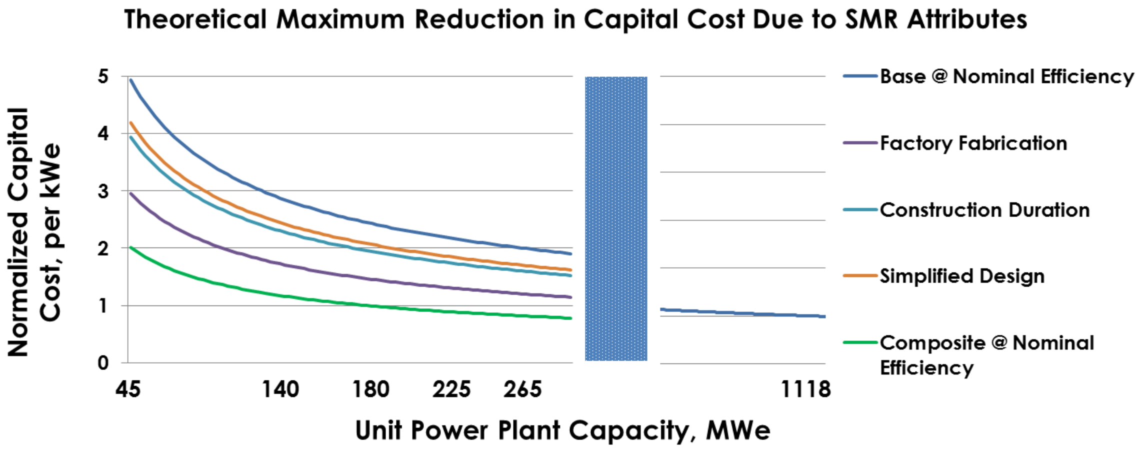

Fig. 3 Normalized capital cost when base cost is increased due to diseconomies of scale and subsequently reduced due to SMR attributes. Data points correspond to power ratings of proposed SMRs and an AP-1000

The scaling law is applicable only to plants built according to the same basic design concept. Changing to physically smaller units allows a number of options for changing the design concept in a cost advantageous fashion. Three attributes associated with SMRs that can reduce the cost of electricity have been identified and quantified by the Nuclear Energy Agency [7]. These are:

(1) Efficiencies of factory fabrication. The smaller structures and components of SMRs allow a large portion of the system to be manufactured in a factory setting. Factory fabrication allows significant cost savings in the manufacturing process through high levels of repetition, automation and quality control. The recurrent use of hard tooling, reduced weather delays, and a constant labor force also assist in achieving lower capital costs. The NEA attributes a possible 30-40% reduction in specific capital cost due to factory fabrication. Significantly larger percentage reductions have been documented in the case of very high volume production, but nuclear power plants do not fall into this category.

(2) Schedule compression. Factory fabrication also enhances parallel fabrication and reduces the construction schedule, which is a major cost driver of nuclear power. Subsystems can be fabricated in modules and then transported to the site and "plugged" in upon arrival. The NEA attributes a possible 20% reduction in specific capital cost due to reduced construction schedule.

(3) Design simplifications. SMRs may have significant design simplifications in their safety systems. Fewer safety systems and materials lead to reduced specific capital cost. The NEA attributes a possible 15% reduction due to design simplifications.

The potential individual and composite cost savings from each of these three factors as an offset to the cost disadvantage of the scaling law are shown in Figure 3. Even under the assumptions that all of these advantages can be realized simultaneously in a single SMR design concept and that these quantitative advantages will be as large at the higher end of the power range, it is concluded that the maximum composite cost savings in a standalone SMR still results in higher electricity costs than that expected from a standalone GW-class reactor unless the power rating exceeds 200 MWe. The most widely discussed water-cooled SMR designs are at lower power levels and hence can be expected to have higher cost of electricity.

The above analysis ignores several variables that could have a significant role in the economics. First, the scaling law really applies to thermal power, not electrical power, so the effect of varying power conversion efficiency must be taken into account. Second, it is applicable to stand-alone units, and the expectation is that SMRs would be built with higher multiplicity at a given site. Thirdly, the cost of capital has been assumed to be the same for all options and it has been argued that the lower total capital exposure entailed in SMRs would translate into a lower cost of capital. We examine each of these effects in the following analysis.

(1) Efficiency. All other factors being equal, the cost of electricity from a nuclear plant scales inversely with the efficiency. The AP-1000 unit that serves as the benchmark for the cost comparisons operates at 34% efficiency. A number of the water-cooled SMRs are expected to operate at 28% efficiency due to the reduced steam pressure compatible with natural cooling, which is equivalent to a factor of 1.2 increase in power cost.

(2) Multiplicity. Co-located nuclear plants will realize economies of scale by sharing operating labor, fixed systems, buildings and infrastructure. This is already the norm for the industry – two LWRs per site is standard in the U.S. and as many as six LWRs are built in a coordinated fashion in China. About a 10% power cost reduction is obtained by building two co-located plants, rather than one [7], a factor that should be essentially the same for SMRs. The level of additional cost reduction from higher multiplicity is heavily dependent on design details and the attitudes of regulators, but one reference [8] estimates a 17% savings for a six-module plant compared to a two-module plant. Regulatory insistence upon completely independent control and safety nets for each unit preclude materially larger savings at yet higher multiplicity.

(3) Cost of capital. Projects with lower total cost may be financeable at a lower cost of capital. A reduction from 9% to 6% mandated rate of return by investors and financing charges would translate into a nearly 20% project cost savings.

In cases of interest, the combined effect of these three factors leads to a negligible correction of the results presented in Figure 3 for water-cooled reactors. The efficiency factor is a 20% penalty for SMRs while multiplicity and cost of capital are mutually exclusive advantages of this same magnitude (they are mutually exclusive because the initial capital outlay of plants with many units will be comparable to that of GW-scale units).

It is concluded that diseconomies of scale are the predominant factor in the economics of water-cooled SMRs with power levels below 200 MWe. The large redundancy required for SMRs to achieve a base load rating comparable to large-scale LWR facilities is not compensated by the production and schedule advantages attendant to smaller units. This is the universal experience in the power industry and is typical of many other industries as well, including transportation. Achieving cost benefits from building multiple small unit-size modules in place of a smaller number of large unit-size modules can only occur if there is a fundamental change in the process needed to build the units.

If these conclusions are correct, the nuclear power industry faces challenging times. Aging LWRs may not be replaced with modern versions because the costs are unattractive. New versions with attributes that significantly enhance the economics are not in the offing. And the SMR route would seem on the whole to be even less attractive economically. A fundamentally new approach is needed. One such approach is addressed in the next section.

III. CONVERT-AND-BURN REACTOR DESCRIPTION

Helium is an attractive alternative to water for core cooling owing to its compatibility with higher temperature operation and to the safety advantages inherent in a chemically and neutronically inert coolant. It also provides siting flexibility and does not burden water supplies. Use of the coolant directly as a gas turbine working fluid enables the plant to take advantage of high temperature to achieve high electrical conversion efficiency. Helium-cooled thermal reactor designs have a power density in an order of magnitude lower than that of ALWRs. The associated need for large core structures and large amounts of material in the surrounding structures (per unit energy produced) has led some to conclude that helium-cooled thermal reactors will not be economical for electricity and/or process heat generation in some markets.

Because helium is effectively transparent to the neutrons produced in fission, it can also be considered as a coolant for fast reactors, viz gas-cooled fast reactors (GCFR). This concept was pursued in the 1970s but ultimately discontinued due to safety concerns associated with the low thermal inertia and corresponding low safety margins associated with metal-clad fuel, the only available clad choice at that time. However, when modern ceramic materials are employed for cladding, large thermal safety margins can be attained even at high coolant temperatures. Silicon carbide composite (SiC-SiC) is especially attractive for this purpose because it retains its structural integrity at temperatures in excess of 2000 ^{o}C, and many years of exposure in test reactors reveal that at temperatures of interest for GCFRs it experiences very little swelling or degradation of key constitutive properties even at high neutron fluence [9,10]. SiC has a very low neutron absorption cross-section at all fission energies and is likewise practically immune to transmutation in the pertinent fast neutron spectrum.

Achieving unit power levels of interest (200-300 MWe) in a volume small enough to permit factory fabrication and truck transport mandates high uranium packing density in the core. Together with the requirement of high melt temperature, uranium monocarbide (UC) emerges as the preferred fuel composition. A GCFR design based upon UC fuel and SiC-SiC, as both clad and structural material is the basis for our examination of the economics of alternatives to LWRs. This design, referred to as EM^2, is a passively safe, convert-and-burn fast reactor that is physically small enough to permit factory fabrication of the type envisioned for SMRs. By safely venting the fuel of fission product gases, the core is expected to have a lifetime exceeding 30 years during which the reactor is operated at full power without refueling or fuel shuffling. The fact that the fuel core does not need to be accessed for decades simplifies plant operations and reduces the risk of proliferation. The high packing density and large thermal safety margin combine to give rise to high thermal inertia, an additional safety consideration.

The choices of coolant and core materials facilitate high-temperature, high-efficiency operation. With a peak coolant temperature of 850°C and a power conversion design that combines a direct, closed cycle gas turbine with a Rankine bottoming cycle, the 500 MWt unit power results in 265 MWe (net efficiency of 53%) with evaporative cooling and 240 MWe (48% net efficiency) under dry cooling conditions. Dry cooling greatly expands plant-siting options, which is an important consideration for broader global adoption of nuclear power. The basic layout of a four-unit EM^2 power plant, rated at 1060 MWe (960 MWe in the case of dry cooling), is shown in Figure 4. A single reactor building houses all four reactor cores, together with their control rooms, power conversion units, and spent fuel storage areas.

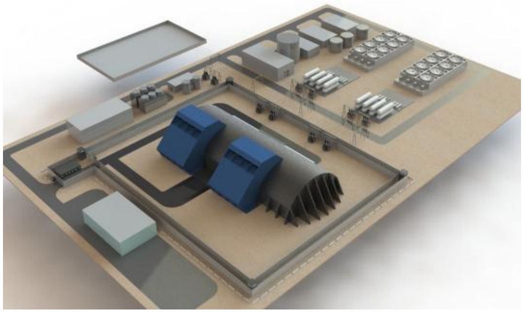

Fig. 4 Site plan for baseline, four-unit 1060 MWe plant

Data associated with this layout are strongly suggestive of improved plant economics. Drawing comparisons to typical LWR plants on a per unit electricity produced basis, an EM^2 plant requires less than 20% of the real estate and less than 20% the nuclear concrete [11], both of which are cost drivers. These reductions reflect the nature of a high efficiency, direct drive system, which simplifies and/or eliminates the need for a number of large items of equipment needed for power conversion and heat rejection. These factors supplement the advantages of the modular approach to construction, which facilitates schedule compression and hence reduces the cost of capital over the period of construction. We shall return to the economics after a brief description of the reactor and its operational features. This description provides enough information to address the economic and sustainability issues, but it is not intended to be thorough enough to permit an in-depth assessment. The reader interested in greater technical detail is referred to other papers for nuclear design [12], thermomechanical design [13], fuel cycle [14], and development status [6].

A cutaway view of the reactor building displaying one of the four individual units is presented in Figure 4. Grade level is at the floor of the maintenance hall, which services all reactors and the below-grade common spent fuel storage area (not shown). Each primary system is enclosed within a sealed below-grade containment consisting of three chambers connected by ducts. The central reactor chamber is enclosed in a concrete shield structure to enable man access to the Power Conversion Unit (PCU) and Direct Reactor Auxiliary Cooling System (DRACS) chambers. The containment structure is suspended from an approximate mid-plane support frame that also supports the primary system. Access to each chamber is through hatches from the grade-level maintenance floor. Each of the vessels depicted in Figure 5 are less than 5 m in diameter, permitting overland transport of completed vessels to the construction site.

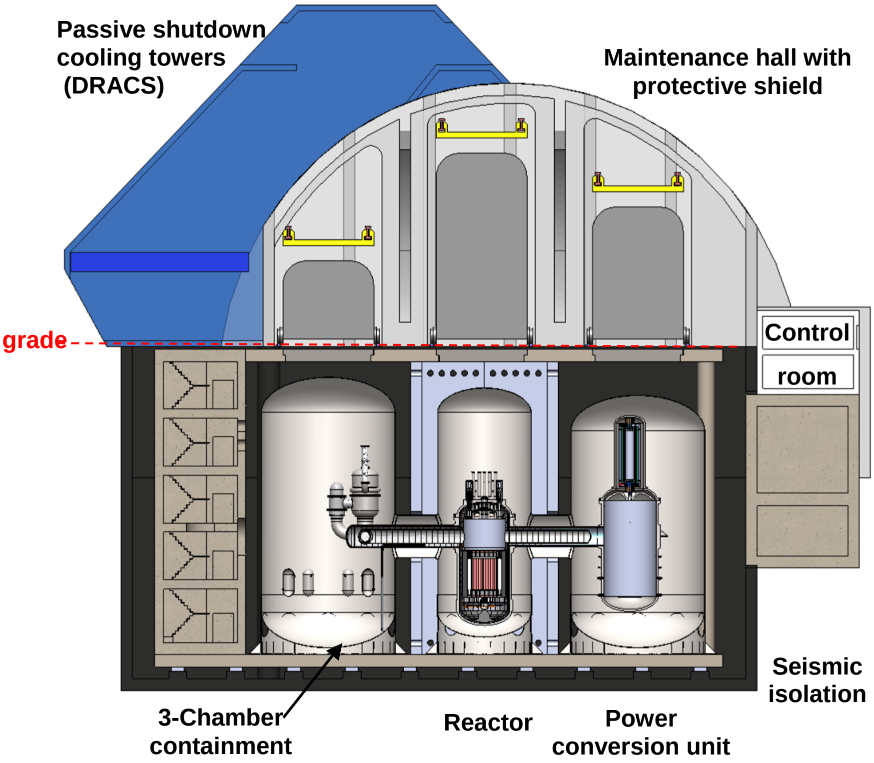

Fig. 5 Cutaway view of reactor building, showing one of four units

The active core is divided into two regions, the fissile starter and the fertile converter; the average enrichment in the core at the beginning of life (BOL) is just over 6%. Virtually all the power at BOL is in the LEU-fueled starter region, but some of the neutrons produced therein convert ^{238}U in the neighboring fertile region to ^{239}Pu, which becomes available for fissioning. Figure 6 shows the time dependence of the excess reactivity and also the relative contributions of ^{235}U and ^{239}Pu to the total fission power as a function of reactor operating time, illustrating the convert-and-burn mode of operation. The excess reactivity never exceeds 2%, which is well within the dynamic range of the control elements. Initially, most of the energy comes from the fission of ^{235}U in the starter fuel. After the first decade, the preponderance of the energy comes from the fission of ^{239}Pu. Direct fast-fission of ^{238}U produces about 20% of the energy. The average burnup is 14.6%, three times that achievable in LWRs.

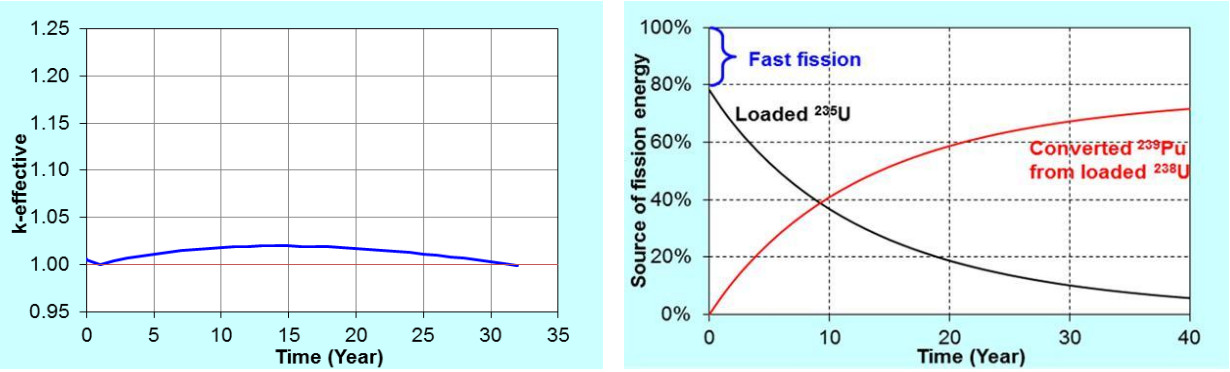

Fig. 6 Reactivity (left) and contributions to fission power (right) as a function of time

IV. ECONOMICS OF EM^2

Sensitivity analyses are useful in determining how uncertainty may affect economic outcomes in terms of net present value. The discounted free cash flow model is used as a base framework for financial modeling. Each major parameter of interest is varied by +/- 10%. The specific parameter of interest is varied with all other parameters held constant.

In the sensitivity analysis of EM^2, summarized in Figure 7, the cost of capital is the single largest factor. Cost of capital is driven by the expected rate of return to equity investors and required debt financing charges. The cost of capital used here is the weighted average cost of capital (WACC), which includes a tax shield on debt,

$$WACC = Rd(1 - Tc)\left(\frac{D}{V}\right) + Re\left(\frac{E}{V}\right), \qquad (2)$$

where

Rd = cost of debt,
Tc = corporate tax rate,
D = value of debt,
Re = cost of equity,
E = value of equity, and
V = enterprise value.

The second largest driver is net efficiency. As discussed previously, the efficiency of EM^2 is improved owing to the use of a direct drive gas turbine and high operating temperature. With efficiency as the second largest economic driver, the EM^2 financial return at 53% efficiency has a marked improvement over water-cooled SMR designs at a nominal 28% efficiency.

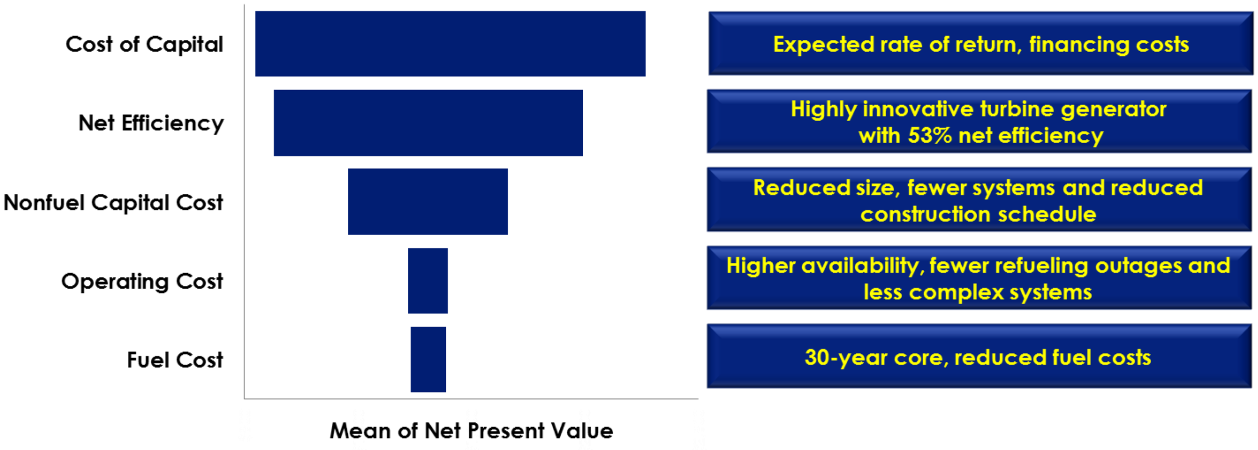

Fig. 7 Tornado chart highlighting the comparative impact of ±10% variations in the parameters that serve as the largest economic drivers for EM^2

The last three major drivers are nonfuel capital cost, operating cost and fuel cost. The Generation IV Forum's code of accounts outlines a method for arriving at overnight construction, annual operation and maintenance (O&M), and fuel costs [15]. Overnight construction cost includes capitalized preconstruction costs, direct construction costs, field indirect costs, field management costs, owner costs and supplementary costs. Interest during construction and first core fuel costs are not included in the overnight capital cost. Fuel is treated as a capitalized asset and depreciated on a modified accelerated cost recovery schedule because the fuel core life lasts 30 years. O&M costs are expensed every year and include staffing, consumables, maintenance, subcontracts, overheads and capital replacement costs.

Levelized cost of electricity (LCOE) is a common metric used to compare the competitiveness of electrical generation technologies. LCOE is equivalent to the break even sales price over the life of the plant for a required rate of return. Capital and operating costs are considered as well as financial parameters such as: cost of capital, inflation, escalation (if applicable), taxes, depreciation, and time value of money (through discounting).

As efficiency increases, the amount of product per unit cost is increased and the LCOE is reduced. The LCOE is reduced by approximately 50% when the efficiency is increased by the same factor. Figure 8 illustrates this concept.

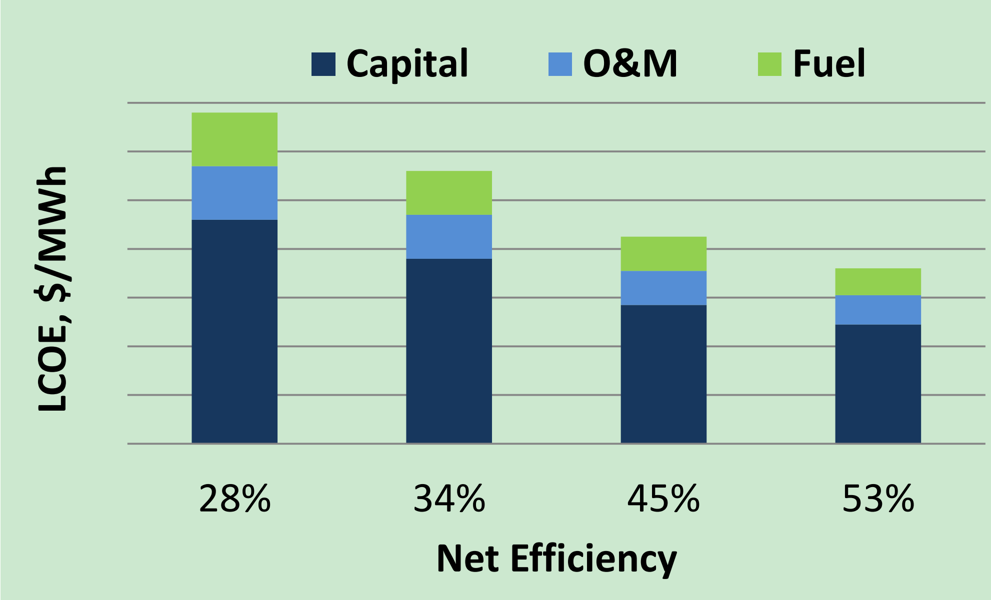

Fig.8 An illustrative example of the reduction in LCOE due to increasing efficiency

Better uranium utilization in EM^2 translates into lower life cycle fuel costs, although the threefold advantage in burnup is moderated by the increased enrichment, higher fabrication costs (see Table I) and cost of capital adjustments stemming from the need to have three decades worth of fuel available on day one.

TABLE I. ROUGH COMPARISON OF LWR AND EM^2 FUEL COST PER KG

Cost Item	LWR ($/kg U)	EM^2 ($/kg U)
Mining and conversion	900	1200
Enrichment	500	700
Fabrication	500	800
Waste management	1100	1300
Total	3000	4000

If EM^2 is operated not in a once-through mode, but in a multi-generation mode with end-of-cycle fuel being recycled for use in a subsequent cycle, the fuel cost advantages can be enhanced because no new uranium resources or enrichment services are needed. This would be advantageous economically if the recycled fuel can be produced less expensively than fresh fuel. In this regard, it is instructive to compare the economics of recycling convert-and-burn fuel with that applicable to LWR fuel. LWR fuel at end of life has only 25-30% of the initial fissile content and thus has a proportionately smaller energy value than fresh fuel (in practice, recycled spent LWR fuel must be upblended before reuse in a reactor). As a consequence, it is only economically sensible to reuse LWR fuel if it can be recycled at a cost of less than 25-30% of the $3000/kg cost of fresh LWR fuel. This is not achievable with today's technology. End-of-cycle EM^2 fuel, in contrast, has about 120% of energy content of fresh fuel, owing to a conversion ratio slightly greater than unity and the fact that converted fuel is more reactive than fresh fuel. Reuse of this fuel is thus economically favorable if the recycling cost is less than 120% of the $4000/kg cost of fresh EM^2 fuel, a much less daunting proposition (for comparison, the cost of aqueous reprocessing in France is usually estimated to be $15,00-$2,000/kg and this is also a remotely-operated process). This topic will be revisited in Section V.

Plant availability also plays an important role in the economics of any power source. This is an unknown in EM^2 because the plant has not yet been built and operated. However, 70% of the downtime in today's LWRs is for fueling [16], a process that is not required in EM^2. It is thus reasonable to assume that, if EM^2 is extensively deployed, it would eventually equal or surpass the already excellent availability and capacity factor standards established by the nuclear power industry.

Disposal of nuclear waste is not a very important economic consideration, but it does represent an important societal cost and has emerged as a major impediment to the broader implementation of nuclear power in some markets. In a once-through fuel cycle, EM^2 produces only one-fifth as much waste mass per unit electricity generated as today's nuclear plants. This factor is derived from combining the approximate factor of three increase in burnup, which results in that same factor decrease in the mass of waste generated per unit thermal energy generated, with the approximately 1.6 increase in thermal conversion efficiency. Mass is only one factor in determining waste disposal costs, but it is a significant one and has been used as the defining characteristic of geological repositories [16]. A similar reduction factor is applicable to waste volume (albeit there is a yet to be quantified volumetric contribution from the gases vented from the core and the resins used to store that material), while a smaller reduction pertains to waste heat. If the fuel is reused, the waste-related costs per unit electricity generated are further reduced. Decommissioning costs are also expected to be lower than existing nuclear plants because so much less material is involved in plant construction on a per unit energy produced basis.

V. SUSTAINABILITY OF CONVERT-AND-BURN REACTORS

Sustainability in this context refers to how long nuclear power can make significant contributions to global energy supply. For simplicity, we restrict attention to a uranium-based fuel cycle; thorium-based fuel cycles have comparable resource limitations, but closing the fuel cycle is more problematic. Sustainability is driven by two factors – the projected availability of economically affordable uranium and the amount of useful energy extracted per unit mass of uranium. The former is dominated by geological and mining technology considerations and the latter is governed by the specifics of the fuel cycle.

Turning first to the question of resource availability, it is noted that uranium is quite abundant in the earth's crust. One indication of this abundance is the fact that the rate at which rivers leach uranium into the world's oceans is orders of magnitude greater than the amount of uranium needed to supply 100% of the global energy demand [17]. This is in principle a perpetual supply, lasting as long as the sun continues to keep the earth in its present temperature range. But the great preponderance of this uranium is at exceedingly low concentrations, making recovery unaffordable with today's technology.

The NEA recently estimated the known and as yet unknown economically recoverable uranium reserves at 5.5 million tonnes (MT) and 10.5 million MT, respectively [18]. The threshold applied to establish "economic" was a mining cost of <$130/kg, about three times the current spot price. These reserves are large compared to the rate of uranium extraction, which peaked at 70 thousand MT in 1980 and has been in the 35-50 thousand MT annually in the last decade. Actual utilization of uranium has been steadily increasing, but a substantial fraction of the uranium consumed in recent years has come from secondary sources, primarily weapons stockpile drawdowns and depleted uranium (these are not included in the NEA resource estimates, but would not make a significant impact if they were).

The total energy that could be extracted from this resource is computed on the assumption that every uranium nucleus in the ore is fissioned, which would release about 1000 GW-days of energy per metric ton of uranium. This amounts to about 1.5×10^7 GW-yr of energy for the known economically recoverable reserves (and a factor of three higher if the projected but as yet unknown economically recoverable reserves are included). This is one order of magnitude higher than the corresponding figure for the world's total economically recoverable fossil fuel reserves (7.8 trillion barrels of oil equivalent, or 1.7×10^6 GW-yr). As an energy source three orders of magnitude larger than the current annual global energy consumption (at about 500 Quads), it is adequate to meet demand for centuries.

The nuclear fuel cycle in use today does not support the above optimistic resource outlook because only a small fraction of the uranium nuclei undergo fission. About one nucleus in every 140 is the fissionable 235 isotope but, in actual practice, the uranium utilization factor in LWRs is even smaller, less than one part in 200. This dramatically changes the sustainability conclusions: what is in principle an order of magnitude greater energy resource than fossil fuels becomes an order of magnitude lower energy resource, one that could only meet the plant's total energy need for a single decade.

Even a single pass mode of operation in a high temperature convert-and-burn reactor improves this resource picture significantly because uranium utilization is improved (a higher burnup fraction) and because the increased temperature translates into better energy conversion. But the big payoff in sustainability comes with fuel reuse. If enough (typically 50% is adequate) of each fission product is removed, the end-of-cycle fuel can be reused in a new cycle without adding any new fissionable material (fertile material is used for make-up). The effective uranium utilization increases rapidly with the number of burn cycles for two reasons: (1) comparable burnups occur in each generation, and (2) reuse as make-up fuel of the depleted uranium, which is produced as a byproduct of the initial fuel load.

If such a fraction of every fission product is removed at the end of each cycle, the reactivity reaches a steady state and can be continued indefinitely, allowing full uranium resource utilization. It is to be noted that the recycling process need not reduce the fuel to its elemental constituents and in fact need not involve any separation of actinides at all, which would be preferable from the standpoint of proliferation resistance. One promising approach to accomplishing this is the Archimedes mass filter [19], which takes advantage of the rather large gap between the mass of the actinides and that of the fission products.

VI. CONCLUSIONS

Economic considerations alone suggest that, in its present embodiment of GW-scale LWRs, nuclear power is unlikely to provide an increasing share of global energy supply. SMRs offer essentially the same technology with the potential for cost savings on several grounds, most notably factory fabrication and shortened construction schedules. However, these cost savings do not fully offset the penalty of reduced economy of scale. It is concluded that genuine innovation is required to change the economic realities of nuclear power. EM^2 is offered as an example of such innovation, embodying as it does the benefits attributable to small modular reactors but at nearly double the thermal conversion efficiency of the water-cooled units. Significantly lower power cost is forecast and the approach offers far more promise for the long-term sustainability of nuclear power.

ACKNOWLEDGMENT

The authors are grateful to Dr. Robert Schleicher and Puja Gupta for valuable input.

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John Parmentola, Ph.D.

Senior Vice President,
Energy and Advanced Concepts

Dr. Parmentola has built a career as a pioneer, entrepreneur and innovator, with broad experience in the private sector, academia and high-level positions within the federal government and defense community.

As Senior Vice President at General Atomics, he leads the California-based technology company's Energy and Advanced Concepts Group, focusing on energy, defense, advanced computing and oversight of DIII-D National Fusion Facility, the largest in the United States (U.S.). The Group's innovations include a revolutionary waste-burning compact advanced reactor, setting new land-speed records with maglev systems and building the world's most powerful superconducting electromagnet.

Dr. Parmentola served as Director for Research and Laboratory Management for the U.S. Army, directing lab management policy, infrastructure and security for all Army laboratories, research, development and engineering centers, and base realignment and closure efforts. He also oversaw a $1-billion combined budget for basic and applied research, manufacturing technologies, small business innovative research, and high-performance computing programs.

In addition, Dr. Parmentola served as science and technology advisor to the chief financial officer of the U.S. Department of Energy (DOE), where he provided technical, budgetary, and programmatic advice to DOE leaders for more than $7B in science and technology investments.

He also co-founded the Advanced Systems and Concepts Office of the Defense Threat Reduction Agency to address major national challenges concerning the threat of weapons of mass destruction, and has served as principal scientist at MITRE Corp., where he worked in applying advanced technology associated with the $1.8-billion Cheyenne Mountain Upgrade Program.

Born in the Bronx, New York, Dr. Parmentola earned a bachelor's of science in physics cum laude from Polytechnic Institute of Brooklyn, and his doctorate in physics from MIT. He was a Professor of Physics at West Virginia University.

Dr. Parmentola received the 2007 Presidential Rank Award for Meritorious Executive. He was also an Air Intelligence Agency nominee for the R. V. Jones Central Intelligence Agency award, and a recipient of the Outstanding Civilian Service Award and the Superior Civilian Service Award for his contributions to the U.S. Army. He received the Alfred Raymond Prize and the Sigma XI Research Award, and is a Fellow of the American Association for the Advancement of Science. He has presented and published more than 400 speeches, papers, and articles in science and technology policy and is the author of an authoritative book on space defense.

Enclosure 3

Committee on Science, Space, and Technology

U.S. House of Representatives

Witness Disclosure Requirement - "Truth in Testimony"
Required by House Rule XI, Clause 2(g)(5)

1. **Your Name:** Dr. John A. Parmentola

2. **Are you testifying on behalf of the Federal, or a State or local government entity?** Yes [✓ No]

3. **Are you testifying on behalf of an entity that is not a government entity?** [✓ Yes] No

4. **Other than yourself, please list which entity or entities you are representing:**

General Atomics, Energy and Advanced Concepts Group

5. **Please list any Federal grants or contracts (including subgrants or subcontracts) that <u>you or the entity you represent have received</u> on or after October 1, 2011:**

See Exhibit A

6. **If your answer to the question in item 3 in this form is "yes," please describe your position or representational capacity with the entity(ies) you are representing:**

Senior Vice President

7. **If your answer to the question in item 3 is "yes," do any of the entities disclosed in item 4 have parent organizations, subsidiaries, or partnerships that you are not representing in your testimony?** [✓ Yes] No

8. **If the answer to the question in item 3 is "yes," please list any Federal grants or contracts (including subgrants or subcontracts) that were received by the entities listed under the question in item 4 on or after October 1, 2011, that exceed 10 percent of the revenue of the entities in the year received, including the source and amount of each grant or contract to be listed:**

See Exhibit B

I certify that the above information is true and correct.

Signature: John Parmentola **Date:** 5/5/15

False Statements Act Certification

You are specifically advised that providing false information to this Committee/Subcommittee, or concealing material information from this Committee/Subcommittee, is a crime, and you can be punished for that. If you acknowledge this, please sign the bottom of this form and return to the Committee. This form will be made part of the hearing record.

John Parmentola

Witness signature

Date 5/5/18

EXHIBIT A - Response to Enclosure 3, Question No. 5

General Atomics - Energy and Advanced Concepts Group
Federal Grants/Subgrants/Contracts/Subcontracts
October 1, 2011 through March 31, 2015

No.	Description	GA Project	Customer
1	NSTX Fusion Device	30041	U.S. Department of Energy
2	DIII-D	30200	U.S. Department of Energy
3	ADVANCED CONCEPT EXPLORATION FC	30247	U.S. Department of Energy
4	Modeling Plasma Response	30251	University of California, San Diego
5	EDGE SIMULATION LABORATORY	30271	U.S. Department of Energy
6	NGNP Conceptual Design Studies	30302	Battelle Energy Alliance
7	BGCAPP FOAK II	30335	Parson Infrastructure & Technology Group Inc.
8	Fusion Science Center	30343	University of Rochester
9	LLNL Target Agreement	30347	Lawrence Livermore National Laboratory
10	Baseload Concentrating Solar Power Gen	30349	U.S. Department of Energy
11	BLU Demilitarization Using Cryofracture	30355	Advanced Technology International
12	LRIP Operations for Cryofracture Process	30361	Advanced Technology International
13	Hy-Tec EAFB	30363	U.S. Air Force
14	SAVIOR Unique Mobile Land/Water Survell.	30365	U.S. Army RDECOM Acquisition Center
15	ITER Central Solenoid Coil	30370	UT Battelle, LLC
16	Cellulosic Derived Biodiesal Program	30379	Eastern Kentucky University
17	HPDC MPHB RD&D	30381	Advanced Research Projects Age
18	Selective Gaseou Extraction: Research, D	30382	U.S. Department of Energy
19	Rockeye Bomblet Demil Operations	30383	Advanced Technology International
20	Project Raven	30384	Ralph Perkins Industries
21	CTAPS	30385	Naval Research Laboratory
22	Aluminum Power System	30387	Office of Naval Research
23	Characterization report for Janus12B	30388	Harvard University
24	TAPS	30389	Ralph Perkins Industries
25	ICF	30390	U.S. Department of Energy
26	SCIDAC Fusion Materials Modeling	30391	U.S. Department of Energy
27	Extreme Scale Data	30392	U.S. Department of Energy
28	Viscous Plastic Flow	30395	U.S. Department of Energy
29	Accident Tolerant Fuel Project	30396	Westinghouse Electric Company
30	Nuclear Energy University Programs - Rea	30398	Texas A&M University
31	NLUF - Laser Pulse and Plasma Investig.	30401	U.S. Department of Energy
32	BGCAPP Post FOAK Support	30402	Parson Infrastructure & Technology Group Inc.
33	Advanced SMR R&D Industry Support	30403	U.S. Department of Energy
34	TAPS II	30404	Ralph Perkins Industries
35	Scenarios and Control EAST/KSTAR	30405	U.S. Department of Energy
36	Modeling Plasma Response	30414	University of California, San Diego
37	Cryofracture Facility at MCAAP	30416	Advanced Technology International
38	ITER LFSR Diagnostic System	30417	Princeton Plasma Physics Laboratory
39	Coated Alloy Foil Targets	30420	University of Washington
40	Raven II	30422	Ralph Perkins Industries
41	NSTX Research -Plasma Boundary Interface	30423	U.S. Department of Energy
42	ITER Wide Angle Viewing System	30424	Princeton Plasma Physics Laboratory
43	Advanced Tokomak Modeling	30425	U.S. Department of Energy
44	EHT SBIR Support	30428	Eagle Harbor Technologies Inc.
45	PPPL TIP	30429	Princeton Plasma Physics Laboratory
46	DOE Education Outreach	30430	U.S. Department of Energy
47	Mod to EFIT Code	30435	Princeton Plasma Physics Laboratory
48	ONR UUV MRS Network Link	30436	Leidos
49	LLNL Task Agreement	30437	Lawrence Livermore National Laboratory
50	ARC - Complex SiC - SiC Structures	30438	U.S. Department of Energy
51	HOLLOMAN MAGLEV FOLLOW-ON	37023	U.S. AIR FORCE

EXHIBIT A - Response to Enclosure 3, Question No. 5
General Atomics - Energy and Advanced Concepts Group
Federal Grants/Subgrants/Contracts/Subcontracts
October 1, 2011 through March 31, 2015

52	New Fuel Receipt Support	39293	Battelle Energy Alliance
53	Support Reactor Relicensing Tasks	39364	Battelle Energy Alliance
54	HPPP Engineering Support Service	39387	Rock Island Contracting Center
55	SAICTead iSCWO	39406	Leidos
56	Nonlinear Evolution of the Weibel	39418	Lawrence Livermore National Laboratory
57	MIT-LL 0.8" WG Components	39419	Massachusetts Institute of Technology
58	Support to Reactor Tech Programs	39420	Shaw Environmental and Infrastructure
59	ROK SCWO Support	39421	McAlester Contracting Office
60	Fabricate Waveguide and Components	39422	UT Battelle, LLC
61	Targets for MEC Commissioning Experiment	39424	SLAC National Accelerator Laboratory
62	I&C-IPT Plasma Control Group Support	39425	UT Battelle, LLC
63	ITER Disruption Mitigation	39426	UT Battelle, LLC
64	Ion Cyclotron Heating Concept & Design	39428	UT Battelle, LLC
65	Feasibility and Safety Assessment for Ad	39430	Oregon State University
66	Tritium Autonomous Power Source	39431	Athena Energy Corp
67	ONRTS Phase II	39432	Hydro Technologies
68	SiC Joining	39433	Battelle Energy Alliance
69	LCLS MEC Targets	39439	SLAC National Accelerator Laboratory
70	SEM Lab Services	39440	Coorstek
71	SWIM Web Portal Maintenance	39441	UT Battelle, LLC
72	Supt of Uranium Processing Facility Rev.	39442	Navarro Research & Engineering
73	MTLS Phase I Test Support	39448	ARSC Research & Technology Solutions
74	SHEDS	39450	Naval Surface Warfare Center-Crane
75	MITR Feasibilility Study	39454	Battelle Energy Alliance
76	Acoustic Measurement & Connector Topology	39479	University of Texas at Dallas
77	Modified Battery Modules	39481	Naval Surface Warfare Center-Crane
78	Targets for LINAC Coherent Light Source	39482	SLAC National Accelerator Laboratory
79	Salt Waste Continuation	39485	Parson Infrastructure & Technology Group Inc.
80	LINAC Carbon Targets	39498	SLAC National Accelerator Laboratory
81	Material Processing for Energy Applications	39506	San Diego State University
82	Diamond Multi-Step Targets	39508	SLAC National Accelerator Laboratory
83	Update Control Sys & Support for SCWO	39512	McAlester Contracting Office
84	Support to BGCAPP Construction and Syste	39513	Parson Infrastructure & Technology Group Inc.
85	Targets for MEC Experiments	39515	SLAC National Accelerator Laboratory
86	Test Articles, 7P3S	39516	Naval Surface Warfare Center-Crane
87	Aluminum Microdot Targets	39518	SLAC National Accelerator Laboratory
88	Kirtland AFB Waveguide Components	39524	Leidos
89	Modeling Dynamic Fracture	39529	UT Battelle, LLC
90	Mu2e	39532	Fermilab
91	Fabrication of SiC/SiC Tubes	39533	UT Battelle, LLC
92	Test and Evaluation Battery System	39536	Ralph Perkins Industries
93	ICF OPERATING/Capital	30272/30273	U.S. Department of Energy
94	Miscellaneous Intercompany Purchase Orders	Various	Various

EXHIBIT B - Response to Enclosure 3, Question No. 8
General Atomics - Energy and Advanced Concepts Group
Major Federal Grants/Subgrants/Contracts/Subcontracts
October 1. 2011 through March 31, 2015

No.	GA Project Name	GA Project No.	Customer Name	Funding Source	Contract Number	Amount*
1	DIII-D	30200	U.S. Department of Energy	DOE	DE-FC02-04ER54698	331,327,790.00
2	BGCAPP FOAK II	30335	Parson Infrastructure & Technology Group Inc.	DOD	W52P1J-09-C-0013	15,111,398.00
3	ITER Central Solenoid Coil	30370	UT Battelle, LLC	DOE	DE-AC05-00O22725	120,857,816.86
4	ICF	30390	U.S. Department of Energy	DOE	DE-NA0001808	84,093,831.00
5	Mu2e	39532	Fermilab	DOE	618313	20,323,263.00

*Amount awarded during the period October 1, 2011 through March 31, 2015