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Small Modular Nuclear Reactors: LEGO for Adults or the New PC Revolution?

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Companies mentioned in this report:
Apple (NASDAQ: AAPL)
Solyndra (Private)
Babcock & Wilcox (NYSE: BWC)
Bechtel Power (Private)
Generation mPower LLC (Private)
Westinghouse Electric Co. (Private)
NuScale Power (Private)
Fluor Corp. (NYSE: FLR)
SMR, LLC (Private)
Holtec International (Private)
The Shaw Group (NYSE: SHAW)
TerraPower (Private)
Intellectual Ventures (Private)
Microsoft (NASDAQ & NYSE: MSFT)
Argonne National Laboratory (Private)
GE Energy (NYSE: GE)
Hyperion Power Generation (Private)
Duratek (NASDAQ: DRTK)
EnergySolutions (NYSE: ES)

Products mentioned in this report:
UX Uranium
CL Light Sweet Crude Oil (WTI)
NG Natural Gas Henry Hub

Executive Summary

In today's world of electric cars, large LED televisions and just about everything **Apple** (AAPL), the need for increased electrical power has become vital for the U.S. to remain competitive on the global stage. Contrary to some views, we are not a nation of slackers. We are a country trying to find its way in the 21st century. Sure, we make mistakes like investing in **Solyndra**, but we must continue to move forward and not be afraid to find tomorrow's energy sources. As basketball great Michael Jordan once said: "I've missed more than 9,000 shots in my career. I've lost almost 300 games. 26 times, I've been trusted to take the game-winning shot and missed. I've failed over and over and over again in my life. And that is why I succeed." One way **Blue Phoenix Inc.** (BPI) believes the U.S. can succeed to "power" its future growth and industrial swagger is by implementing *small modular nuclear reactors* (SMRs). It is our belief that SMRs can do for energy what the PC did for computing. Somewhere Steve Jobs must be looking down at us from above thinking "i-modular." Our analysis rips the veil off the SMR industry and highlights names to watch in the space, including one Jobs' old friend Bill Gates endorses.

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Table of Contents

List of Tables

Background

According to the International Atomic Energy Agency, the global demand for small modular reactors could reach 500 to 1,000 reactors by 2040.[1] The Obama administration has certainly been gun-shy about pulling the trigger on a national energy policy, but all could be forgiven if they help usher in a warm reception toward small nuclear reactors (SMRs) which are typically 125-300 megawatts (MW) in size. That warm and fuzzy stance on SMRs is backed by the department's 2012 budget proposal which includes a request for $500mln over five years to help develop SMRs. These SMRs would be owned by a utility and would supply electricity to the Oak Ridge National Lab in Tennessee. This is certainly a step in the right direction for meeting the country's goal of cutting carbon emissions by 28% from 2008 levels by 2020.

So while drilling for oil off the shore of Louisiana is again moving forward despite no national safety mandate, coal use is off slightly as natural gas and hydropower help satisfy more electricity needs.[2] But is that enough? Blue Phoenix Inc. (BPI) does not think so. In fact, we believe unless the U.S. adopts SMRs and expedites the permitting process prior to 2018, there is little chance we can meet that 2020 emissions target.

Historically, the three biggest problems plaguing the growth for building nuclear reactors have been safety, long-term waste, and cost. However, the costs of construction of SMRs would range from a few hundred million dollars to $2 billion, versus over $10 billion for a twin-unit nuclear complex. Granted, SMRs are not built to compete with output levels from new nuclear plants, and they are really only a quarter of the power seen in big reactors. But these SMRs can help reduce our carbon footprint and the need for coal plants. SMRs produce dependable baseload power that is more affordable for isolated communities, and they can be used in remote areas by energy and metals production companies while traditional reactors cannot.

The first mainframe computer (HUAC) cost millions of dollars. The first personal computer (PC) was the IBM 5100, which was introduced in 1975. The Apple II, which had a keyboard and color graphics capability, retailed for $1,290 back in 1977. The point is that as computers became more compact and more usable, demand surged as the PC became widely adopted by the masses. Now the letters "PC" as we know it can have new meaning because the SMRs can redefine power needs by adding supply when needed at a low cost. Therefore "PC" can be considered "Personal Charge" in the future, and that bodes well for makers of SMRs.

President Barack Obama wants to help, too, designating $853 million for nuclear research, including small-scale reactors, in his proposed 2012 budget.[3]

[1] http://www.wealthdaily.com/articles/small-modular-reactors-nuclear-power-game-changer/2400
[2] http://www.eia.gov/steo/
[3] http://online.wsj.com/article/SB10001424052748704409004576146061231899264.html

Issues & Barriers to Entry

There is an uncertain future of nuclear power post Fukushima, which could curb investment and permitting, as well as research and development (R&D) needed to validate new technologies associated with the advancement of SMRs. BPI firmly believes exodus out of the nuclear space by investors and leading industrial countries like Germany was a gross overreaction (see our 10/28/2011 note titled *Uranium Investors Welcome Home*). However, Fukushima does illustrate a good lesson to be learned and public opinion about nuclear energy has become cynical. This makes it ever more difficult for new companies to break into the nuclear industry when trusted name brands who have established a solid reputation control a majority of this space.

Even before the Fukushima disaster, regulation and permitting was, and continues to be, extremely strict. The Nuclear Regulatory Commission (NRC) has a rigorous application process. It takes years of testing reactors and facilities before the application is even submitted to the NRC. It then takes several more years (approximately three) before the application is reviewed and (hopefully) approved. Other agencies also have interests in regulating various aspects of nuclear reactors. The Environmental Protection Agency (EPA) has to oversee actions such as the use of bodies of water for cooling, as well as proper nuclear waste disposal. State and other local regulators also account for additional directives.

The application process is a timely and costly one. But the capital cost of nuclear reactors is an even greater burden. From obtaining permits, mining uranium, and training/educating your employees, to purchasing land, buildings, and maintaining high levels of security, nuclear reactors are exorbitant. There is still a high cost structure for SMRs, despite output (300 MWe at best) being much less than traditional reactors that have 1,000 to 1,600 MWe. There is also a great need for high security of the SMRs, which would add to overall cost structure.

SMR Advantages

With the rising prices of foreign oil and the potential environmental effects of hydraulic fracturing to obtain natural gas, nuclear energy stands out as an obvious alternative energy source. Quite simply, nuclear energy is clean and reliable. It is a carbon-free energy source that does not release air pollution like present-day fossil fuel plants. It also generates electricity over 90% of the time, unlike solar and wind energies which are extremely intermittent. The US continues to see its dependence on nuclear grow, as ground has recently been broken for nuclear power plant construction in both Georgia and South Carolina.

The outlook for nuclear energy is encouraging, but the fact of the matter still remains that smaller utilities cannot afford the high capital cost of building new reactors. But have no fear, SMRs are here! SMRs, typically the size of a railroad car or smaller, can range anywhere between 25-300 MWe of power. Because of their size, these reactors are factory-built and then shipped to the nuclear site for a fraction of the price of a large reactor. This volume manufacturing through pre-assembly and standardized shipping helps reach economies of scale, thus lowering costs. As an example, NuScale Power anticipates its 12-module, 540-

MWe plant to cost approximately $2.2-2.5 billion, which is significantly less per unit of output than a large reactor.[4] SMRs also owe some of their cost-savings to their simpler design by eliminating the need for several components.

SMRs also offer the element of scalability: the ability to add modules as the need for electricity increases. Since SMRs are seen as energy sources for remote locations, as these areas quite possibly grow and energy demand increases, more modules can easily be added to the current system for additional output power.

SMRs exhibit passive safety systems as well. These systems use physical properties, rather than electronic measures, in the event of an emergency shutdown. SMRs use gravity-induced rods in the event of a shutdown. These control rods are held in place electromagnetically in place above the core, so if power is lost, the rods lower into the core by the force of gravity and shut down the primary nuclear reaction. This means no emergency diesel generators and no reliance on off-site power. Moreover, these safety systems also require no operator intervention for seven days in the event of an accident. For further safety, and also security, these reactors can also be placed underground due to their smaller size.

Nuclear Reactor Generations

Nuclear reactors can be classified in a number of different ways: type of nuclear reaction, moderator material, coolant, generation, phase of fuel, use, etc. While most of these attributes offer their own distinct advantages and disadvantages, it is our belief at BPI that the generation classification reveals the most significant investment foresight.

There are four principal categories of nuclear reactor generations. Generation I reactors include early prototypes developed from initial nuclear research during the period of 1945-1965. Almost all of these reactors are now retired. Generation II reactors, which span 1965-1995, are comprised of the light water reactors (LWRs) that are used for a majority of today's commercial power. Within the Generation II reactors falls the sub-category of Generation II+ reactors. These reactors, developed post 2000, consist of modernized advancements and improvements in safety, economics, and operating life. Generation III reactors have been the central focus point from 1995-2010. These advanced LWRs have seen leaps and bounds in improving fuel technology, thermal efficiency, safety, and standardization. A sub-category of Generation III+ reactors exists as well. These reactors are dubbed the "near-term deployment" reactors, and they will see further enhancements to economics, sustainability, safety, and reliability between the years of 2010-2030. Finally, there are the Generation IV reactors. These reactors will not be deployed until the year 2030+, as they require more R&D and technological progressions. Once these reactors are available, the nuclear world will be vastly different from what we see today. The Generation IV reactors will show even greater improvements in economics, sustainability, safety, efficiency, and reliability, as well as reducing (by possibility consuming) waste and being proliferation resistant. Below, Table 1 summarizes the nuclear reactor generations.

[4] http://www.delmarvanow.com/article/20111201/OPINION01/112010364

Table 1: Nuclear Reactor Generations

Generation	Deployment	Brief Description	Notes
I	1945-1965	Early Prototypes	Early prototypes and initial nuclear research.
II	1965-1995	Commercial Power	Light water reactors (LWRs).
II+	Post 2000	"Modernized"	Improved safety and economics.
III	1995-2010	Advanced LWRs	Improved fuel technology, superior thermal efficiency, passive safety systems, and standardized design.
III+	2010-2030	"Near-Term Deployment"	Improved economics, sustainability, safety, and reliability.
IV	2030+	The Future/More R&D	Continued improvements in economics, sustainability, safety, efficiency, and reliability. Minimal waste and proliferation resistant.

Nuclear Reactor Types

There are a number of different reactor types, some currently available and others requiring additional R&D. Pressurized water reactors (PWRs) and boiling water reactors (BWRs) present the lowest technological risk since both types have been manufactured for decades. However, there are several other types of Generation IV reactors that offer unique improvements to existing designs. These include the following:

- Supercritical Water Reactor (SCWR)
- Traveling Wave Reactor (TWR)
- Fast Neutron Reactor (FNR)
- High Temperature Reactor (HTR)
- Molten Salt Reactor (MSR)
- Aqueous Homogeneous Reactor (AHR)

A summary of all eight SMR types can be found below in Table 2.

Table 2: Nuclear Reactor Types

Type	Advantages	Disadvantages
PWR	1. Stable 2. Most advanced technology 3. Separate primary and secondary cooling loops	1. Complexity to maintain very high pressure 2. Corrosive products in coolant leads to maintenance and replacement
BWR	1. Less complex 2. No corrosive products 3. Standardized design	1. Complex to manage nuclear fuel consumption 2. Control rods hydraulically lifted from below
SCWR	1. Simpler design 2. Higher thermal efficiency, more reliable	1. Higher pressure and temperature 2. Higher enrichment level of uranium
TWR	1. Uses both U-235 and U-238 as fuel 2. Reduces proliferation risks 3. More stable and sustainable	1. Currently theoretical, needs more R&D
FNR	1. Reduces radiotoxicity of waste and waste's lifetime	1. Uneconomical 2. More complex 3. Needs highly enriched fissile material
HTR	1. Natural cooling 2. Graphite core has high heat capacity and structural stability	1. Very high temperatures 2. Corrosion materials for molten salt coolant
MSR	1. Increased safety and efficiency 2. "Melt-down proof"[5]	1. Costs of thorium and lack of testing for thorium as coolant[6] 2. Higher temperatures
AHR	1. Little enriched uranium is needed 2. Self-controlling features 3. Ability to handle very large increases in reactivity	1. Unproven technology needing further R&D

Investment Thesis

Due to the background information BPI has uncovered during its research, we believe that the most promising SMR investments meet the following criteria: a Generation III+ PWR near submitting its NRC application that is designed and manufactured by a reputable and experienced firm. A SMR fitting this description lends itself to an investment period of approximately 7+ years, while posing the least risk due to the decades of experience in PWR technology by firms. We discuss several companies that we believe meet these criteria and their SMR technology is summarized in Appendix 2.

[5] http://www.innovationnewsdaily.com/nuclear-power-thorium-future-1834/
[6] http://energyfromthorium.com/joomla/index.php?option=com_content&view=article&id=64&Itemid=63

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Near-Term Investments

The Babcock and Wilcox Company (BWC) is a publicly traded firm that is headquartered in Charlotte, NC. Aimee Mills, Communications Specialist, believes this company's brand recognition and its alliance with **Bechtel Power** lend credibility that their SMR, the B&W mPower. The company describes its SMR in the following manner:

> The B&W mPower reactor builds on the strength of two industry leaders – Babcock & Wilcox Nuclear Energy (B&W NE) and Bechtel – which have formed a joint company, Generation mPower LLC. Generation mPower combines B&W NE's expertise in nuclear engineering and manufacturing, including an existing NSSS supply chain, with Bechtel's plant engineering, procurement and construction capability.[7]

Perhaps that is why **Generation mPower LLC** is the only company that already has their first utility company lined up to purchase and use their SMR. And the Tennessee Valley Authority (TVA) is quite a reputable first customer to procure. Aside from the obvious benefit of the TVA securing orders of the mPower, another advantage is the "plug-and-play" method adopted for the SMR's core, which makes its replacement much simpler. It also minimizes water use, as it is designed to accommodate both an air-cooled and water-cooled condenser on the secondary coolant system to condense the steam and return it to the reactor as "feedwater." This "will allow siting the reactor in a variety of locations that do not have abundant sources of water cooling."[8] A picture of the mPower can be seen in Appendix 3.

The Cranberry Township, PA based **Westinghouse Electric Company, LLC** is another reputable firm with a reliable SMR design being released in the near future. The Westinghouse SMR is a smaller design based upon the Westinghouse AP1000 design. The Westinghouse AP1000's claim to fame is the fact that it is the only Generation III+ reactor to receive design certification by the NRC. If this does not say enough for the outlook of the Westinghouse SMR, Angela Fenwick (Public Relations and Marketing Communications) boasted to BPI about the single pressure vessel that contains all components associated with the steam supply system.[9] A picture of the Westinghouse SMR can be seen in Appendix 3.

NuScale Power, LLC is a private company headquartered in Corvallis, OR that is solely focused on constructing and selling its SMR. The company's Chief Marketing Officer, Bruce Landrey, took some time to discuss with BPI the SMR's competitive advantages. He directed BPI's attention to four topics: safety, scalability, volume manufacturing, and commercial availability. NuScale's unique design of placing the reactor in a steel containment vessel underground in a pool of water, coupled with its natural circulation and passive cooling, offers an extremely safe design for removing residual heat from the fuel. Mr. Landrey also describes this as a "truly scalable" design, offering anywhere between one to twelve units (or 45-540 MWe) depending on its purpose (i.e., small power demand from remote location versus a bigger utility scale). NuScale can reach economies of scale since each module is

[7] Interview with Aimee Mills, Communications Specialist, The Babcock & Wilcox Company, 12/06/2011
[8] Interview with Aimee Mills, Communications Specialist, The Babcock & Wilcox Company, 12/06/2011
[9] Interview with Angela Fenwick, Public Relations & Marketing Communications, Westinghouse Electric, 12/06/2011

factory-made and shipped by rail, truck, or barge. But perhaps NuScale's biggest advantage is the fact that the company has had its own test facility in operation since 2003, lending itself to the nearest term commercial availability. In October 2011, the engineering, procurement, construction, and maintenance services organization **Fluor Corporation** (FLR) purchased a $30M majority interest in NuScale.[10] NuScale expects additional relationships to form in the upcoming years.[11] A picture of NuScale's SMR can be seen in Appendix 3.

SMR, LLC (a subsidiary of **Holtec International**, a private firm in Jupiter, FL), currently enlisting the engineering and construction services of **The Shaw Group Inc.**, (SHAW) is dedicated to developing its HI-SMUR (Holtec Inherently-Safe Modular Underground Reactor). The company defines the HI-SMUR's mission as the "utmost [in] safety and security." This can be seen in the underground reactor vessel, which has no penetrations in order to provide a drain-down path for the reactor coolant. By eliminating coolant pumps and being inherently safe (i.e., not relying on off-site power to cool the core in the event of a forced shutdown), the HI-SMUR is passively safe in every aspect of its operation. Similar to NuScale's SMR, the HI-SMUR can be installed as a single unit or a cluster. SMR, LLC also sees the HI-SMUR being shop manufactured and then delivered to the site, thus leading to volume manufacturing and economies of scale.[12] A picture of the HI-SMUR can be seen in Appendix 2.

Long-Term Investments

Although PWRs are the near-term deployment SMRs of the next decade, there are a number of potential SMR technologies on the horizon. A key element for these future SMRs is that they no longer use water as a coolant. Current PWRs use rivers, seawater, and other natural bodies of water to cool their systems. These waterbeds can lose their functionality due to extreme weather conditions or bio-fouling regulations. Also, the pumps that circulate the water through the reactor system can suffer leaks at the seals, so maintenance and replacement is necessary.[13] Together with maintaining extremely high pressure, these two factors combine to add to the overall complexity of the system.

We begin our discussion of long-term SMR investments with a company that has a rather famous investor. Bill Gates of **Microsoft Corporation** (MSFT) is a primary investor in **TerraPower, LLC** (a subsidiary of **Intellectual Ventures** located in Bellevue, WA).[14] TerraPower is passionately involved in advancing its TWR design. The TWR, although still in its early stages, has a promising future, which can be seen by its numerous alliances most notably with **Argonne National Laboratory** and **GE Energy** (GE). BPI was able to speak with Sarah Dirndorfer, Project Coordinator for Potomac Communications Group, who works alongside the TerraPower media team. She provided us with materials that discussed the

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10 http://investor.fluor.com/phoenix.zhtml?c=124955&p=newsarticle_pf&id=1617012
11 Interview with Bruce Landrey, Chief Marketing Officer, NuScale Power, 11/28/2011
12 http://www.holtecinternational.com/
13 http://www.roe.com/pdfs/technical/galena/20070312_containment_whitepaper_rev01.pdf
14 http://raymondpronk.wordpress.com/2010/02/04/bill-gates-goes-nuclear-with-the-terrapower-traveling-wave-reactor-the-next-big-thing-innovation-and-technology-making-a-difference/

TWR's very distinct feature of nuclear transmutation; a truly remarkable feat that would change the world of nuclear energy. This process converts fertile material into fissile fuel as it runs. Through this process, the TWR can reach a state of high fuel utilization without the need for enriched uranium or reprocessing. It instead burns depleted uranium, natural uranium, or spent fuel. According to TerraPower, there is currently 700,000 metric tons of this low-level nuclear leftover product in the U.S. alone. The TWR's 14-ton canister of depleted uranium could generate 60 million MWh of electricity, which is enough to power 6 million U.S. households for one year. The TWR can also run on a self-sustained basis for 40-60 years without the need to refuel or remove used fuel. The TWR results in a cleaner, safer fuel cycle.[15] A picture of the TWR can be seen in Appendix 3.

Hyperion Power Generation is another company in the process of developing a Generation IV reactor. This Denver, CO based private company was founded in 2007 specifically to commercialize the Hyperion Power Module (HPM). The HPM is a FNR that offers a number of advantages over present day PWRs. Cody Pearson, Corporate Knowledge Manager at Hyperion, told us that he sees distinct advantages arise due to the HPM's fuel and coolant. The HPM uses ≈20% enriched uranium nitride. This unique fuel type and enrichment level allows the HPM to operate for 7-10 years, which is significantly longer than today's PWRs (18-24 months), thus alleviating supply lines. The HPM also uses a lead bismuth eutectic (LBE) coolant, simplifying the reactor's design while simultaneously improving safety. This liquid metal boils at three times the reactor's operating temperature, permitting core operation at ambient pressure and eliminating the requirement of a pressure vessel. An additional bonus is that LBE is an excellent gamma shield. Hyperion is led by CEO Robert Prince, who saw **Duratek, Inc.** (DRTK), a nuclear waste management firm, grow under his leadership until its acquisition by **EnergySolutions, Inc.** (ES) in 2006. Hyperion sees a number of strategic alliances on its horizon, utilizing their new CEO's rolodex. [16] A picture of the HPM can be seen in Appendix 3.

Conclusion

Nuclear energy and SMRs are vital to U.S. energy growth. This piece focused on American-based manufacturers of SMRs that fit BPI's investment criteria: **1)** established and trusted brand, **2)** Generation III+ reactor, **3)** PWR, and **4)** NRC application near submission. A SMR fitting this description lends itself to an investment period of approximately 7+ years, while posing the least amount of risk due to the decades of experience in PWR technology.

BPI believes that we have introduced the major players in the SMR space, but we recognize that by no means is this piece exhaustive. For further information on the SMRs mentioned in this piece, or the companies that produce them, please see Appendix 1 for a list of company websites. Additionally, a list of well-advanced small- and medium-sized reactors from around the globe can be found in Appendix 4.

[15] Interview with Sarah Dirndorfer, Project Coordinator, Potomac Communications Group Inc., 12/06/2011

[16] Interview with Cody Pearson, Corporate Knowledge Manager, Hyperion Power Generation, 11/21/2011

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Appendix 1: List of SMR & Company Websites

SMR	Company	Website
Westinghouse SMR	Westinghouse	http://www.westinghousenuclear.com
mPower	Babcock & Wilcox	http://www.babcock.com
NuScale SMR	NuScale	http://nuscale.com
HI-SMUR	Holtec	http://www.holtecinternational.com
TerraPower TWR	TerraPower	http://www.terrapower.com/home.aspx
Hyperion PM	Hyperion	http://www.hyperionpowergeneration.com

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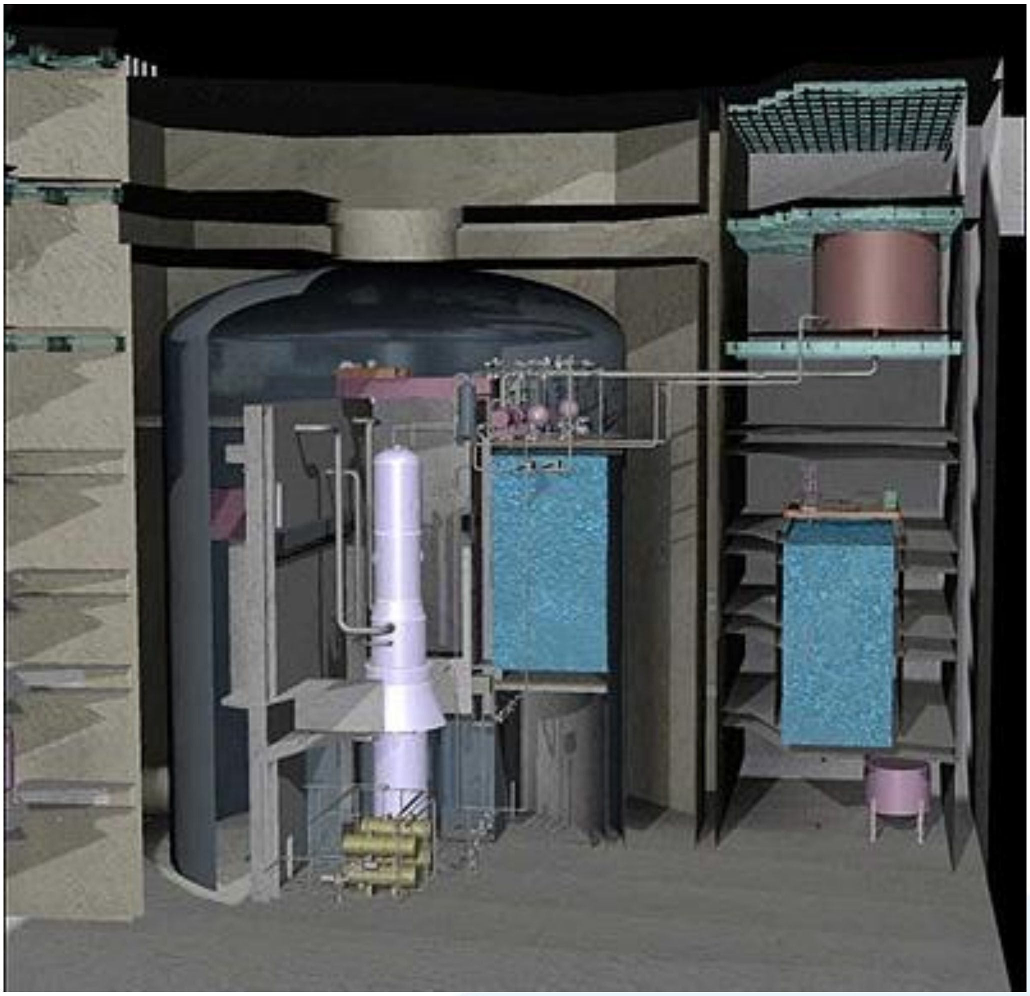
Appendix 2: Summary of SMRs

SMR	Company	Type	Coolant	Moderator	MWe	MWth	Core	Fuel	Refuel	Deployment
Westinghouse SMR	Westinghouse	PWR	Light Water	Light Water	225	800	Control Rods	≈5% Enriched Uranium	2 Years	2020
mPower	Babcock & Wilcox	PWR	Light Water	Light Water	125	400	"Plug & Play"; Control Rods	≈5% Enriched Uranium	4-5 Years	2020
NuScale SMR	NuScale	PWR	Light Water	Light Water	45	160	Control Rods	≈5% Enriched Uranium	2 Years	2018
HI-SMUR	Holtec	PWR	Light Water	Light Water	140	N/A	Control Rods	≈5% Enriched Uranium	2 Years	N/A
TerraPower TWR	TerraPower	TWR	Molten Sodium	N/A	500	1200	Control Rods	Depleted / Natural Uranium	40-60 Years	2025
Hyperion PM	Hyperion	FNR	LBE	Graphite	25	70	Control Rods	≈20% Enriched Uranium Nitride	7-10 Years	2015

Appendix 3: Images of SMRs

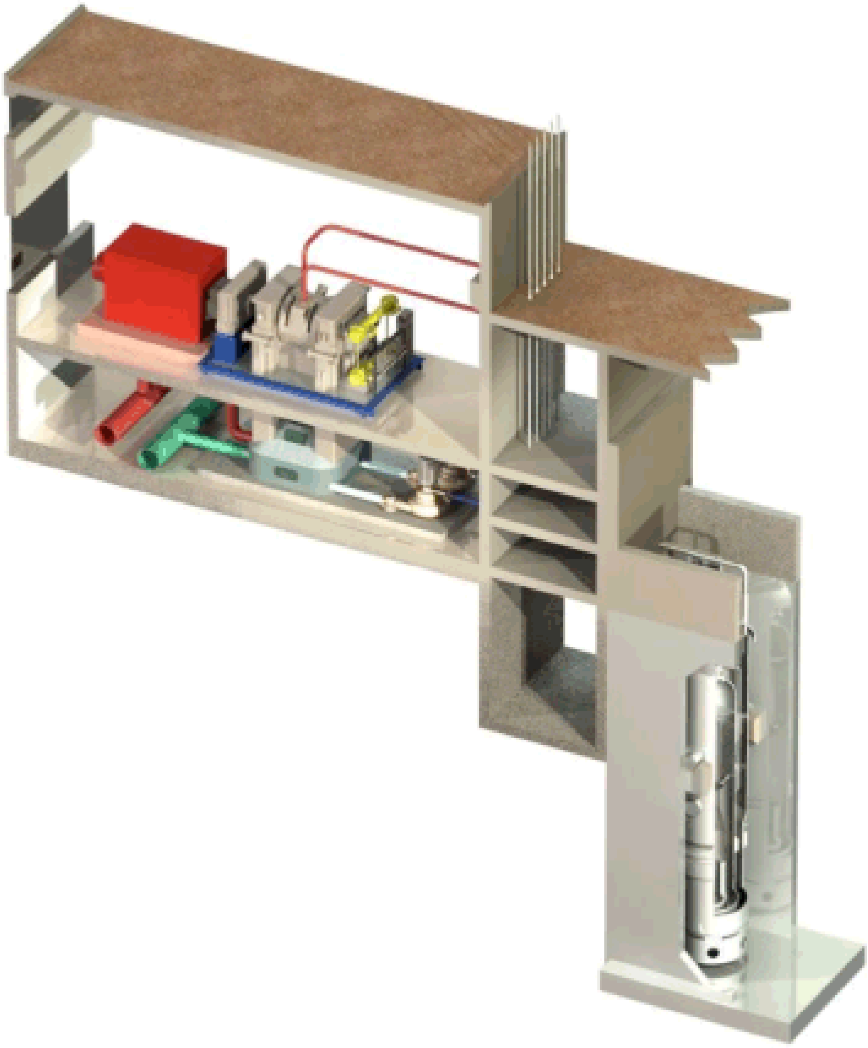


A3.1 The B&W mPower

Source: The Babcock and Wilcox Company

A3.2 Westinghouse SMR

Source: Westinghouse Electric Company



A3.3 NuScale SMR

Source: NuScale Power

A3.4 TerraPower TWR

Source: TerraPower

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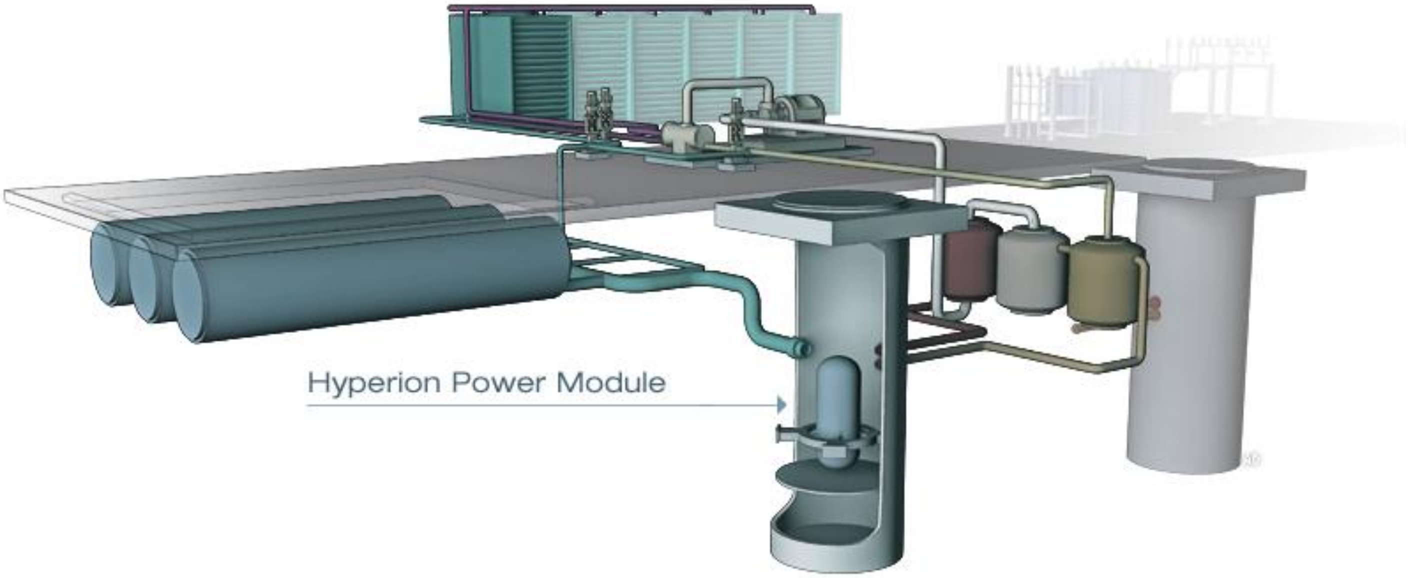

A3.5 Hyperion Power Module

Source: Hyperion Power Generation

Appendix 4: Well-Advanced Global Medium & Small Reactors

Name	Capacity	Type	Developer
KLT-40S	35 MWe	PWR	OKBM, Russia
VK-300	300 MWe	BWR	Atomenergoproekt, Russia
CAREM	27 MWe	PWR	CNEA & INVAP, Argentina
IRIS	100-335 MWe	PWR	Westinghouse-led, international
Westinghouse SMR	200 MWe	PWR	Westinghouse, USA
mPower	125 MWe	PWR	Babcock & Wilcox, USA
SMART	100 MWe	PWR	KAERI, South Korea
NuScale	45 MWe	PWR	NuScale Power, USA
HTR-PM	2x105 MWe	HTR	INET & Huaneng, China
PBMR	80 MWe	HTR	Eskom, South Africa
GT-MHR	285 MWe	HTR	General Atomics (USA), Rosatom (Russia)
BREST	300 MWe	FNR	RDIPE, Russia
SVBR-100	100 MWe	FNR	Rosatom/En+, Russia
Hyperion PM	25 MWe	FNR	Hyperion, USA
Prism	311 MWe	FNR	GE-Hitachi, USA
FUJI	100 MWe	MSR	ITHMSO, Japan-Russia-USA

Source: World Nuclear Association

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