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ECONOMIC AND EMPLOYMENT IMPACTS OF SMALL MODULAR NUCLEAR REACTORS

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ECONOMIC AND EMPLOYMENT IMPACTS OF SMALL MODULAR NUCLEAR REACTORS

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Section 1: Introduction and Highlights

Global energy demand is growing and, while fossil fuels will continue to play an important role in supplying future energy requirements, the role of nuclear power may increase significantly as rising energy demand is balanced with the need to effectively address issues such as climate change, domestic energy security, and electricity access and utilization by developing economies. While nuclear power is likely to be a major provider of future energy needs, the structure of the commercial nuclear power industry may change. In the U.S., the commercial development of nuclear energy during the 1970s was characterized by large power plants designed to generate electricity. Although the construction of new nuclear power plants experienced a hiatus in the U.S. over recent decades, the continued development of large nuclear plants of approximately 1,000 megawatts (MW)[1] and higher continued elsewhere and demonstrated advances in safety, performance, and efficiency. While advances in large nuclear power facilities continue, the recent resurgence of interest in nuclear power in the U.S. has also led to increased attention and statements of Administration support for the development and licensing of new technologies such as smaller-scale reactor systems, including the creation of an office within the Department of Energy to aid in these activities (Chu, 2010; Black, 2010).

Several recent studies and government presentations document the revived interest in small nuclear power reactors for a variety of uses (Ingersoll, 2009; Carelli, et al., 2010; Office of Nuclear Energy, 2009; World Nuclear Association, 2010). This increased attention on small reactors is influenced primarily by factors such as the initial reduced capital costs compared to traditional nuclear facilities and the potential for small nuclear facilities to provide power in areas where the infrastructure to support large reactors may be lacking. A recent report by the World Nuclear Association generalized the primary advantages of small modular nuclear reactors (SMRs) over traditional nuclear reactor designs, stating that "modern small reactors for power generation are expected to have greater simplicity of design, economy of mass production, and reduced siting costs. Many are also designed for a high level of passive or inherent safety in the event of malfunction" (World Nuclear Association, 2010).

Because of such attributes, SMRs are capable of obtaining a strong market presence and supplying an increasing portion of rising energy demand over the coming decades. As a result, a prospective investigation of their market potential and economic importance is warranted. This report, conducted by the Center for Advanced Energy Studies' Energy Policy Institute, evaluates the future market potential and economic impact of the manufacture, construction, and operation of SMRs in the U.S. for a 20-year period. More generally, it seeks to answer an important question: What impacts might domestic SMR manufacture have on the U.S. economy under given scenarios?

To do so, this study begins by reviewing the types, advantages, and potential uses of SMRs currently under development. The market potential is assessed by developing estimates of projected energy demand until 2030, the estimated share of energy production by SMRs, and the estimated market share of SMRs likely to be manufactured in the U.S. Four cases are developed to cover a range of scenarios of

[1] Throughout the report, MW refers to electrical capacity except where specifically noted.

future energy demand and SMR adoption. The economic impacts of a domestic SMR industry are then estimated by calculating the effects of manufacturing SMRs in the U.S. for both domestic use and for export to other countries. In addition to the impacts from manufacturing and constructing SMRs in the U.S., the continuing operation of SMRs will generate further economic activity, the impacts of which are also estimated in this study.

Total nuclear market share for electricity generation in each case comes from established models and datasets provided by the US Energy Information Administration, the International Atomic Energy Agency, and the Electric Power Research Institute. These models and datasets internalize some displacement of fossil fuels by nuclear power due to greenhouse gas regulation and technological advances. Therefore, in this study's market analysis SMRs are assumed to capture only a share of the forecasted nuclear power capacity additions. It is reasonable to posit that SMRs are capable of displacing additional non-nuclear electricity generation sources, but this displacement depends on factors outside of the study parameters and the datasets provided by the above organizations.

Findings at a Glance

- Types of SMR designs are reviewed
    - SMRs utilizing light water reactor (LWR) designs have advantages for Nuclear Regulatory Commission (NRC) licensing requirements in the U.S.

- SMRs have some advantages over large-scale facilities
    - Relatively small size and modularity means lower initial capital expenditures, shorter manufacturing lead-times, and potentially less risk of cost overruns.
    - Modular design offers better matching to a variety of grid infrastructure, has the ability to incrementally increase supply, and offers flexibility in adapting to changing market conditions.
    - SMRs offer improved fabrication and construction logistics.
    - SMRs retain, and seek to enhance, the safety features of conventional nuclear plants. Also, as with conventional nuclear plants, SMRs produce essentially zero criteria and carbon dioxide emissions.

- SMRs can be used for a variety of purposes
    - In addition to electricity generation, SMRs are suitable for industrial heating, desalination, and hydrogen production, as well as other uses. Although this report discusses a range of possible uses for SMRs, it does not quantitatively incorporate uses other than electricity generation into the demand projections because of the degree of uncertainty involved with projecting the demand for alternative uses.

- Four scenarios for the growth of the domestic SMR industry through 2030 are analyzed, based on projections of growth in nuclear power capacity, SMR market share of the capacity growth, and the market penetration of U.S. manufacturers.

- High Nuclear Adoption Case: With high rates of added nuclear capacity, moderate rates of SMR market share of added nuclear capacity, and moderate market penetration by domestic SMR manufacturers, almost 40 SMRs will be manufactured annually in the U.S. by 2030. This represents a strong "greenhouse gas legislation" case.
- Moderate Nuclear Adoption Case: With moderate rates of added nuclear capacity, moderate rates of SMR market share of added nuclear capacity, and moderate market penetration by domestic SMR manufacturers, an estimated 30 SMR units will be manufactured annually in the U.S. by 2030.
- Low Nuclear Adoption Case: With low rates of added nuclear capacity, moderate rates of SMR market share of added nuclear capacity, and moderate market penetration of domestic SMR manufacturers, only a few SMR units will be manufactured annually in the U.S. by 2030. This represents the "business-as-usual" case.
- A "What if" Disruptive Nuclear Adoption Case: With high rates of added nuclear capacity, disruptively high rates of SMR market share of added nuclear capacity, and moderate market penetration by domestic SMR manufacturers, approximately 85 SMR units will be manufactured annually in the U.S. by 2030.

➢ An economic analysis estimates the total economic impacts of SMR manufacturing, construction, and operation of a representative 100 MW SMR unit.
  - A prototypical 100 MW SMR costing $500 million to manufacture and install on-site is estimated to create nearly 7,000 jobs and generate $1.3 billion in sales, $627 million in value-added, $404 million in earnings (payroll), and $35 million in indirect business taxes.
  - The annual operation of each 100 MW SMR unit is estimated to create about 375 jobs and generate $107 million in sales, $68 million in value-added, $27 million in earnings (payroll), and $9 million in indirect business taxes.

➢ Given the expected number of SMRs to be manufactured in the U.S. under each of the four market analysis scenarios, the economic analysis projects the maximum economic impacts of a developing domestic SMR industry through 2030.[2]
  - High Nuclear Adoption Case: In 2030, the domestic manufacturing and construction of SMRs will be responsible for an estimated 255,000 jobs annually, $48.3 billion in annual sales, $23.2 billion in annual value-added impacts, $15 billion in annual earnings, and $1.3 billion in annual indirect business taxes. Cumulatively through 2030, the domestic

[2] These projections do not include support service revenue and job impacts from enrichment services. Several SMR designs assume uranium enrichment levels higher than those associated with conventional reactors. This study uses a prototypical light-water reactor design to model economic impacts, and the study team assumed the generic design would not require a higher enrichment level. In addition, the study team assumed growth to be linear between the low-point in 2015 to a high-point in 2030. Therefore, if actual manufacturing of SMR units begins after 2015, a corresponding linear shift in the economic outputs would likely occur in the years after 2030.

operation of SMRs is responsible for about 81,000 jobs, $23 billion in sales, $15 billion in value-added, $6 billion in earnings, and $2 billion in indirect business taxes.

- Moderate Nuclear Adoption Case: Annual economic impacts in 2030 for manufacture and construction are estimated to be 215,000 jobs, $40.5 billion in sales, $19.4 billion in value-added impacts, $12.5 billion in payroll earnings, and $1.1 billion in indirect business taxes. Cumulatively through 2030, the domestic operation of SMRs is responsible for more than 50,000 jobs, $15 billion in sales, $9.6 billion in value-added, $4 billion in earnings, and $1.3 billion in indirect business taxes.
- Low Nuclear Adoption Case: In 2030, the domestic SMR manufacture and construction industry is projected to have annual economic impacts estimated at almost 21,000 jobs, $3.9 billion in sales, $1.9 billion in value-added, $1.2 billion in earnings, and more than $100 million in indirect business taxes. Cumulatively through 2030, the domestic operation of SMRs is responsible for approximately 7,000 jobs, $1.9 billion in sales, 1.2 billion in value-added, $500 million in earnings, and more than $160 million in indirect business taxes.
- Disruptive Nuclear Adoption Case: The economic analysis projects that in 2030, the domestic manufacturing and construction of SMRs will be responsible for slightly more than 600,000 jobs annually, $113.5 billion in annual sales, $54.6 billion in annual value-added impacts, $35.2 billion in annual payroll earnings, and $3.1 billion in annual indirect business taxes. Cumulatively through 2030, the domestic operation of SMRs is responsible for approximately 200,000 jobs, $57.1 billion in sales, $36.4 billion in value-added, $14.8 billion in earnings, and $4.9 billion in indirect business taxes.

Section 2: Benefits and Applications of SMR Technologies

According to International Atomic Energy Agency (IAEA) definitions, a large conventional nuclear reactor typically exceeds an output of 700 MW. In contrast, small nuclear reactors are defined as those producing less than 300 MW (IAEA, 2007). The fundamental uniqueness of SMRs lies in their size and modularity. Modularity is commonly defined as “the process of converting the design and construction of a monolithic plant or stickbuilt scope to facilitate factory fabrication of modules for shipment and installation in the field as complete assemblies“ (Carelli, et al., 2010). The modular approach allows for greater standardization of components and processes compared to large nuclear power plants. Modular fabrication also enables cost reduction opportunities resulting from economic learning as the number of SMRs deployed over time increases. In support of this argument, preliminary evaluations of the capital outlay and O&M costs indicate that the lack of initial economies of scale would be counterbalanced by the modular and integral design approach of SMRs (Carelli, et al., 2010).

SMR Designs

There are numerous SMR designs under development globally. Only a small portion of these designs are expected to become NRC-certified and commercially available within the U.S. in the next 10 to 20 years.

A summary of SMR firms that have submitted a letter of intent to certify their reactors with the NRC appears in Table 1, and not all of these letters of intent will necessarily result in a submittal and eventual licensing. For SMRs to reach their potential, it will be necessary for a great reduction in designs and competitors.

These SMR designs can be categorized into three distinct groups based upon the actual design type, licensing and commercial deployment schedule, and design maturity (Office of Nuclear Energy, 2009). Small light water reactor (LWR) designs are generally intended for electricity generation and have a deployment schedule of five to ten years. Companies utilizing these designs are Babcock & Wilcox, NuScale Power, and Westinghouse Nuclear. Non-LWR designs (very high temperature or pebble bed reactors) are designed to generate process heat for use in industrial applications and have a deployment schedule of ten to 15 years. Advanced reactor concepts (liquid metal-cooled fast reactors) can be used for fuel recycling purposes and have extended fuel life. These designs have the longest licensing and deployment schedule of the three groups, estimated at 15 to 25 years. Several firms are using this design concept, including Toshiba, GE-Hitachi, and Hyperion.

Table 1: SMR vendors that have submitted letters of intent to certify designs to NRC

Firm ~Product	Reactor Type	Reactor Power	Refueling	Planned NRC Submittal
Babcock & Wilcox ~mPower	LWR	400 MWt 125 MWe	5 years	Q1 2012
NuScale Power ~NuScale module	LWR	150 MWt 45 MWe	2 years	
Westinghouse ~IRIS	LWR	1000 MWt 335 MWe	3-3.5 years	Q3 2012
Toshiba ~4S	Sodium-cooled fast reactor	30 MWt 10MWe	30 years	October 2010
GE-Hitachi ~PRISM	Sodium-cooled fast reactor	840 MWt 311 MWe	1-2 years	Mid 2011
PBMR (Pty.), Ltd. ~Pebble Bed Modular Reactor	PBMR	400 MWt 165 MWe	Online refueling	2013
Hyperion ~ Hyperion Power Module	Lead-bismuth-cooled fast reactor	70 MWt 25 MWe	7-10 years	

MWt = Megawatt thermal capacity
MWe = Megawatt electric power capacity
Source: *Adapted from Nuclear Regulatory Commission Advanced Reactors Website*

In addition to the companies and concepts listed in Table 1, at least two other U.S. companies have proposed SMRs design concepts.[3] The General Atomics EM2 (Energy Multiplier Module) is a 240 MW electric factory-produced system that would be truck or train transportable. The unit would be helium-cooled and provide process heat at 850 degrees C (Smith, 2010a). Advanced Reactor Concept's ARC-100 system uses a sodium cooled fast reactor design to produce 100 MW of electricity in a factory-produced, rail transportable design. The system is designed to operate for more than 20 years without refueling (IAEA, 2010b).

While the NRC is actively engaged in developing technology-neutral guidelines for new plant licensing, it has developed its current regulations based on 40 years of design and operation of LWR facilities (U.S. Nuclear Regulatory Commission, 2010). In addition, the NRC has been challenged to significantly upgrade its workforce and capacity to license LWR designs in the last five years (U.S. Government Accountability Office, 2007). Because of these factors, the SMRs which utilize light water designs should have a distinct advantage over non-LWR reactors in the NRC design and certification process, and the Department of Energy has publicly endorsed this view with the aim to financially assist SMR LWR designs through the licensing process (Chu, 2010). This should lead to faster certification and give LWR designs an early adoption advantage in the SMR market. An example of this LWR advantage is the backing of Babcock & Wilcox by three large utilities, Tennessee Valley Authority, First Energy Corp. and Oglethorpe Power Corp. These utilities recently signed a multi-firm agreement to solidify a mutual commitment to acquire necessary approval for the commercial use of B&W's new reactor design within the U.S (Smith, 2010). Likewise, NuScale Power has met with Energy Northwest, a joint operating agency for public utilities, about interest in adopting its design, and Energy Northwest has initiated studying SMRs and held informational meetings with its local partners (Dininny, 2009; Haviland, 2009).

Attributes

These three design sets (LWR, very high temperature, and advanced reactor concepts/liquid metal-cooled) have specific attributes that position them for a variety of applications. When directly compared to conventional nuclear power plants, several unique attributes of SMRs may provide advantages over larger reactor designs in some markets. Smaller reactors tend to be less expensive with regards to initial capital outlay and are expected to utilize improved fabrication and construction logistics. Because of their modular nature, SMRs may offer operational flexibilities (Ingersoll, 2009). In terms of capital outlay, the investment timing for SMRs can be deferred towards the end of construction due to the shorter construction times, providing a higher net present value for the investment. In addition, the construction of multiple SMRs may provide lower financial risk than those associated with constructing a single large nuclear reactor (Carelli, et al., 2010).

[3] The designs listed in this study are not necessarily all-inclusive but are intended as examples of concepts being developed in the U.S. In DOE presentations, other designs that are highlighted are Areva's ANTARES (Non-LWR) and advanced reactor concepts including Brookhaven Technology Group's DEER, Sandia National Laboratory's Right-Sized Reactor, and TerraPower's Traveling Wave Reactor (Office of Nuclear Energy, 2009).

Other advantages of SMRs over conventional nuclear reactor designs include less risk for cost overrun due to the modular construction, increased flexibility to increase generating capacity (add modules) as needed (Ingersoll, 2009), and potential lower overall cost per kW of electricity generation capacity. The modularity of SMRs is of particular relevance when considering investment flexibility in shifting market conditions. SMRs are better suited to match demand growth by incrementally increasing supply (Carelli, et al., 2010). In stable or predictable market conditions where long-term planning is feasible, the modularity of SMRs promotes "scalability," while in uncertain market conditions this feature will enhance the "adaptability" of plant deployment (Carelli et al., 2010, p. 405). Since SMRs are assumed to require much shorter lead times—financing is one example—than large reactor deployments, these smaller reactors allow investors the flexibility to quickly adapt to changes within the market. Additionally, SMRs can be mass produced, are exportable, and, in some designs, can offer longer-term energy reliability because of infrequent refueling requirements.

SMRs are also capable of facilitating improved matching between plant capacity and grid capacity in areas that are not well interconnected to sizable power grids (Carelli, et al., 2010). Some developing country environments present less mature technical infrastructures or smaller electrical grids. These areas would generally not able to accept connection to large, concentrated power stations where one unit could represent a significant fraction of a country's electricity generating capacity. This can reduce the market potential for large nuclear reactors and fossil fuel plants and, at the same time, reduce electricity availability in some countries. Due to their design approach, SMRs are capable of providing electric power to these areas with small or limited electrical grid infrastructures.

Based on the aforementioned attributes, SMRs may be well-suited for the following applications: electricity generation in both developed and developing markets, industrial process heat, desalination, hydrogen production, oil shale recovery, transmission boosting, and district heating (Sanders, 2009). The next sections highlight the applications that have the most potential for large-scale commercialization.

Electricity Generation

The primary market function of nuclear power plants has been to generate electricity. In recent years, nuclear power has provided approximately 15% of the world's electricity (World Nuclear Association, 2009), with approximately 440 nuclear power plants in 31 countries (IAEA, 2010). More than 55 nuclear power reactors are currently under construction, with the vast majority of current construction occurring in Asia and in the Russian Federation. Globally, almost 150 reactors are on order or planned to be operating within the next 8 to 10 years (IAEA, 2010a; World Nuclear Association, 2010). The U.S., France, and Japan produce 30.8%, 16.2%, and 9.7% of the world's nuclear-generated electricity, respectively. Russia, South Korea, and Germany each generate more than 5% of the world total (International Energy Agency, 2009).

The U.S. is the world leader in terms of total electricity generated by nuclear power because of its operating 104 reactors, which have produced between 18% and 20.6% of electricity generated annually in the U.S. since 1990 (Nuclear Energy Institute, 2010). Investment in new nuclear capacity was largely

halted in the late 1970s due to cost overruns and public concerns about safety in the wake of Three Mile Island (Congressional Budget Office, 2008), ending what has been called the "first nuclear era" in the U.S. (Ingersoll, 2009). However, nuclear power gained a larger share of electricity generated in the U.S. during the past few decades because of improved safety practices and operations, as well as investments in uprates at existing facilities. Improvements in operations are exemplified by the increased capacity factor of nuclear generation, which has increased from 57.4% in 1987 to an average of about 90% in the 2000s (Nuclear Energy Institute, 2010). In response to nuclear power's improved operations and its value as a clean energy resource, the Energy Policy Act of 2005 (EPACT 2005) provided new regulatory and tax incentives for investment in new nuclear generation. In addition, the Department of Energy has included substantial loan guarantees for nuclear power in the 2011 budget request, and the Administration has justified the guarantees in terms of combating climate change (Pulizzi & Buurma, 2010). These developments may signal a resurgence, "renaissance," or "second nuclear era" of nuclear power in the U.S. (Weinberg, 1985; Ingersoll, 2009).

In comparison to the U.S., 17 countries (18 including Taiwan) have a larger proportion of electricity generated by nuclear power, with Lithuania and France in the lead at more than 75% (IAEA, n.d.). France and Japan provide examples of countries that have pursued a concerted effort to have a long-term commitment to nuclear power. Japan has the third largest installed electricity generation capacity in the world, and about 30% is generated by nuclear power (EIA, 2008). Both France and Japan pursued restructuring plans since the 1970s due to their relative lack of indigenous fossil fuels and increasing demand for electricity. In addition to building nuclear power plants for electricity generation, these two countries have implanted both front-end (enrichment) and back-end (reprocessing) nuclear fuel cycle facilities (IAEA, 2007). While other countries also made some shifts from fossil fuel to nuclear power for electricity generation during the past few decades, these shifts were conducted at a significantly slower pace and at a lower level than the measures taken by Japan and France.

There are a number of factors that may signal an expanded role for nuclear power in both developed and less established markets in the coming decades. Most forecasts incorporate an increasing global demand for electricity, resulting from countries' efforts (particularly from those in the developing world) to grow their economies and improve the quality of life for their populations. The risks associated with global climate change may force governments to limit the development of power generation by means of burning hydrocarbons; this strengthens the potential for nuclear energy growth with its lack of greenhouse gas and other pollutant emissions. Despite this forecast of strong growth in clean energy demand, several factors and certain circumstances may make SMRs more attractive than conventional reactor builds in both the domestic and international arena.

While deployment of nuclear power has predominantly occurred in developed countries during the past few decades, an IAEA study forecasts that developing countries and emerging markets will be the primary locations of nuclear energy additions by 2050, with roughly equal proportions through 2030 (IAEA, 2007). Population growth rates are expected to rise within these developing countries while birth rates in developed countries have decreased to at or below self-sustaining rates. Furthermore, a comparison of energy use per capita among countries indicates that the growth rate in power demand

will be much greater in developing nations (IAEA, 2007). As a result future energy demand will also increase most significantly in developing countries; therefore these nations are likely the primary target for long-term future nuclear plant deployment.

The primary obstacle for many developing countries lies in their lack of available resources to build a large scale nuclear reactor that costs billions of dollars and requires at least several years to construct. Aside from costs, other key factors may inhibit the production of conventional nuclear reactors or larger fossil fuel plants within these countries (IAEA, 2007). Electrical grids with limited capacity are susceptible to operation and stability issues when power variations in excess of 10% of the total grid capacity occur. In certain countries, regardless of whether the population is concentrated in urban areas or dispersed in remote regions, the grid is not well-developed or robust (Carelli et al., 2010). As a result, SMRs may be an attractive alternative due to their ability to be used as both incremental and distributed generation sources. With this potential, however, come security concerns regarding transport and emplacement of SMRs in remote areas of some developing countries.

Additional Applications

Besides electricity generation, additional applications may be well-suited for SMR systems in the future. While the applicability of nuclear energy to additional applications is not dependent on facility size, the actual use of large nuclear facilities does not occur due to economic considerations. Currently, only a few countries utilize nuclear energy for non-generation purposes, primarily desalination and district heating (IAEA, 2008). A brief overview of the application possibilities for SMRs is provided below.

Desalination. The IAEA has identified desalination as possibly the leading non-electric civilian use for nuclear energy. Water scarcity is becoming an increasingly problematic global issue in both developed and developing countries. As noted in an IAEA (2007) report,

> Because of population growth, surface water resources are increasingly stressed in many parts of the world, developed and developing regions alike. Water stress is counter to sustainable development; it engenders disease; diverts natural flows, endangering flora and fauna of rivers, lakes wetlands, deltas and oceans; and it incites regional conflicts over water rights. In the developing world, more than one billion people currently lack access to safe drinking water; nearly two and a half billion lack access to adequate sanitation services. This would only get worse as populations grow. Water stress is severe in the developed world as well….In light of these trends, many opportunities in both developed and developing countries are foreseen for supply of potable water generated using nuclear process heat or off-peak electricity (p. 23).

The desalination of sea water requires large amounts of energy and is not dependent on a particular fuel for heat or electricity. The IAEA (2000) defines nuclear desalination as “the production of potable water from sea water in a facility in which a nuclear reactor is used as the source of energy for the desalination process” (p. 3). The three technologies that comprise nuclear desalination are nuclear, the desalination method, and the system that couples them together (IAEA, 2000). The feasibility of integrated nuclear desalination plants has been proven with over 175 reactor-years of experience worldwide (IAEA, 2007a).

Large-scale, proven commercial technologies for desalination can be grouped into distillation processes and the reverse osmosis process. Distillation technologies require heat to create steam which condenses and separates fresh water from brine. Reverse osmosis requires only electricity to push fresh water from the higher pressure saltwater side of a semi-permeable membrane to the lower pressure freshwater side. An IAEA study (2007a) on the economics of nuclear desalination reported that "SMRs offer the largest potential as coupling options to nuclear desalination systems in developing countries" (p. 4). Furthermore, the study found that the costs for nuclear desalination are roughly similar to that of natural gas desalination, and could be substantially lower depending on fuel costs (IAEA, 2007a). Based on a preliminary assessment of the global desalination market through 2030, particularly in developing countries, desalination has the potential to provide a strong market for SMRs if they can successfully compete with conventional nuclear plants and other sources of generation (Arthur, 2010).

Process Heat for Industrial Applications and District Heating. SMRs can be used to provide heat over temperature ranges from 100 to 200 degrees centigrade to over 800 degrees centigrade, depending on the design of the SMR and the technology used in it. During the production of electricity, more than half of the heat generated is rejected at low temperature. This residual heat is usable for various industrial applications. Higher temperature process heat can be used for a variety of industrial applications, such as the production of glass, plastics, steel, and ammonia (Office of Nuclear Energy, 2009). In addition concepts for producing carbon-neutral synthetic fuels and chemicals, often propose the coupling of systems, including nuclear, for a source of carbon-free heat and hydrogen needed in their processes (Los Alamos National Laboratory, 2008). Given the modularity of SMRs, these reactors offer advantages in areas or applications where heat is needed but where the large heat output and expense of a large nuclear reactor makes its application impractical.

District heating is an existing low temperature process heat application provided by nuclear plants in cold regions. Most often district heating is coupled with electric generation as a cogeneration application, but there are some very small single purpose nuclear district heating plants in existence. From a central location, a district heating system provides essential heat for residential and commercial needs such as space and water heating. The heat is often obtained from a cogeneration plant burning fossil fuels, although there are several alternatives, such as nuclear power, geothermal heating, central solar heating, and landfill gas. Low- temperature heat from nuclear reactors for district heating has been demonstrated in Russia, the Ukraine, Bulgaria, the Czech Republic, Slovakia, Hungary, and Sweden (Csik & Kupitz, 1997). In the past, the low price of fossil fuels have discouraged nuclear district heating plants (IAEA, 2009a), although higher prices may make alternatives, including process heat from SMRs, more attractive in the future.

Hydrogen Production. Hydrogen is considered a clean, convenient and versatile energy carrier with a wide variety of current and potential uses. The potential market for transportation use and as a replacement for liquid fossil fuels has been a driver in the past decade for nuclear-hydrogen research and demonstration programs (Office of Nuclear Energy, 2010; IAEA, 1999). Almost all hydrogen is currently produced for chemical industry applications, including the refining of high sulfur content crude

oil. While most hydrogen is produced via steam reforming of hydrocarbons, it can be produced via electrolysis and high temperature chemical reactions, methods that can produce no greenhouse gas emissions. Conventional reactors, both large and of the SMR variety, can provide electricity for electrolysis. High temperature reactors that are capable of providing high temperature process heat for electrolytic, thermochemical, hybrid, and other applications are under development through the Department of Energy's Next Generation Nuclear Demonstration Plant program. SMRs, based on gas-cooled or pebble-bed designs, could be used for hydrogen production in the future.

Approach to SMR Market Potential

While the potential uses and benefits of SMRs outlined above are numerous but certainly not all-inclusive, this study incorporates only the market potential for electricity production, using forecasts from established agencies and organizations. At present, electricity is the largest and most well-defined of the potential SMR applications. The cogeneration markets are ignored in this forecast for two reasons. First, the market size for these applications is anticipated to be significantly smaller than the electricity generation market. Second, the degree of uncertainty in estimating future cogeneration markets is significant and would taint the overall demand forecasts of nuclear electricity generation from the reputable sources used for this study. Because of the omission of markets other than electricity generation, this study's forecasts for SMR demand should be viewed as conservative in nature.

Aside from the potential high temperature applications noted above, this study makes no assumptions about which of the SMR technologies currently under development will be deployed for different uses or at different locations. The fact remains that no SMRs have yet been certified by the NRC and the earliest this is expected to happen is 2015. Therefore the technical and financial performance of different SMR designs has not yet been proved and the differing strengths and weaknesses of these designs cannot be currently evaluated. Under these circumstances, it is difficult to determine the market potential that exists for each design. As a result, a 'prototypical' 100 MW SMR will be assumed for the market potential and resulting economic analysis below.

Section 3: SMR Market Potential

The purpose of determining the market potential is to enable an economic impact analysis of small modular reactor manufacturing and operations in the U.S. over the next 20 years. This is achieved by first estimating the number of SMRs *manufactured* in the U.S., and second by estimating the number of these reactors *operating* in the U.S. during this time period.

This report presents four distinct cases projecting the potential economic impact of SMR systems through 2030. These cases are referred to as Low, Moderate, High, and Disruptive. Each case incorporates added nuclear power capacity for electricity production, the market share of SMRs for that capacity, and penetration of U.S. manufacturers into the overall global SMR market.

Methodology

Forecasted capacity additions for the nuclear power industry as a whole were used as a basis for projecting the number of SMR systems manufactured. The forecasted nuclear capacity data was extracted from recent U.S. Energy Information Agency, Electric Power Research Institute, and International Atomic Energy Agency studies. Their data were compiled to form scenarios for Low, Moderate, and High nuclear power growth in the U.S. and internationally. Estimates for the annual market share of SMRs as a portion of total nuclear power additions were then applied, giving a power generating capacity. This generating capacity was converted into an SMR unit count by applying the nominal SMR generating capacity of 100 MW. The resulting number of SMRs represents the total projected SMR market potential for both domestic and international markets. The U.S. SMR manufacturer's share was subsequently applied to establish an estimate for total SMR units manufactured in the U.S.

As mentioned previously, this methodology assumes that SMRs are only used for electricity generation and that they only capture a share of the forecasted nuclear power capacity additions. Additional SMR displacement of other non-nuclear electric generating sources is not accounted for in the projections that were not already included in the data from the various agencies. The growth of the SMR market is assumed to be linear from the time the first system is brought on line through 2030. Once deployed, it is assumed that each SMR system will operate through the study's timeframe of 2030. SMRs are expected to have an operational lifetime similar to that of conventional nuclear plants, which exceed the present study's parameters.

Domestic Nuclear Capacity Projections

The projections for U.S. nuclear capacity additions were taken from EIA and EPRI reports released in 2009. Data for the Low scenario was extracted from the "Reference Case" described in the *EIA Updated Annual Energy Outlook 2009 (April 2009)*. The "Reference Case" takes into consideration the macroeconomic outlook of the U.S. and the enactment of the American Recovery and Reinvestment Act passed into law in February 2009. The case assumes that regulatory impact on the energy markets is limited only to currently enacted legislation (as of April 2009). The report projects 3.4 gigawatts (GW) of expansion at existing nuclear power plants, 13.1 GW of new capacity, and 4.4 GW of retirements in the period up to 2030. This is a net increase of 12 GW nuclear generating capacity by 2030. This scenario is referred to as "No Green House Gas (GHG) Legislation."

The Moderate scenario uses EPRI's Prism case as the projection for U.S. nuclear capacity growth. EPRI is a non-profit organization that conducts third party research on challenges faced by the electric power industry. This case assumes that there will be 10 GW of nuclear capacity added in the U.S. by 2020 and another 54 GW by 2030. It is assumed that U.S. nuclear capacity will not be reduced by plant retirements. EPRI's analysis is based upon an aggressive effort to reduce $C0_2$ emissions, with technology advancement being the limiting factor for further deployment of nuclear power.

U.S. nuclear capacity projections offered in the High scenario are extracted from the EIA Report - *Energy Market and Economic Impacts of H.R. 2454, the American Clean Energy and Security Act of 2009 (August 2009)*. The "Basic Case" from this EIA report provides the data used in this scenario. This case assumes low emission technologies including nuclear are developed and deployed on a large-scale in a timeframe consistent with CO_2 reduction requirements of the American Clean Energy and Security Act of 2009 (ACESA), commonly known as Waxman-Markey after its legislative sponsors. In this scenario, U.S. nuclear power capacity is nearly doubled over the next 20 years with an expected net increase of 90 GW. This case is also referred to as the Greenhouse Gas (GHG) Legislation case.

The plot shown in Figure 1 below represents the total U.S. nuclear generating capacity by year for each of the three scenarios. Figure 2 indicates additions in generating capacity by year. This plot represents gross capacity added as plant retirements are not deducted. The zero-added nuclear capacity forecasted in the year 2021 for the GHG Legislation and Reference cases is from data and models supplied by EIA. The zero-added capacity results from scheduled expiration of the nuclear production tax credit. EPACT 2005 provided for a production tax credit of 1.8¢ per kilowatt hour of electricity produced by an advanced nuclear power facility, with a national limitation of 6,000 MW allocated to the credit. EIA conservatively assumes that the tax credit will not be renewed and builds for 2021 are solely a result of the tax credit. However, the congressional intention of the tax credit and other nuclear incentives created by EPACT 2005 was to provide assurance for new nuclear construction and investment following a period where no plants had been ordered since 1978 (Holt, 2006). While EIA's assumption of zero-added capacity in 2021 may prove to be overly conservative, it has been retained for this study so as not to alter any of the external models and datasets from EIA, IAEA, and EPRI.

Figure 1

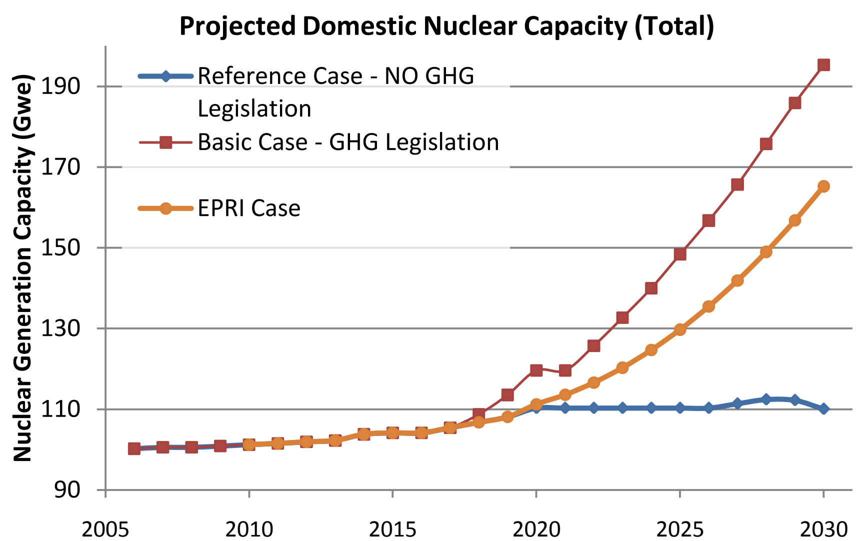
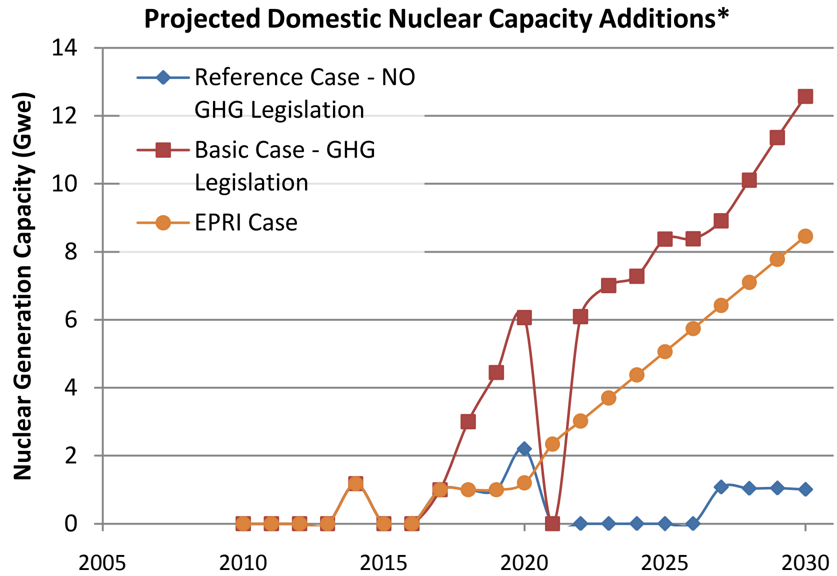


Figure 2



*The dips in the Reference and Basic Cases result from EIA's assumption of zero-added capacity in 2021 due to the expiration of the production text credit (see discussion in previous text). These may prove to be overly conservative, but they have been retained for this study so as not to alter any of the external models and datasets from EIA, IAEA, and EPRI.

International Nuclear Capacity Projections

International nuclear capacity data for the Low scenario was extracted from the "Reference Case" described in the EIA *International Energy Outlook 2009*. This case reflects continued growth of the nuclear generating capacity resulting from rising fossil fuel prices and increased global regulation of greenhouse gas emissions. It assumes most of the older nuclear plants currently in operation will continue to operate through 2030. However, there is the expectation that nuclear capacity in Europe will experience minimal growth due to plans for the phasing out of nuclear programs in countries such as Germany and Belgium.

The Moderate and High nuclear capacity scenarios use the "High Case" from the IAEA *Energy, Electricity and Nuclear Power Estimates for the Period up to 2030 – 2009 Edition*. Data representing U.S. contributions to this capacity have been removed so as to only depict international nuclear capacity. This IAEA case assumes that the current global economic crisis is "overcome in the near future" and that economic and electricity demand growth essentially resumes to pre-crisis levels. The case also assumes expanding implementation of policy targeted to address climate change concerns globally. Figures 3 and 4 illustrate projections for total international nuclear generating capacity and incremental capacity growth, respectively.

Figure 3

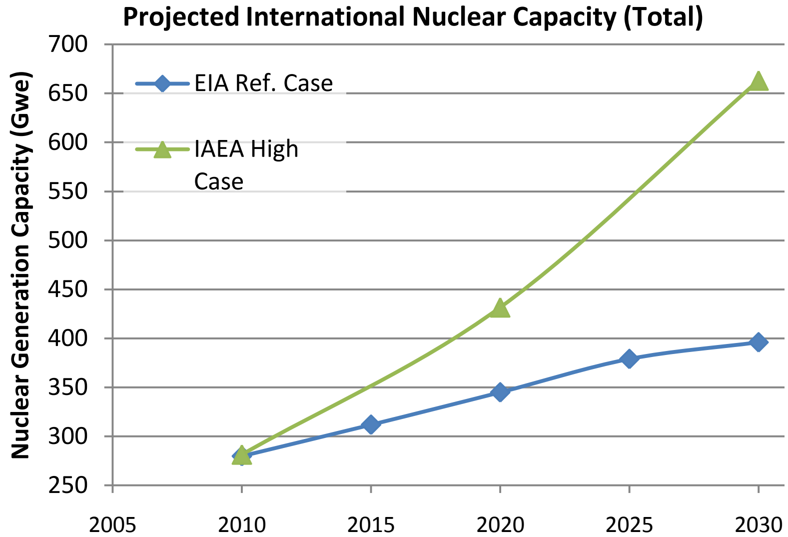
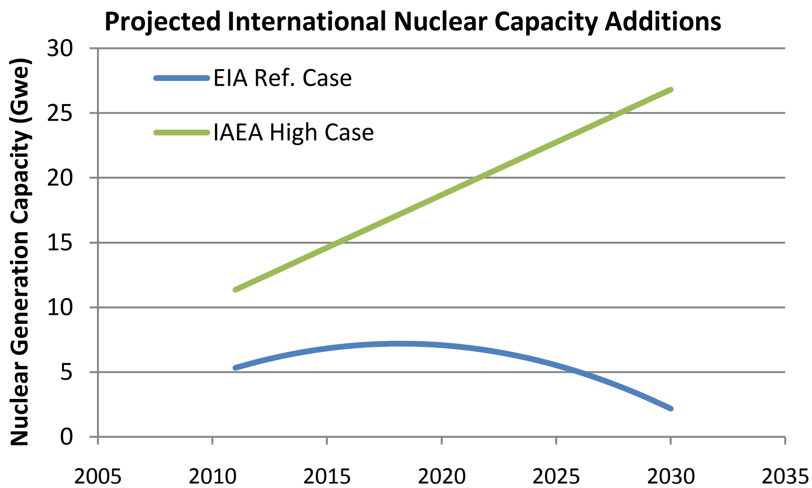


Figure 4



SMR Share of Nuclear Market

There are two scenarios presented for SMR market share as a percentage of new nuclear power installations – Moderate Deployment and Disruptive Technology. Both scenarios assume that SMRs capture a growing piece of the overall nuclear capacity additions from the time of their initial commercial deployment through 2030. Increasing demand in nuclear capacity is assumed to result in a corresponding increase in demand for SMR systems. The first year of possible commercial manufacture for SMR systems is assumed to be 2015. This is based on the published intentions of light water SMR manufacturers to submit design certification applications to the NRC beginning in 2011, at the time the present study was initiated (NuScale Power, n.d.; Babcock & Wilcox Company, 2009; U.S. Nuclear Regulatory Commission, 2010). The actual time between applications for design certification to SMR

manufacture and deployment in a commercial power setting may be significantly longer than the four years projected. In both of the SMR market share cases, the growth is expected to be linear between the low point in 2015 to a high point in 2030; therefore, if actual commercial manufacture of SMR units begins after 2015, a corresponding linear shift in the economic outputs would likely occur in the years after 2030.

The Moderate Deployment scenario was applied to each of the capacity growth scenarios to provide projections for Low, Moderate, and High SMR unit counts. This scenario represents a slow but steady increase in the market share for SMR systems. In this scenario, SMRs are assumed to begin at a 2% capture rate in 2015, culminating in a capture of 32% of nuclear capacity additions by 2030.

The disruptive technology market share represents a "what if" type scenario in which energy markets embrace SMR technology such that there is a significant replacement of large-scale nuclear facilities by SMRs. In this case, SMRs are assumed to capture 75% of nuclear additions by 2030. As previously discussed, numerous characteristics of proposed SMR designs can serve to overcome barriers that have limited the growth of the nuclear power industry (Ingersoll, 2009; Carelli et al., 2010). Such characteristics include:

- Suitability to meet the demand requirements for smaller "off grid" energy markets
- Scalability to meet the increasing demand of developing energy markets
- Low "over-night" capital costs relative to gigawatt scale nuclear facilities
- Incremental cost benefits realized from modular factory construction of reactor and turbine components
- Improved transportability
- Reduced site construction times
- Longer fuel cycles
- Placement of the reactor vessel underground to improve security from terrorist and proliferation threats
- Incorporating off-site refueling and off-site spent fuel storage for use in undeveloped regions
- Incorporating inherent and passive safety features
- Reduced dependence on water as a coolant opening up areas previously unsuited for nuclear plants such as the arid, western U.S.

The disruptive scenario is matched with the High nuclear capacity growth scenario to represent a highest possible SMR market potential.

The data in Table 2 summarizes the projections for SMR market share of new nuclear power capacity for each scenario.

Table 2: SMR Market Share of New Nuclear Power Facilities

SMR Market Share Scenario	2015	2020	2025	2030
Moderate Deployment	2%	12%	22%	32%
Disruptive Technology	5%	30%	55%	75%

U.S. Market Share for SMR Manufacturing

Projections for SMR manufacturing market share captured by U.S. firms are separated into two categories, international market share and domestic market share. In each category, the market share captured by domestic SMR manufacturers is assumed to be constant over the time period under consideration. U.S. manufacturers are assumed to capture 50% of the domestic SMR market and about 20% of the international SMR market. These estimates were made based upon the following considerations

- SMR development activity is underway in at least 7 countries (World Nuclear Association, 2010).
- U.S. manufacturers may realize a preference for U.S. design certification from the NRC.

The domestic and international market share projections were applied to the total SMR demand estimates to derive the number of units built annually in the U.S.

Overview of the Four Cases for SMR Manufacture and Operation

As described above, the three primary factors considered in the analysis are growth in nuclear power capacity, SMR market share of that capacity growth, and U.S. manufacturer penetration into the SMR market. Table 3 summarizes the scenarios used to build each of the cases for estimating SMR economic impacts.

Table 3: SMR Case Overview

SMR Economic Impact Case	Added Nuclear Capacity Scenario	SMR Market Share of Added Nuclear Capacity	SMR Market Share for U.S. Manufacturers
Low	Low Adoption	Moderate SMR Deployment (32% by 2030)	50% of Domestic, 20% of Int.
Moderate	Moderate Adoption	Moderate SMR Deployment (32% by 2030)	50% of Domestic, 20% of Int.
High	High Adoption	Moderate SMR Deployment (32% by 2030)	50% of Domestic, 20% of Int.
Disruptive	High Adoption	Disruptive Technology (75% by 2030)	50% of Domestic, 20% of Int.

Tables 4 – 6 provide overviews of each of the nuclear capacity scenarios utilized for this study.

Table 4: Low Nuclear Adoption Scenario

Domestic	**International**
EIA Updated Annual Energy Outlook 2009 Reference Case with ARRA Report #: SR-OIAF/2009-03	EIA International Energy Outlook 2009 Reference Case Report #:DOE/EIA-0484(2009)
• Reflects only current laws and policies. • 3.4 GW of expansion at existing plants, 13.1 GW of new capacity, and 4.4 GW of retirements. • 10 new nuclear power plants are completed through 2030. • Most existing nuclear units continue to operate through 2030.	• Reflects support for new nuclear capacity from rising fossil fuel prices, greenhouse gas emissions regulations. • Most of the older nuclear power plants in the OECD countries and non-OECD Eurasia will be granted life extensions. • OECD Europe expected to see a small decline in nuclear power generation.

Table 5: Moderate Nuclear Adoption Scenario

Domestic	**International**
EPRI The Power to Reduce C02 Emissions 2009 PRISM Analysis EPRI Report 1020389	IAEA Energy, Electricity and Nuclear Power Estimates for the Period up to 2030 2009 Edition IAEA High Case IAEA Report IAEA-RDS-1/29
• Substantially increased deployment of advanced nuclear power plants. • Existing fleet continues to operate safely at high capacity factors. • Ongoing efforts to extend the service of existing plants beyond 60 years. • Construction of 10 GW of advanced reactors by 2020, and ultimately 64 GW by 2030.	• Economic crisis overcome in the near future. • Past rates of economic growth and electricity demand, especially in the Far East, would essentially resume. • Implementation of policies targeted at mitigating climate change. • Underlying fundamentals point to continued strong growth in the longer term.

Table 6: High Nuclear Adoption Scenario

High Case Domestic	High Case International
EIA Energy Market and Economic Impacts of H.R. 2454 ACESA Basic Case Report #: SR-OIAF/2009-05	IAEA Energy, Electricity and Nuclear Power Estimates for the Period up to 2030 2009 Edition IAEA High Case IAEA Report IAEA-RDS-1/29
• Assumes low emissions technologies including nuclear are developed and deployed on a large scale in a timeframe consistent with CO2 reduction requirements of ACESA legislation.	• Economic crisis overcome in the near future. • Past rates of economic growth and electricity demand, especially in the Far East, would essentially resume. • Implementation of policies targeted at mitigating climate change. • Underlying fundamentals point to continued strong growth in the longer term

Other Considerations

SMR deployment is assumed to capture a percentage of the forecasted additions to nuclear generating capacity. In each of the third party studies listed above, nuclear growth comes, in part, at the expense of fossil fuel electricity generation. This is primarily due to expected increasing costs for carbon emissions. Each of the studies also assumes that nuclear capacity additions will be GW scale facilities. Since SMRs have generating capacities more comparable to fossil fuel electric plants, particularly natural gas plants, it is reasonable to assume that SMRs may be better suited to capture market share from fossil fuel plants than from traditional GW scale nuclear facilities. In addition, SMR manufacturers may be in a position to fill demand currently met by the natural gas and coal-fired power plants if tradeoffs between high initial costs (nuclear) and high carbon emissions (fossil fuel) become more evenly balanced due to environmental policy changes.

While environmental policy changes may lead to larger demand and more rapid deployment of SMRs than generally assumed, other factors may hinder SMR deployment. Issues such as spent fuel storage, licensing, public acceptance, and supply chain factors may prove to be significant over the coming years. The specifics of how these issues are resolved are likely to significantly impact the future of small modular nuclear reactors. Each of these is discussed briefly below.

The storage of spent fuel is an important one for from both a cost and public acceptance perspective. Domestic firms developing SMR designs address the issue of spent fuel storage by assuming that spent fuel will either be stored on-site at the SMR location or off-site at a permanent location. The primary

benefit of on-site storage is that it is the storage method used by all commercial nuclear power facilities currently operating in the U.S. and naturally complement on-site refueling. However, on-site refueling and spent fuel storage would present potential security challenges for proliferation prevention. On-site storage is also considered to be a temporary solution and is practical only for the life of the power plant. Although off-site storage has the benefit of improved security over on-site storage, long-term storage options at secured off-site locations are currently non-existent in the U.S.

Another major issue with significant potential impacts on the future of SMRs in the U.S. concerns the speed at which SMRs are likely to be adopted. Factors such as licensing, public acceptance, and supply chain issues may hinder significant SMR deployment in the future. In terms of licensing, it is important to note that current regulations and licensing procedures were developed with consideration for large scale, light-water reactor facilities (U.S. Nuclear Regulatory Commission, 2010). SMR designs do not fit into the current framework partly due to their size, associated technologies such as in-vessel instrumentation, and the use of advanced designs (other than light-water). Licensing for commercial manufacturing and operation are completely dependent on the NRC's ability to establish new procedures with consideration for SMR projects.

In addition, the licensing of new SMR facilities is likely to be affected by the degree of public acceptance of nuclear technologies in general. Though the U.S. currently has the highest number of operating nuclear power reactors in the world (IAEA, 2010), growth in the domestic nuclear power industry has stagnated since 1990. While costs have been a factor, segments of the public remain concerned about nuclear waste disposal and, to some extent, safety. Lack of public acceptance toward nuclear energy in general, as well as the public's lack of familiarity with SMRs and associated technologies, may affect the speed of SMR licensing and deployment in the U.S.

Finally, the hiatus in new nuclear power plant construction in the U.S may affect the nuclear industry's ability to rapidly deploy new nuclear facilities on a large scale. The lack of nuclear construction over recent decades has, to a large degree, forced U.S. nuclear component suppliers to either focus on international markets or exit the nuclear industry (Kenley, et al., 2009). This weakened supply chain position could present a significant challenge for U.S. SMR manufacturers in the event of rapidly increasing demand. Foreign manufacturers may realize an advantage in this regard, allowing them to capture SMR market share from U.S. manufacturers. On the other hand, with respect to domestic manufacturing capabilities, other industrial sectors associated with defense and ship building, as examples, could provide the base needed for factory-based SMR production.

While the scenarios used here incorporate the effects of market conditions over time, including environmental policy changes, it is important to note that unexpected changes in regulatory policy, licensing procedures, public acceptance, security requirements, and supply chain factors may be significant. As a result, the actual path for the future demand for SMR manufacturing and operation may deviate from the projections derived in this study.

In addition, it is important to note that the operations to transform projections of energy demand projections into the forecast numbers of SMR units manufactured and operated are mathematically linear. This means that the projected numbers of SMR units are, in effect, a re-scaling of the energy demand projections. As a result, any perturbations that occur in the energy demand projections will impact the final SMR counts. For example, the dip in the number of SMRs manufactured in the year 2021 for both the high and disruptive cases are reflections of the drop off in additional capacity for 2021 in the EIA Basic and Reference cases, shown earlier in Figure 2 and now appearing in Figure 6, caused by the scheduled expiration of the advanced nuclear production tax credit. As explained earlier, this may prove an overly conservative assumption, but it has been retained to respect the integrity of EIA's data and models.

Overview of Results

The projected demand for domestic SMR manufacturing and operations are summarized below. Detailed results for the number of SMRs manufactured and operating in the U.S. on a year-by-year basis are provided in Appendix A. These annual estimates for SMR manufacturing and operation are used to generate the estimated economic impacts in Section 4 of this report.

Figure 5 indicates the cumulative number of SMR units operating per year in the U.S. for each SMR Economic Impact Case described above. The plot in Figure 6 represents the number of SMR units built in the U.S. per year for each case. As mentioned previously, the nominal unit SMR generating capacity is assumed to be 100 MW.

Figure 5

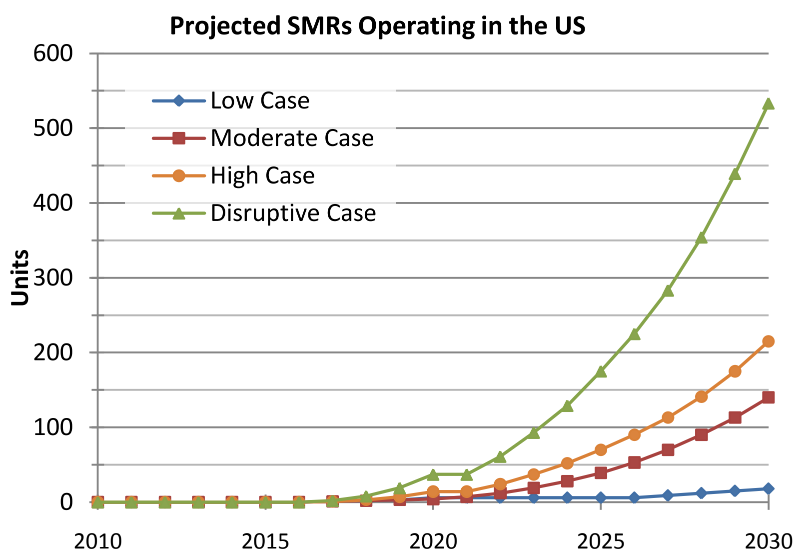
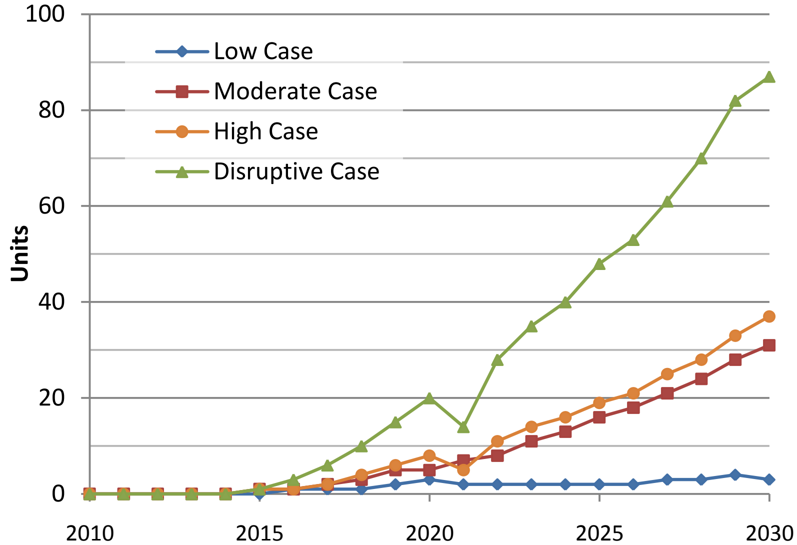


Figure 6

Projected SMRs Manufactured in the U.S.



In the low SMR adoption case, there are only two to four SMRs manufactured in the U.S. each year between 2020 and 2030. In this case, the infrastructure to manufacture several SMRs per year in the U.S. may be too expensive to warrant the investment, so this "business-as-usual" case will not lead to a concerted SMR manufacturing effort in the U.S., if only the domestic market is considered.

Both the moderate and high SMR adoption cases assume that some greenhouse gas legislation is passed that penalizes CO_2 emissions. For these cases, the number of SMRs manufactured in the U.S. increases from 5 to 8 in 2020, to 31 to 37 in 2030. The total number of SMRs operating in the U.S. would increase from 4 to 14 in 2020, to 140 to 215 in 2030.

The disruptive case represents a significant resurgence of nuclear manufacturing in the U.S. The number of SMRs manufactured yearly in the US would more than quadruple from 20 units in 2020 to 87 units in 2030. The number of SMRs operating in the U.S. increases by more than an order of magnitude from 37 in 2020 to 533 in 2030.

Section 4: Economic Impacts

The manufacture of SMRs in the U.S., the construction of on-site facilities where each SMR is to be located, and the annual operation of SMRs will generate a variety of economic effects. This section of the study describes the types of economic impacts stemming from SMR manufacturing, construction, and operation as well as how these impacts are measured. The economic impacts are estimated on a national basis and reported in a variety of measures commonly used in economic impact analysis.

The basis for estimating the magnitude of the economic impacts from the development of a domestic SMR industry is the marketing analysis described above. Each of the four scenarios used in estimating the demand for SMRs provides the projected numbers of SMRs manufactured in the U.S., deployed in the U.S., and in operation in the U.S. on an annual basis through 2030. The economic impact analysis employed here is developed using these annual projections by using the previously-described 100 MW prototypical SMR as a basis for analysis.

The impacts stemming from the domestic manufacturing and on-site construction of each 100 MW SMR unit are first estimated and then aggregated across the number of units projected in each of the four marketing analysis scenarios. There are additional impacts stemming from the annual operation of each SMR deployed in the U.S. The economic impacts of operating each 100 MW SMR unit are estimated and aggregated across the number of SMR units in operation in the U.S. for each of the four scenarios.

Input-Output Analysis

The economic impacts of manufacturing, construction, and operation of SMRs are calculated using standard estimation techniques collectively known as Input-Output (I-O) analysis. An underlying concept in I-O analysis is the notion that industries are closely linked and that economic activity in one industry ripples across other sectors of the economy, generating impacts both directly and indirectly. The direct effects of an industry stem from the employment and salaries in the industry itself. In addition, there are secondary, or indirect impacts when the activity in one industry affects related industries. Each industry purchases raw inputs from other industries that add value to their product or service. These other industries in turn purchase inputs from still more industries that add value to their product or service. These types of purchases from "backward linked" industries constitute the indirect effects of the economic activity of the original industry. Finally, there are the induced economic impacts caused by the direct and indirect dollars being re-spent in the economy. The direct, indirect, and induced economic impacts are well known to economists and are calculated using I-O analysis.

In terms of the economic impacts of the SMR industry, the direct effects stem from the actual change in final demand for SMR units. An increase in SMR demand, for example, will create additional employment and salaries within the SMR industry. The indirect effects stem from the purchases of goods and services by the SMR industry from suppliers in other domestic industries. In effect, the SMR industry's backward linkages, as its purchases from other firms, ripple through the economy in a chain-like manner. The induced effects stem from the increase in wage and salary earnings and other household income that ripples though the economy as direct and indirect dollars are spent and re-spent in the national economy. The biggest driver of these induced effects is employee spending from wage and salary payroll and earnings.

The presence of indirect and induced economic effects means that an initial increase in demand for a given industry's output will get multiplied in the economy. The size of the multiplier effects is of primary concern in I-O analysis and is an important component in determining the overall economic impacts of industry changes. In essence, multipliers determine how the direct change in final demand of a single

industry ripples throughout all the other industries in an economy. Two basic types of multipliers are recognized in standard I-O analysis. Type I multipliers measure the direct changes and the indirect effects of an industry's backward linkages. Type II multipliers, also known as Social Accounting Matrix (SAM) multipliers, are larger in magnitude and more broad-based by virtue of the fact that they include the direct, indirect, and induced effects. They assume wages, salaries, and other income circulate through the economy along with backward linkages of business purchases. Type II multipliers measure the direct, indirect, and induced impacts from a change in final demands as measured by sales (output). Because the sum of the direct, indirect, and induced measures the total impact of an industry to an economy, this report will employ Type II multipliers. Once the Type II multipliers for the SMR industry are calculated, they can be used to estimate the changes in the overall economic activity of the U.S. economy stemming from different levels of activity in the SMR industry.

There are a variety of I-O modeling software programs and data systems that are available for economic impact modeling. They include programs from REMI - *Economic Modeling Inc*, EMSI - *Economic Modeling Specialists, Inc.*, RIMS II - *Regional Input-Output Modeling System*, and IMPLAN - *Impact Analysis for Planning.* IMPLAN is one of the oldest and most widely used modeling software, being originally developed for the United States Department of Agriculture Forest Service in the late 1970s and early 1980s. The IMPLAN model has great flexibility, robustness, and transparency. For these reasons, IMPLAN was chosen as the software platform and data system for this study.

I-O models are first and foremost a system of national or regional accounts within an economic accounting framework that measures the interdependence among the producing and consuming sectors of an economy. They identify the relationship between a given set of demands for final goods and services and the inputs required to satisfy those demands. The IMPLAN model, for example, provides estimates of production, employment, employee compensation, business income, and taxes for each of over 400 sectors of the U.S. economy. Although I-O models can be utilized for descriptive models of the economy, their primary use is as predictive models for estimating impacts on the economy from changes in final demands in given industries. In such predictive models, multipliers are estimated in order to assess the overall economic impact of industry changes.

Input-Output Model of the SMR Industry

The manufacturing and construction of SMRs are in the planning and development stages. The major players in the market have yet to fully emerge. The manufacturing and construction of SMRs will likely occur at various locations throughout the United States. The supply chain will likely span the entire country, as well as include international suppliers. In addition, the market for SMRs is largely a national market. For these reasons, a nationwide approach to the I-O analysis was employed and national (U.S.) models of the SMR industry were created.

In order to estimate the economic impacts of a developing SMR industry on the national economy, two IMPLAN models were constructed. The first was a disaggregated 440 sector model and the second was an aggregated 21 sector model. The simpler aggregated model is used in this study to report the results

of the I-O analysis in a user-friendly format. The more complex disaggregated model was utilized as a benchmark to compare and calibrate the outputs of the aggregated model.

The economic data employed in the analysis model are from calendar year 2007. Although 2008 economic data is available for use in IMPLAN, it was avoided because of the recession's effect on the model parameters. Year 2009 data was not available at the time of this study and was a recession year in any case. Year 2007 was judged to be the best platform for forecasting of the economic impacts of SMRs. The forecasted economic impacts were in constant 2007 dollars. To facilitate the economic forecast modeling, it was assumed that composition of the U.S. economy remained constant over the forecast period. An alternative approach would have required a comprehensive forecast of the U.S. economy over the next 20 years, a task that is beyond the scope of this study.

The economic impacts of a developing SMR industry stem from three different types of economic activity. The first is the manufacturing of the SMR units themselves. The second is the construction of the facilities in which the SMRs are located. The third is the ongoing operations of SMRs for generating electricity. Each of these is described below.

Manufacturing SMRs. SMR manufacturing is quite different than the construction of traditional nuclear plants. SMRs will be manufactured and produced at a manufacturing facility (factory) as a completed unit, transported to the operational location, and installed on-site. In contrast, a traditional nuclear power plant is constructed on-site and the construction techniques are well-developed and well-known.

The manufacture of SMRs in the United States, on the other hand, currently is in the planning and development stages and the costs and production techniques are proprietary. As a result, data on cost, employment, and production techniques are not available. Traditional input-output studies of the effects of industry changes normally utilize an extant industrial sector or build a new industrial sector model. This was not an option and an alternative approach was utilized in which an aggregated SMR sector was created consisting of the nine IMPLAN sectors that are identified with nuclear power plant manufacturing. These sectors are shown in Table 7.

Table 7: SMR Manufacturing Sectors

IMPLAN Industry Number	IMPLAN Industry Description
125	All other basic inorganic chemical manufacturing
133	Pharmaceutical preparation manufacturing
186	Plate work and fabricated structural product manufacturing
188	Power boiler and heat exchanger manufacturing
189	Metal tank (heavy gauge) manufacturing
198	Valve and fittings other than plumbing
255	Irradiation apparatus manufacturing
256	Watch, clock, and other measuring and controlling device manufactu
375	Environmental and other technical consulting services

Construction of SMRs. As with the manufacturing of SMRs, there was a lack of construction and installation expenditure data for SMRs. The modularity of the SMRs suggests a wide range of location and employment possibilities beyond what might be covered in IMPLAN Sector 35, (i.e. nonresidential manufacturing). Thus we employed an aggregated manufacturing SMR sector composed of the industrial sectors shown in Table 8.

Table 8: SMR Construction Sectors

IMPLAN Industry Number	IMPLAN Industry Description
34	Construct new nonresidential commercial
35	Construct new nonresidential manufacturing
36	Construct other new nonresidential structures
39	Maintenance & repair construct of nonresident structures

Operation of SMRs. As described in the previous section of this report, SMRs are suitable for a wide range of potential uses. However, given the uncertainties associated with estimating the demand for uses other than electricity generation, the economic impacts stemming from the operation of SMRs are calculated with only this use in mind. Unlike the modeling of the manufacturing and construction of SMR units, the economic impacts of power generation facilities are well known. These are incorporated into the specific IMPLAN sector for power generation, Sector 31. This sector was used to estimate the operational revenues/expenditures of the SMRs. It should be noted that the use of Sector 31 can be problematic because it includes all electricity generation. Expenditure patterns for traditional, large-scale nuclear power facilities are different than coal and natural gas fired plants. However, SMRs are still in the planning stage and the operating expenditure patterns and operating employment are not yet known. As a result, the use of the IMPLAN Sector 31 to estimate the economic impacts of operations is reasonable until further data become available.

Estimating Manufacturing, Construction, and Operations Expenditures and Revenues

As described in Section 3 of this report, the economic impacts of a developing SMR industry are estimated using a prototypical 100 MW SMR unit. This forms the basis of the approach taken with the study's aggregated IMPLAN model. The economic measures of the model for each prototypical unit, such as sales, value-added, wage and salary earnings, and indirect business taxes, were multiplied by the annual projections of the number of SMRs to be constructed and operated in the U.S. for the next 20 years (2010-2030).

For the estimates of the impacts stemming from the manufacturing and construction of SMRs, the I-O model used here relies on estimates for the costs of these activities. These are the direct expenditures for manufacturing and construction. The estimates of the resulting indirect and induced economic effects are subsequently estimated utilizing the Type II multipliers for these activities. Manufacturing and construction costs are measured in terms of capacity costs as denoted in kilowatts (kW) or

megawatts (MW), an instantaneous measurement of what a generation source can produce at a single point in time. Therefore, the cost of capacity, construction, and capital is measured in $/kW or $/MW.

As described above, both the costs and production techniques for SMR manufacturing and construction are proprietary. Published sources give cost estimates for SMRs ranging from $3000-$7000 per kilowatt of installed capacity, with a number of vendors stating they are aiming for the lower end of the spectrum (Wesoff, Kanellos, & St. John, 2009). Based on input from industry sources, the present study uses an estimate for manufacturing and construction costs for a typical SMR to be a midrange and competitive $5000/KW. For the prototypical 100 MW plant used in this study, this equates to $500 million per SMR. The project team estimates that approximately 87% of the total cost of the SMRs would be in manufacturing and 13% would be in construction and installation. Furthermore, it is assumed in this analysis that a typical SMR would be manufactured and constructed within a year in the U.S.

The economic impacts of the manufacture and construction of SMRs was based on the number of new plants constructed each year. In contrast, the economic impacts of the operation of SMRs were based on the number of plants *cumulatively in service* in the U.S. Annual revenues for a prototypical 100 MW SMR are estimated as follows. First, it was necessary to estimate the price of electricity sold from each unit. Price estimates for electricity in the U.S. are commonly denoted in terms of dollars per kilowatt-hour (KWh) of electricity. This study estimates a competitive price of $0.075/kWh for the life of the prototypical SMR,[4] and a range of $0.05-$0.09/kWh has been reported for differing designs (Wesoff, Kanellos, & St. John, 2009). Second, the annual output of electricity from the prototypical SMR unit was estimated based on the assumption that the unit will operate at 90% efficiency over the course of a year. Based on these assumptions, the typical 100 MW plant generates estimated annual revenues of $59,130,000 (90 MW x 1000 kW/MW x $0.075 kWh x 8760 hours/year = $59,130,000/year).

Economic Impacts of a Typical SMR Unit

Given the estimated expenditures for the manufacturing and construction of each SMR unit and the annual revenues derived from the sale of electricity from each unit, the economic impacts of the SMR industry can be calculated using the estimated multipliers for each of these activities, as derived from the IMPLAN aggregated model described above. The aggregated model yields the multiplier estimates for each of these activities. These multipliers, coupled with the estimated expenditures for SMR manufacturing and construction as well as the revenues derived from SMR operation, yield the total economic impact of each activity per SMR.

[4] A variety of factors impacts this number, including financing terms of Nth-of-a-kind SMRs, plant life, and different utility regulatory regimes. If a higher estimated price for electricity were chosen (or higher capital cost per SMR), it would result in higher economic and employment impacts due to the I-O modeling method utilized in this study.

The economic impacts reported in this study include the direct, indirect, and induced effects, as discussed above. These can be expressed by several different measures. The most common are the following:

1) Sales (output) economic impacts which represent changes in total transactions.
2) Value-added impacts are a measure of gross domestic product at the national, regional, or local area. It includes employee compensation and proprietor income, other property income, and indirect business taxes.
3) Employee compensation and proprietor income measure earnings and payroll impacts.
4) Employment (jobs) includes the impacts on full and part-time workers.
5) Indirect business measures the impacts on sales taxes, property taxes, excise taxes, and all other taxes except personal income taxes and corporate income taxes.

Sales (output) economic impacts are the broadest measure of economic activity. While they include some double counting of impacts and are considered to be less accurate in some ways than other measures, they are one of the most commonly reported. Value-added impacts are the most accurate broad measure of economic activity but they are sometimes difficult for policy-makers to interpret. Salary (payroll) impacts and the employment impacts are the easiest to explain and understand. Finally, indirect business taxes are a measure of the tax impacts of a change in final demand (excluding income taxes).

While all of the measures of economic impacts are presented in graph and tabular form below, the following section provides a brief explanation of the sales (output) multipliers for a prototypical 100 MW SMR unit.

Sales (Output) Impact Components: Direct, Indirect, and Induced Impacts per SMR. The sales (output) multipliers for all economic sectors in the aggregated model are presented in Table 9. These include the direct, indirect, and induced effects and the Type 1 and Type II (SAM) multipliers for each industry.

Table 9: IMPLAN Output Multipliers

Description	Direct Effects	Indirect Effects	Induced Effects	Total	Type I Multiplier	Type II (SAM) Multiplier
Production Agriculture	1.000000	0.996176	0.524671	2.520847	1.996176	2.520847
Ag, Forestry, Fish & Hunting	1.000000	0.443921	0.718608	2.162529	1.443921	2.162529
Mining	1.000000	0.654963	0.596948	2.251911	1.654963	2.251911
Nuclear Power Generation	1.000000	0.376339	0.435090	1.811429	1.376339	1.811429
Utilities	1.000000	0.746149	0.514559	2.260708	1.746149	2.260708
SMR Construction	1.000000	0.787949	0.885841	2.673790	1.787949	2.673790
Construction	1.000000	0.918940	0.722067	2.641007	1.918940	2.641007
Food Processing	1.000000	1.425418	0.612926	3.038344	2.425418	3.038344

Manufacturing	1.000000	1.019005	0.645757	2.664762	2.019005	2.664762
SMR Manufacturing	1.000000	0.872598	0.727505	2.600104	1.872598	2.600104
Retail trade/Wholesale Trade	1.000000	0.494960	0.766249	2.261208	1.494960	2.261208
Transportation & Warehousing	1.000000	0.767610	0.807901	2.575511	1.767610	2.575511
Information/ Education/Social	1.000000	0.759661	0.748092	2.507752	1.759661	2.507752
Real Estate, Finance & insurance	1.000000	0.563218	0.495409	2.058627	1.563218	2.058627
Professional/Tech/Scientific/Tech	1.000000	0.589225	0.953767	2.542991	1.589225	2.542991
Health & Social Services	1.000000	0.562431	0.945108	2.507539	1.562431	2.507539
Arts- Entertainment & Recreation	1.000000	0.584933	0.833100	2.418033	1.584933	2.418033
Accommodation & Food Services	1.000000	0.816050	0.772855	2.588905	1.816050	2.588905
Other Services	1.000000	0.716444	0.827296	2.543740	1.716444	2.543740
Federal Govt.	1.000000	0.073626	1.016510	2.090136	1.073626	2.090136
State and Local Govt.	1.000000	0.136605	1.106367	2.242972	1.136605	2.242972

The manufacture of the typical SMR generates direct sales (output) impacts of $435 million per SMR. This is derived by using the estimated $500 million expenditure for the prototypical 100 MW SMR and allocating 87% of this expenditure for manufacturing costs (the remaining 13% is allocated for construction, as described above). The indirect and induced effects are estimated using the Type II multipliers derived from the aggregated IMPLAN model. The Type II sales (output) multiplier was 2.60 for the SMR manufacturing sector in the aggregated model. This multiplier was close in magnitude to the individual industry sectors in the *disaggregated model*, and ranged from 2.63 to 2.79. These sales (output) multipliers are consistent with those expected for a national U.S. model. The general rule-of-thumb for multipliers is the larger and more integrated the economy, the greater the magnitude of a typical multiplier. Comparable U.S. multipliers are typically larger in magnitude than state multipliers; and they in turn are typically larger than comparable multipliers at the county level. Based on the estimated direct expenditures, the indirect effects for each 100 MW SMR are estimated to be $379.58 million and the induced effects are $316.46 million. This gives a total economic impact, as measured by sales, of $1,131 million.

For the construction of a typical SMR, the Type II sales multiplier from the aggregated construction model is estimated to be 2.67, which is consistent with the estimated multipliers for the individual construction sectors in disaggregated model that ranged from 2.53 to 2.86. The direct construction expenditure for a typical SMR, estimated to be $65 million, generates $51.2 million in indirect sales (output) impacts and $57.58 million in induced impacts. The total sales (output) impact stemming from the construction of SMRs is estimated to be $173.8 million.

The sales (output) multiplier for operational expenditures is estimated to be 1.81, which is within the typical range for electrical generation. As described earlier, the operation of a typical SMR generates $59.1 million in annual revenues. These direct sales (output) impacts, coupled with the estimated Type II

multiplier effects, yield an estimated $22.3 million in indirect impacts and $25.7 million in induced impacts. As a result, the total sales impacts from the annual operation of a typical 100 MW SMR is estimated to be $107.1 million.

Total Economic Impacts of a Typical SMR. The *total* economic impacts (direct, indirect, and induced) are presented in Table 10 in terms of sales (output), value-added, payroll (earnings), and indirect business taxes.

Table 10: The Economic Impacts of a Typical SMR

Including the Direct, Indirect, and Induced Impacts

	Sales	Value-Added	Earnings (Payroll)	Employment	Indirect Business Taxes
Manufacturing	$ 1,131,044,963	$ 540,660,687	$ 342,449,451	5,687	$ 30,722,980
Construction	$ 173,796,340	$ 86,517,571	$ 62,185,369	1,238	$ 5,030,832
Total SMR Production	$ 1,304,841,303	$ 627,178,258	$ 404,634,820	6,925	$ 35,753,812
Annual Operations	$ 107,109,777	$ 68,299,751	$ 27,732,333	374	$ 9,128,073
Total	$ 1,411,951,080	$ 695,478,009	$ 432,367,152	7,299	$ 44,881,885

As shown in the table, the manufacturing impacts are $1,131.0 million in sales; $540.7 million in value-added; $342.5 million in payroll earnings; 5,687 jobs; and $30.7 million in indirect business taxes. For construction, the impacts are $173.8 million in sales impacts; $86.5 million in value added; $62.2 million in payroll earnings; 1,238 jobs; and $5.0 million in indirect business taxes.

The total economic impacts for a typical SMR in construction and manufacturing are $1,304.8 million in sales; $627.2 million in value-added; $404.6 million in earnings-payroll; 6,925 jobs; and $35.8 million in indirect business taxes.

The total economic impacts stemming from the annual operation of a typical SMR are as follows: sales impacts $107.1 million; value-added $68.3 million; earnings- payroll $27.7 million; jobs 374; and indirect business taxes $9.1 million.

Economic Impacts of a Developing SMR Industry

In order to estimate the potential impacts of the manufacturing, construction, and operation of SMRs economy-wide, the study couples the estimated demand for SMRs under the four different scenarios derived in Section 3 with the economic impacts estimated for a typical SMR calculated in the I-O analysis described earlier in Section 4. In each of the four demand scenarios, the study team applies the economic impacts of a typical SMR to the 20-year projections of the number of SMRs manufactured and constructed in the U.S. as well as by the number of SMRs cumulatively in operation.

Figures 7.a through e illustrate the various measures of the manufacturing and construction economic impacts projected for each of the next 20 years under each of the four demand scenarios. Figures 8.a through e illustrate the cumulative economic impact for the operation of SMRs in the U.S. under each of the demand scenarios. Appendix B shows the data, on a year-by-year basis, in tabular form.

Figure 7.a

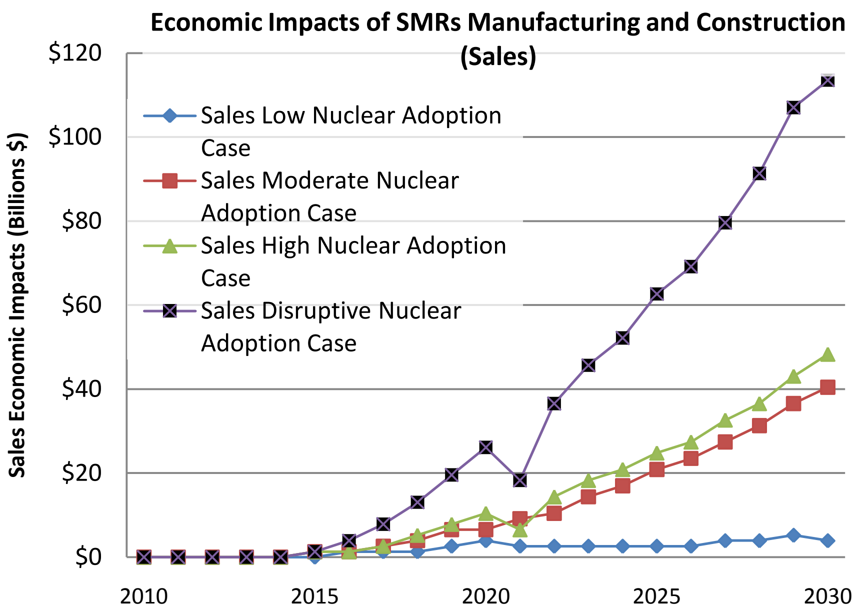


Figure 7.b

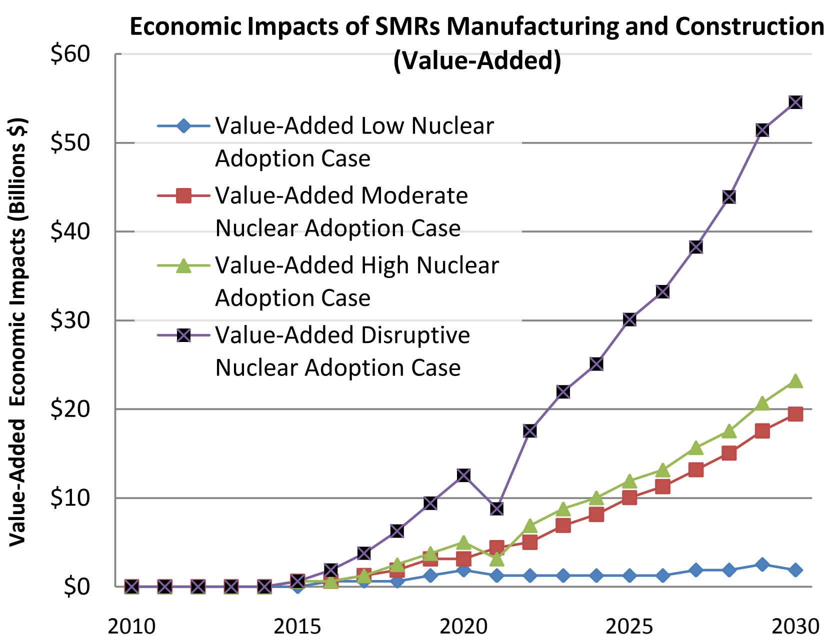


Figure 7.c

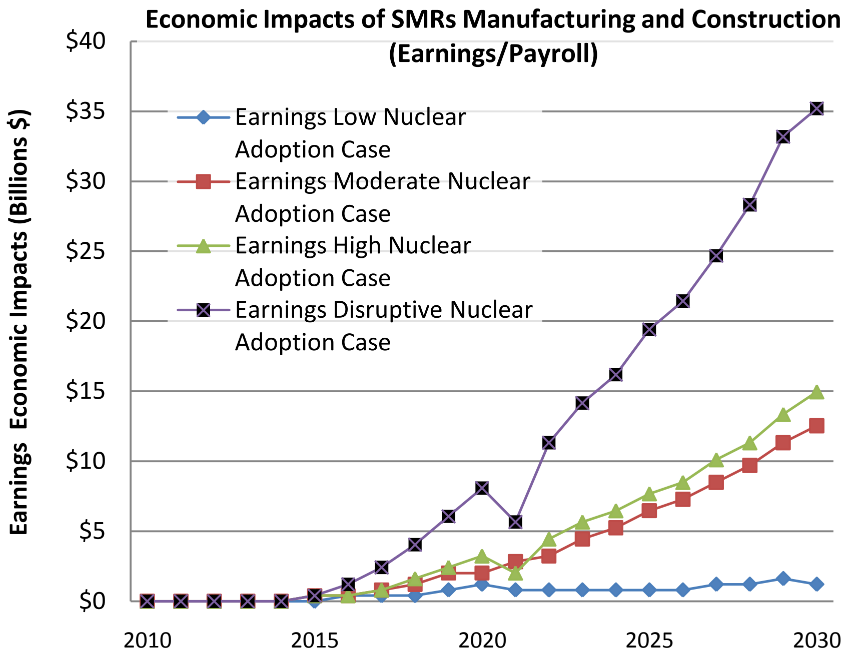


Figure 7.d

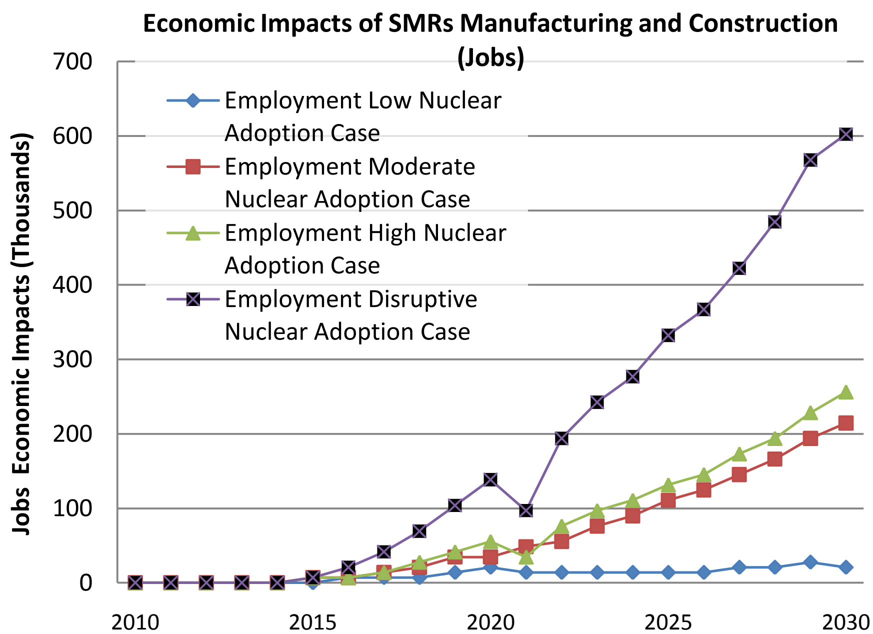


Figure 7.e

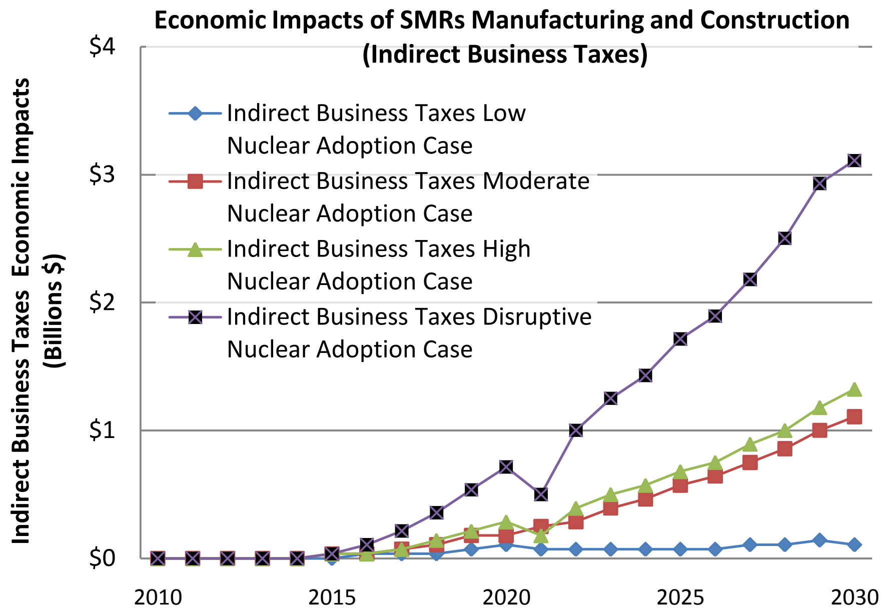


Figure 8.a

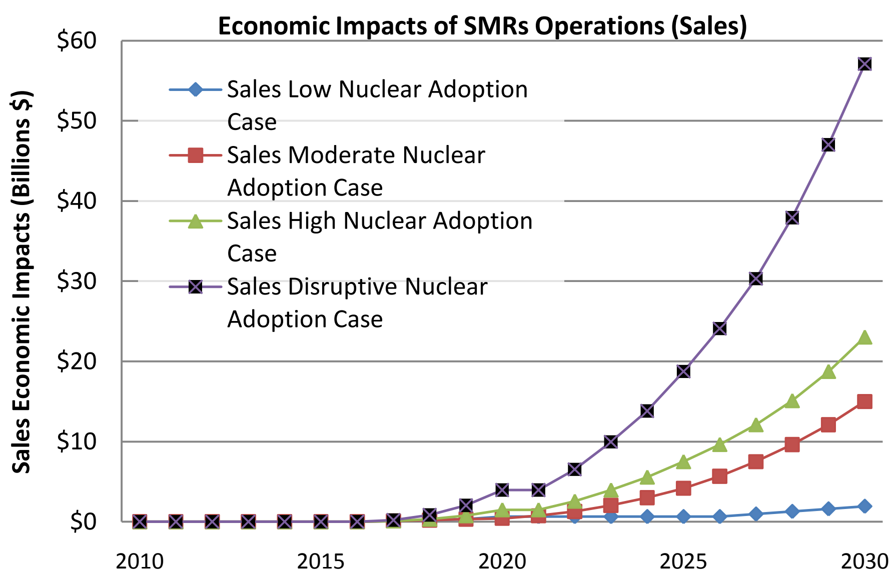
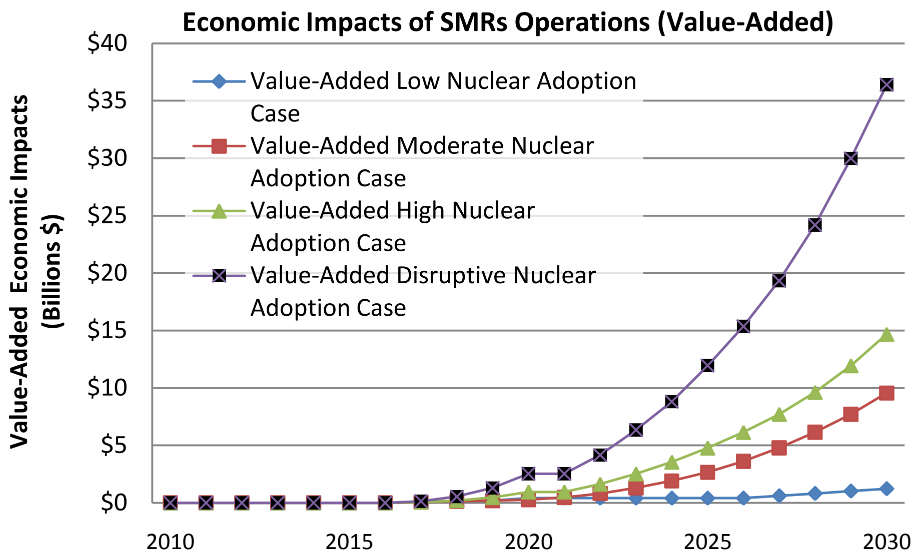


Figure 8.b



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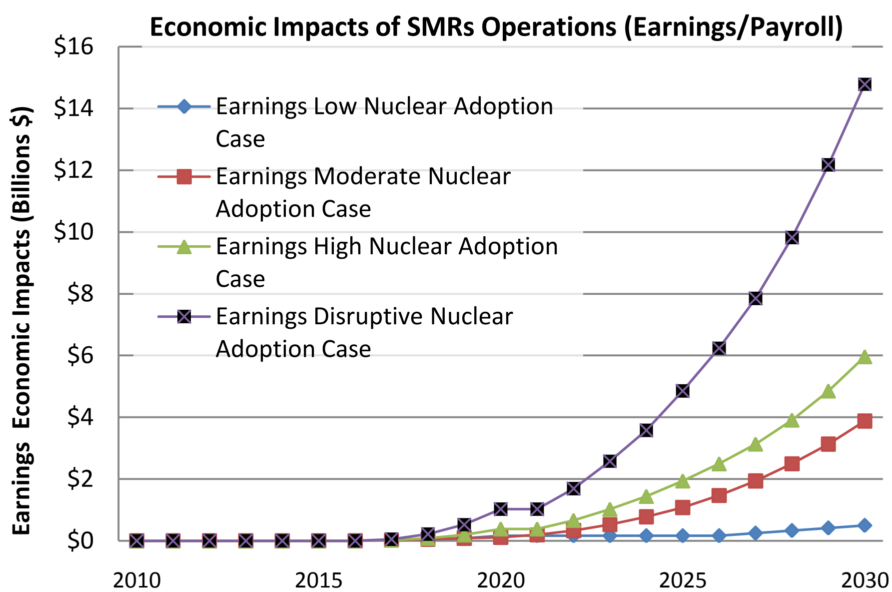


Figure 8.d

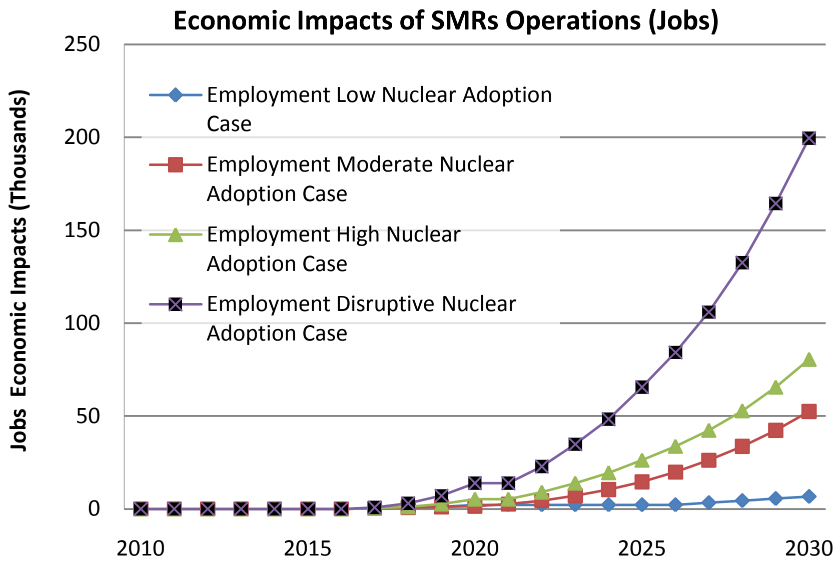
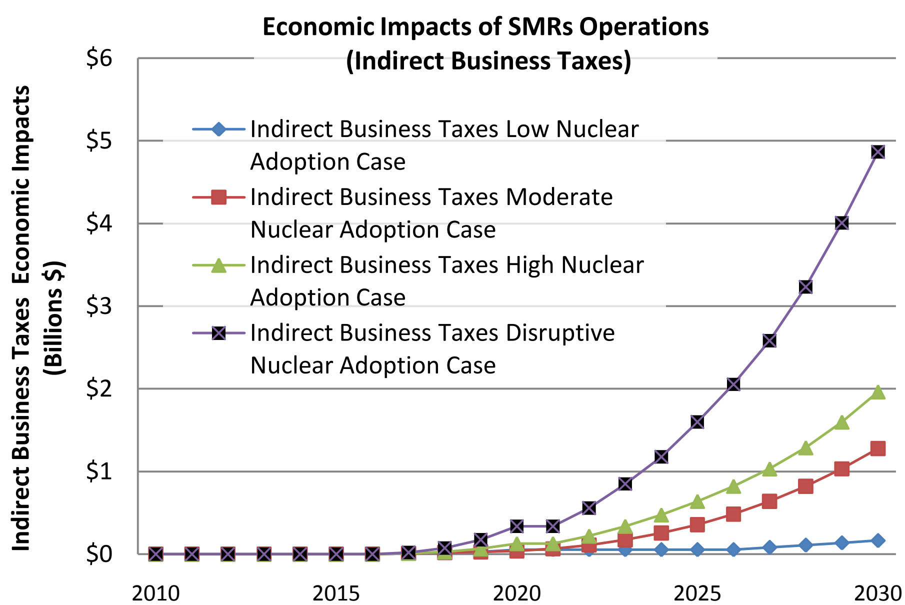


Figure 8.e



Projected Economic Impacts of the SMR Industry by 2030

Under the assumptions utilized in this study, by year 2030 the market for SMRs will be substantially if not fully developed. Figures 9.a through 9.e report various economic impacts by the year 2030 for each of the projected demand scenarios: Low, Medium, High, and Disruptive. The research team reports the economic impacts by sales (output), value-added, earnings (payroll), jobs, and indirect business taxes. These data are presented in tabular form in Appendix C.

Figure 9.a

(Manufacturing and Construction)

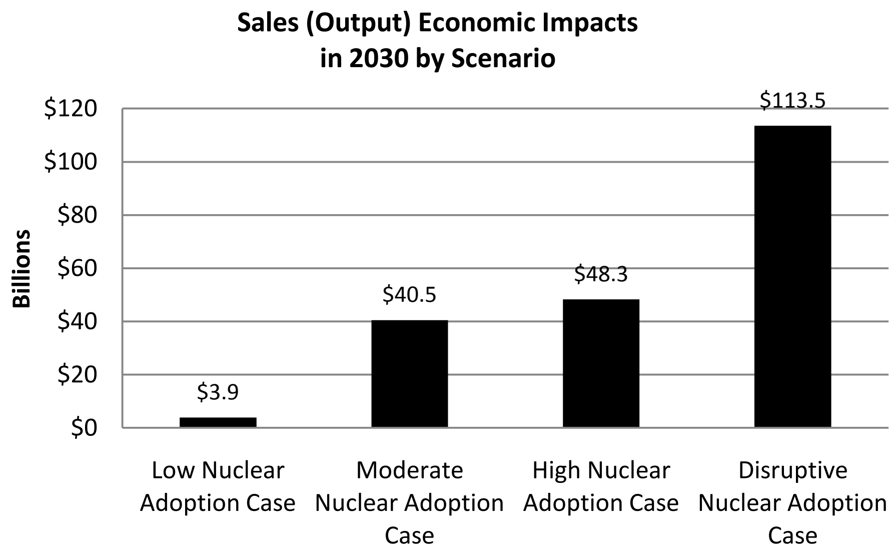


Figure 9.b

(Manufacturing and Construction)

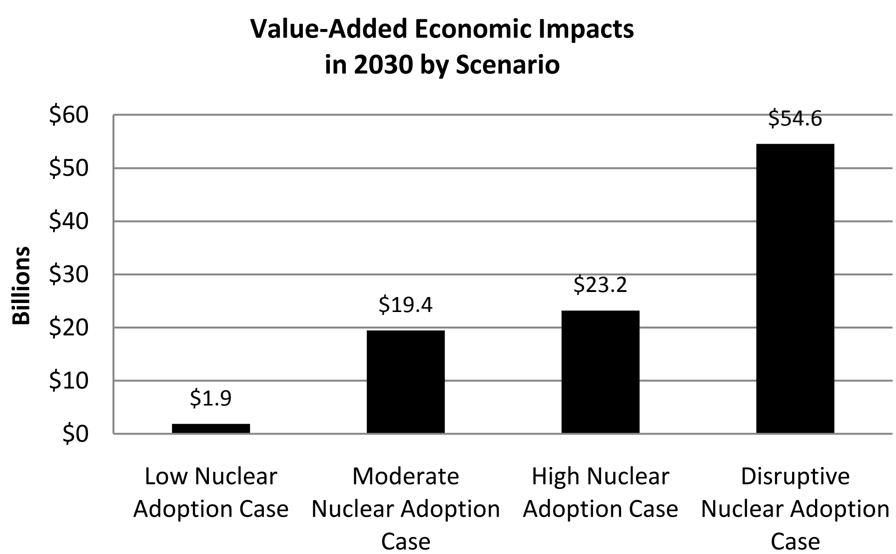


Figure 9.c

(Manufacturing and Construction)

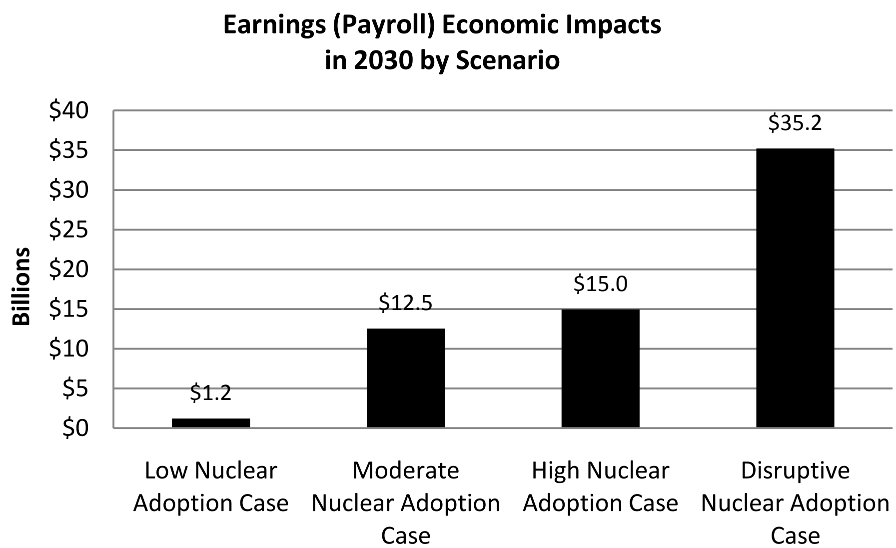


Figure 9.d

(Manufacturing and Construction)

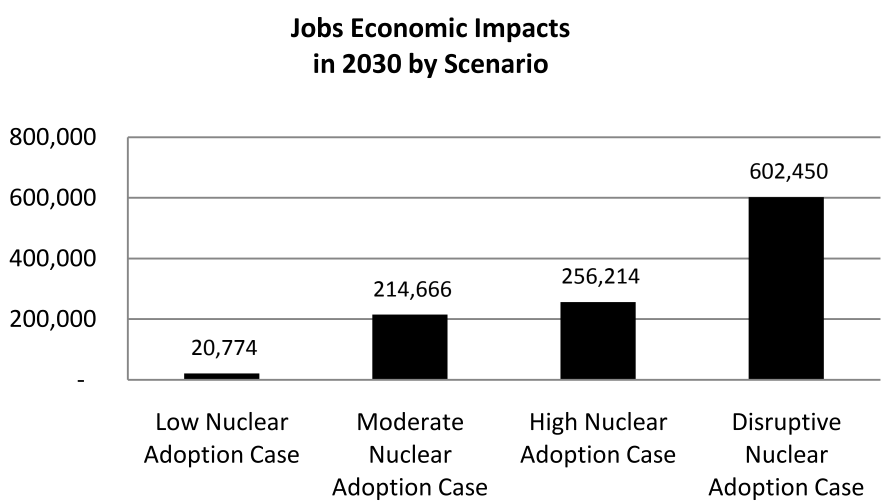
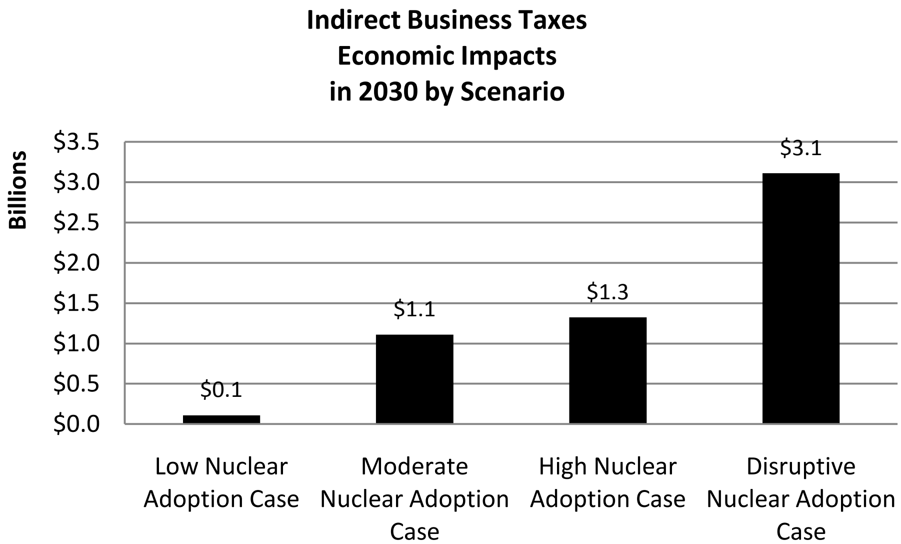


Figure 9.e

(Manufacturing and Construction)



Figures 10. a through e report these measures for the operations of SMRs. As described earlier, the operations impacts stem from the cumulative additions of SMRs throughout the projected twenty-year period until 2030. These data are presented in tabular form in Appendix D.

Figure 10.a

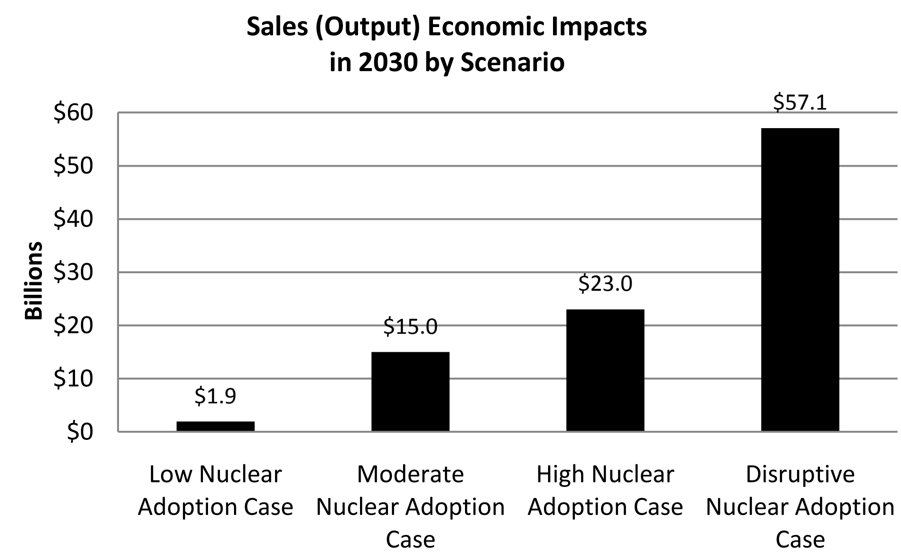


Figure 10.b

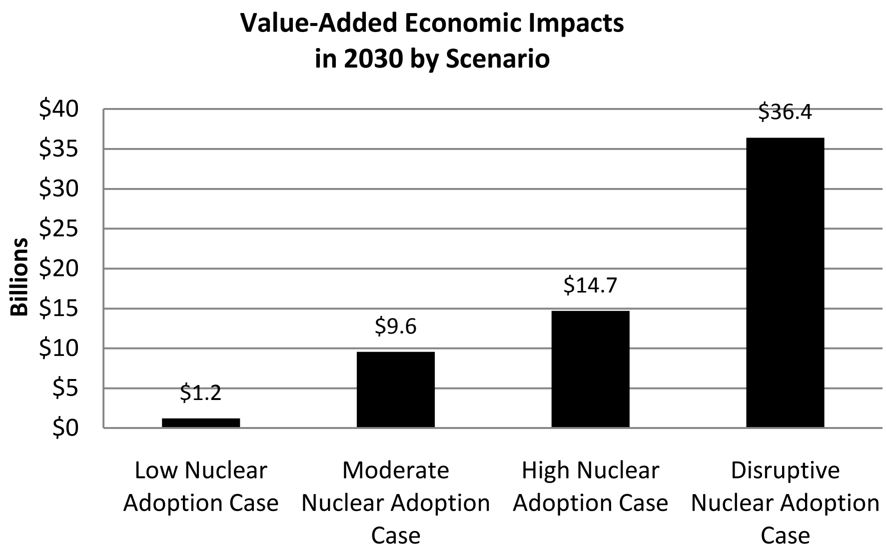


Figure 10.c

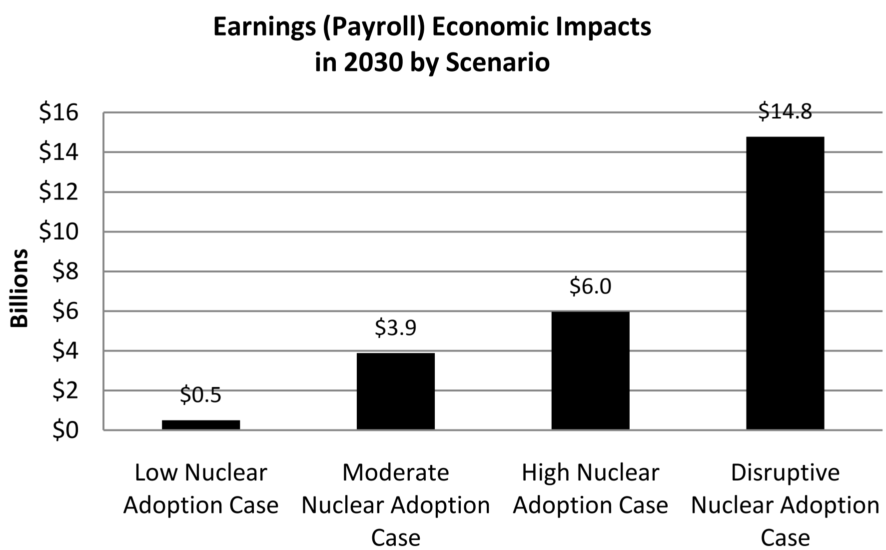


Figure 10.d

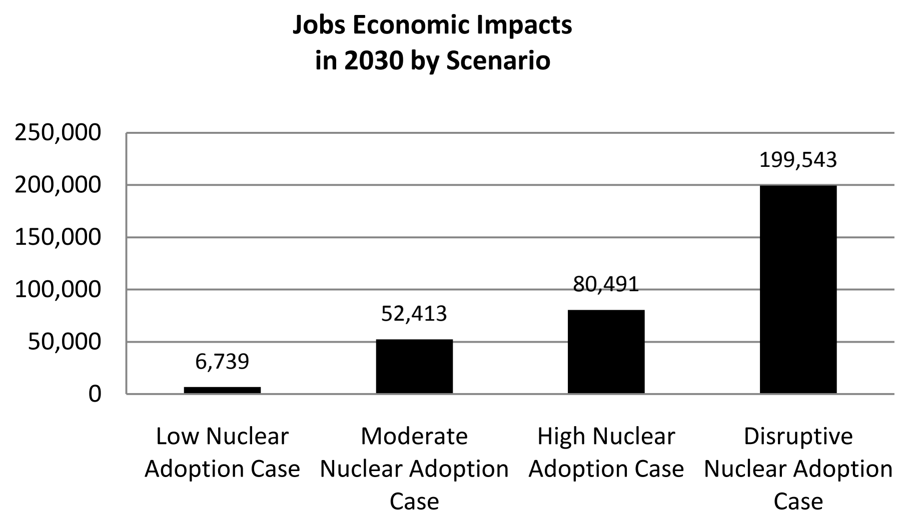
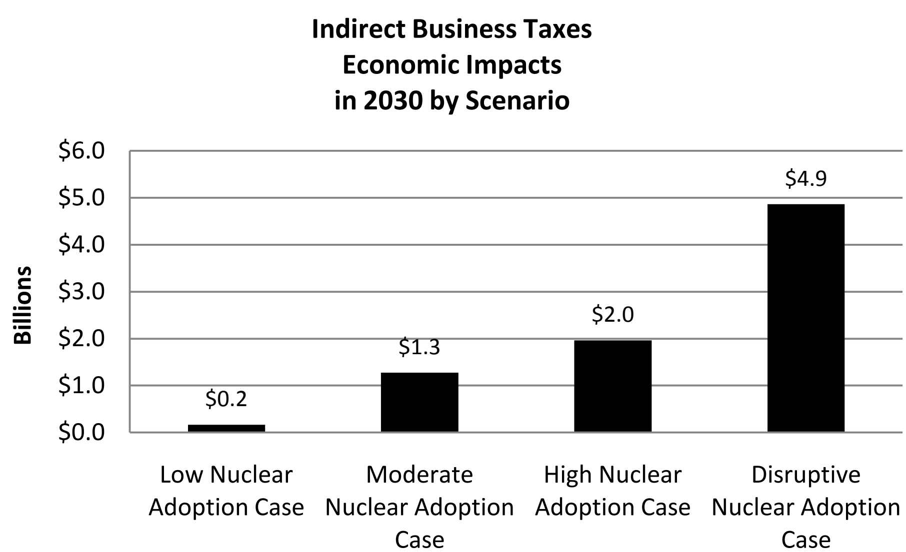


Figure 10.e



Section 5: Concluding Remarks

This study highlights the magnitude of potential benefits from manufacturing SMRs in the U.S. The economic analysis estimates the impacts of SMR manufacturing, construction, and operation of a representative 100 MW SMR unit as follows:

- A prototypical 100 MW SMR costing $500 million to manufacture and install on-site is estimated to create nearly 7,000 jobs and generate $1.3 billion in sales, $627 million in value-added, $404 million in earnings (payroll), and $35 million in indirect business taxes
- The annual operation of each 100 MW SMR unit is estimated to create about 375 jobs and generate $107 million in sales, $68 million in value-added, $27 million in earnings (payroll), and $9 million in indirect business taxes

The development of a robust domestic SMR industry will result in significant economic benefits. Given the assumptions regarding the deployment of SMRs as outlined in the Moderate and High Nuclear Adoption cases, the manufacture and construction of SMRs in 2030 will be responsible for an estimated range of: 215,000 – 255,000 jobs,; $40 - $48 billion in sales; $19 - $23 billion in value-added; $12 - $15 billion in annual earnings; and $1.1 - $1.3 billion in indirect business taxes. From cumulative operations through 2030, SMRs will be responsible for: 52,000 – 80,000 jobs; $15 - $23 billion in sales; $10 - $15 billion in value-added; $4 - $6 billion in annual earnings; and $1.3 - $2 billion in indirect business taxes. Aggressive development of a domestic SMR industry, as outlined in the Disruptive Nuclear Adoption Case, roughly triples these estimated impacts and generates very significant economic benefits.

In stark contrast, the conditions assumed in the Low Nuclear Adoption (also called the No Greenhouse Gas Legislation) case, result in approximately 1/10th of the economic benefits of the High and Moderate cases, with just a few SMRs manufactured domestically on an annual basis by 2030. The results of the Low Nuclear Adoption Case indicate a likely low probability for achieving a globally competitive and stable SMR manufacturing industry in the U.S.

Based on the overall results of this study, a robust SMR market, both globally and nationally, will add to the U.S. manufacturing base and provide a significant number of high-paying jobs in manufacture and operations. This conclusion is based on a number of dependencies that temper the relative certainty of the results.

First, crucial to the success of the SMR manufacturing industry is successfully navigating the NRC licensing process in a satisfactory timeframe. Because the SMR design and manufacturing industry is globally competitive and SMRs will compete with other options for U.S. electricity generation, significant delays or failure of specific designs in NRC licensing could result in a domestic industry that does not realize its potential. Second, the economic impacts and market penetration of SMRs corresponds to the degree of anticipated carbon regulation—the tighter the regulation and the higher the price on carbon, the greater the degree of SMR (and nuclear) success. Third, the issue of siting has not yet been addressed. Nuclear energy may be at its highest public approval rating in more than a generation (Jones, 2010), but it is still an assumption the American public is readily willing to site many new nuclear reactors. In addition, it is assumed that SMRs will be easier to site than traditional nuclear power generation facilities although this notion has not yet been tested. Likewise, competitors to nuclear power, in particular coal plants, have experienced sustained public opposition of late. The degree of public acceptance (or rejection) of nuclear power in relation to its competitors will be important to market penetration in the future.

Finally, this study did not address the domestic investment climate for SMRs. The investment community has long taken a wait-and-see attitude toward the nuclear power industry. Explicit government support for SMRs will have an impact on investment desirability in the sector, as will the availability of what is now closely held data by proprietors. Each of these dependencies merits additional independent research and possible replication of this study as SMRs move closer to realization.

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Appendix A: SMR Electricity Generation Market Potential (4 cases)

Low Nuclear Adoption Case	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US Total Nuclear Capacity Installed (MWe)	0.0	0.0	0.0	0.0	1180.0	0.0	0.0	1000.0	1000.0	1000.0	2207.4	0.0	0.0	0.0	0.0	0.0	0.0	1077.3	1040.1	1049.0	1008.5
US SMR Capacity Installed [All Manufac.] (MWe)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.0	80.0	100.0	264.9	0.0	0.0	0.0	0.0	0.0	0.0	280.1	291.2	314.7	322.7
US SMR Capacity Installed [All Manufac.] (Units)	0	0	0	0	0	0	0	1	1	1	3	0	0	0	0	0	0	3	3	3	3
US SMRs Operating (Units)	0	0	0	0	0	0	0	1	2	3	6	6	6	6	6	6	6	9	12	15	18
US SMR Capacity Installed [US Manfuc.] (MWe)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	40.0	50.0	132.4	0.0	0.0	0.0	0.0	0.0	0.0	140.0	145.6	157.4	161.4
US SMR Capacity Installed [US Manfuc.] (Units)	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	2	2
Inter. Total Nuclear Capacity Installed (MWe)	#N/A	5322.3	5804.6	6214.9	6553.1	6819.4	7013.7	7136.0	7186.3	7164.6	7070.9	6905.1	6667.4	6357.7	5976.0	5522.3	4996.6	4398.9	3729.1	2987.4	2173.7
Inter. SMR Capacity Installed [All Manufac.] (MWe)		0.0	0.0	0.0	0.0	136.4	280.5	428.2	574.9	716.5	848.5	966.7	1066.8	1144.4	1195.2	1214.9	1199.2	1143.7	1044.2	896.2	695.6
Inter. SMR Capacity Installed [All Manufac.] (Units)	0	0	0	0	0	1	3	4	6	7	8	10	11	11	12	12	12	11	10	9	7
Inter. SMR Capacity Installed [US Manufac.] (MWe)		0.0	0.0	0.0	0.0	27.3	56.1	85.6	115.0	143.3	169.7	193.3	213.4	228.9	239.0	243.0	239.8	228.7	208.8	179.2	139.1
Inter. SMR Capacity Installed [US Manufac.] (Units)	0	0	0	0	0	0	1	1	1	1	2	2	2	2	2	2	2	2	2	2	1
Total SMRs Manufactured in the US (Units)	0	0	0	0	0	0	1	1	1	2	3	2	2	2	2	2	2	3	3	4	3

Moderate Nuclear Adoption Case	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US Total Nuclear Capacity Installed (MWe)	0.0	0.0	0.0	0.0	1180.0	0.0	0.0	1000.0	1000.0	1000.0	1200.0	2340.0	3020.0	3700.0	4380.0	5060.0	5740.0	6420.0	7100.0	7780.0	8460.0
US SMR Capacity Installed [All Manufac.] (MWe)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.0	80.0	100.0	144.0	327.6	483.2	666.0	876.0	1113.2	1377.6	1669.2	1988.0	2334.0	2707.2
US SMR Capacity Installed [All Manufac.] (Units)	0	0	0	0	0	0	0	1	1	1	1	3	5	7	9	11	14	17	20	23	27
US SMRs Operating (Units)	0	0	0	0	0	0	0	1	2	3	4	7	12	19	28	39	53	70	90	113	140
US SMR Capacity Installed [US Manfuc.] (MWe)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	40.0	50.0	72.0	163.8	241.6	333.0	438.0	556.6	688.8	834.6	994.0	1167.0	1353.6
US SMR Capacity Installed [US Manfuc.] (Units)	0	0	0	0	0	0	0	0	0	1	1	2	2	3	4	6	7	8	10	12	14
Inter. Total Nuclear Capacity Installed (MWe)	#N/A	11357.0	12170.1	12983.2	13796.3	14609.4	15422.6	16235.7	17048.8	17861.9	18675.0	19488.2	20301.3	21114.4	21927.5	22740.6	23553.8	24366.9	25180.0	25993.1	26806.2
Inter. SMR Capacity Installed [All Manufac.] (MWe)		0.0	0.0	0.0	0.0	292.2	616.9	974.1	1363.9	1786.2	2241.0	2728.3	3248.2	3800.6	4385.5	5002.9	5652.9	6335.4	7050.4	7797.9	8578.0
Inter. SMR Capacity Installed [All Manufac.] (Units)	0	0	0	0	0	3	6	10	14	18	22	27	32	38	44	50	57	63	71	78	86
Inter. SMR Capacity Installed [US Manufac.] (MWe)		0.0	0.0	0.0	0.0	58.4	123.4	194.8	272.8	357.2	448.2	545.7	649.6	760.1	877.1	1000.6	1130.6	1267.1	1410.1	1559.6	1715.6
Inter. SMR Capacity Installed [US Manufac.] (Units)	0	0	0	0	0	1	1	2	3	4	4	5	6	8	9	10	11	13	14	16	17
Total SMRs Manufactured in the US (Units)	0	0	0	0	0	1	1	2	3	5	5	7	8	11	13	16	18	21	24	28	31

Appendix A, continued:

High Nuclear Adoption Case	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US Total Nuclear Capacity Installed (MWe)	0.0	0.0	0.0	0.0	1180.0	0.0	0.0	1000.0	3000.0	4450.0	6066.3	0.0	6092.0	7005.8	7282.3	8374.7	8381.6	8909.9	10110.0	11362.1	12572.4
US SMR Capacity Installed [All Manufac.] (MWe)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	60.0	240.0	445.0	728.0	0.0	974.7	1261.0	1456.5	1842.4	2011.6	2316.6	2830.8	3408.6	4023.2
US SMR Capacity Installed [All Manufac.] (Units)	0	0	0	0	0	0	0	1	2	4	7	0	10	13	15	18	20	23	28	34	40
US SMRs Operating (Units)	0	0	0	0	0	0	0	1	3	7	14	14	24	37	52	70	90	113	141	175	215
US SMR Capacity Installed [US Manfuc.] (MWe)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	120.0	222.5	364.0	0.0	487.4	630.5	728.2	921.2	1005.8	1158.3	1415.4	1704.3	2011.6
US SMR Capacity Installed [US Manfuc.] (Units)	0	0	0	0	0	0	0	0	1	2	4	0	5	6	7	9	10	12	14	17	20
Inter. Total Nuclear Capacity Installed (MWe)	#N/A	11357.0	12170.1	12983.2	13796.3	14609.4	15422.6	16235.7	17048.8	17861.9	18675.0	19488.2	20301.3	21114.4	21927.5	22740.6	23553.8	24366.9	25180.0	25993.1	26806.2
Inter. SMR Capacity Installed [All Manufac.] (MWe)		0.0	0.0	0.0	0.0	292.2	616.9	974.1	1363.9	1786.2	2241.0	2728.3	3248.2	3800.6	4385.5	5002.9	5652.9	6335.4	7050.4	7797.9	8578.0
Inter. SMR Capacity Installed [All Manufac.] (Units)	0	0	0	0	0	3	6	10	14	18	22	27	32	38	44	50	57	63	71	78	86
Inter. SMR Capacity Installed [US Manufac.] (MWe)		0.0	0.0	0.0	0.0	58.4	123.4	194.8	272.8	357.2	448.2	545.7	649.6	760.1	877.1	1000.6	1130.6	1267.1	1410.1	1559.6	1715.6
Inter. SMR Capacity Installed [US Manufac.] (Units)	0	0	0	0	0	1	1	2	3	4	4	5	6	8	9	10	11	13	14	16	17
Total SMRs Manufactured in the US (Units)	0	0	0	0	0	1	1	2	4	6	8	5	11	14	16	19	21	25	28	33	37

Disruptive Nuclear Adoption Case	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
US Total Nuclear Capacity Installed (MWe)	0.0	0.0	0.0	0.0	1180.0	0.0	0.0	1000.0	3000.0	4450.0	6066.3	0.0	6092.0	7005.8	7282.3	8374.7	8381.6	8909.9	10110.0	11362.1	12572.4
US SMR Capacity Installed [All Manufac.] (MWe)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	150.0	600.0	1112.5	1819.9	0.0	2436.8	3152.6	3641.2	4606.1	5029.0	5791.5	7077.0	8521.6	9429.3
US SMR Capacity Installed [All Manufac.] (Units)	0	0	0	0	0	0	0	2	6	11	18	0	24	32	36	46	50	58	71	85	94
US SMRs Operating (Units)	0	0	0	0	0	0	0	2	8	19	37	37	61	93	129	175	225	283	354	439	533
US SMR Capacity Installed [US Manfuc.] (MWe)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	75.0	300.0	556.3	909.9	0.0	1218.4	1576.3	1820.6	2303.0	2514.5	2895.7	3538.5	4260.8	4714.6
US SMR Capacity Installed [US Manfuc.] (Units)	0	0	0	0	0	0	0	1	3	6	9	0	12	16	18	23	25	29	35	43	47
Inter. Total Nuclear Capacity Installed (MWe)	#N/A	11357.0	12170.1	12983.2	13796.3	14609.4	15422.6	16235.7	17048.8	17861.9	18675.0	19488.2	20301.3	21114.4	21927.5	22740.6	23553.8	24366.9	25180.0	25993.1	26806.2
Inter. SMR Capacity Installed [All Manufac.] (MWe)		0.0	0.0	0.0	0.0	730.5	1542.3	2435.4	3409.8	4465.5	5602.5	6820.9	8120.5	9501.5	10963.8	12507.4	14132.3	15838.5	17626.0	19494.8	20104.7
Inter. SMR Capacity Installed [All Manufac.] (Units)	0	0	0	0	0	7	15	24	34	45	56	68	81	95	110	125	141	158	176	195	201
Inter. SMR Capacity Installed [US Manufac.] (MWe)		0.0	0.0	0.0	0.0	146.1	308.5	487.1	682.0	893.1	1120.5	1364.2	1624.1	1900.3	2192.8	2501.5	2826.5	3167.7	3525.2	3899.0	4020.9
Inter. SMR Capacity Installed [US Manufac.] (Units)	0	0	0	0	0	1	3	5	7	9	11	14	16	19	22	25	28	32	35	39	40
Total SMRs Manufactured in the US (Units)	0	0	0	0	0	1	3	6	10	15	20	14	28	35	40	48	53	61	70	82	87

Appendix B: Table of results for each type of economic impact, per year, impact for each scenario

2010 – 2020

Sales Economic Impacts (dollars in Billions)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Low Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ -	$ 130.5	$ 130.5	$ 130.5	$ 261.0	$ 391.5
Moderate Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 130.5	$ 130.5	$ 261.0	$ 391.5	$ 652.4	$ 652.4
High Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 130.5	$ 130.5	$ 261.0	$ 521.9	$ 782.9	$ 1,043.9
Disruptive Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 130.5	$ 391.5	$ 782.9	$ 1,304.8	$ 1,957.3	$ 2,609.7

Value-Added Economic Impacts (dollars in Billions)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Low Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ -	$ 62.7	$ 62.7	$ 62.7	$ 125.4	$ 188.2
Moderate Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 62.7	$ 62.7	$ 125.4	$ 188.2	$ 313.6	$ 313.6
High Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 62.7	$ 62.7	$ 125.4	$ 250.9	$ 376.3	$ 501.7
Disruptive Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 62.7	$ 188.2	$ 376.3	$ 627.2	$ 940.8	$ 1,254.4

Earnings (Payroll) Economic Impacts (dollars in Billions)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Low Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ -	$ 40.5	$ 40.5	$ 40.5	$ 80.9	$ 121.4
Moderate Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 40.5	$ 40.5	$ 80.9	$ 121.4	$ 202.3	$ 202.3
High Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 40.5	$ 40.5	$ 80.9	$ 161.9	$ 242.8	$ 323.7
Disruptive Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 40.5	$ 121.4	$ 242.8	$ 404.6	$ 607.0	$ 809.3

Employment Economic Impacts	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Low Nuclear Adoption Case	-	-	-	-	-	-	6,925	6,925	6,925	13,849	20,774
Moderate Nuclear Adoption Case	-	-	-	-	-	6,925	6,925	13,849	20,774	34,624	34,624
High Nuclear Adoption Case	-	-	-	-	-	6,925	6,925	13,849	27,699	41,548	55,398
Disruptive Nuclear Adoption Case	-	-	-	-	-	6,925	20,774	41,548	69,247	103,871	138,494

Indirect Business Taxes Economic Impacts (dollars in Billions)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Low Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ -	$ 3.6	$ 3.6	$ 3.6	$ 7.2	$ 10.7
Moderate Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 3.6	$ 3.6	$ 7.2	$ 10.7	$ 17.9	$ 17.9
High Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 3.6	$ 3.6	$ 7.2	$ 14.3	$ 21.5	$ 28.6
Disruptive Nuclear Adoption Case	$ -	$ -	$ -	$ -	$ -	$ 3.6	$ 10.7	$ 21.5	$ 35.8	$ 53.6	$ 71.5

Appendix B, continued:

2021 – 2030

Sales Economic Impacts (dollars in Billions)	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Low Nuclear Adoption Case	$ 261.0	$ 261.0	$ 261.0	$ 261.0	$ 261.0	$ 261.0	$ 391.5	$ 391.5	$ 521.9	$ 391.5
Moderate Nuclear Adoption Case	$ 913.4	$ 1,043.9	$ 1,435.3	$ 1,696.3	$ 2,087.7	$ 2,348.7	$ 2,740.2	$ 3,131.6	$ 3,653.6	$ 4,045.0
High Nuclear Adoption Case	$ 652.4	$ 1,435.3	$ 1,826.8	$ 2,087.7	$ 2,479.2	$ 2,740.2	$ 3,262.1	$ 3,653.6	$ 4,306.0	$ 4,827.9
Disruptive Nuclear Adoption Case	$ 1,826.8	$ 3,653.6	$ 4,566.9	$ 5,219.4	$ 6,263.2	$ 6,915.7	$ 7,959.5	$ 9,133.9	$ 10,699.7	$ 11,352.1

Value-Added Economic Impacts (dollars in Billions)	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Low Nuclear Adoption Case	$ 125.4	$ 125.4	$ 125.4	$ 125.4	$ 125.4	$ 125.4	$ 188.2	$ 188.2	$ 250.9	$ 188.2
Moderate Nuclear Adoption Case	$ 439.0	$ 501.7	$ 689.9	$ 815.3	$ 1,003.5	$ 1,128.9	$ 1,317.1	$ 1,505.2	$ 1,756.1	$ 1,944.3
High Nuclear Adoption Case	$ 313.6	$ 689.9	$ 878.0	$ 1,003.5	$ 1,191.6	$ 1,317.1	$ 1,567.9	$ 1,756.1	$ 2,069.7	$ 2,320.6
Disruptive Nuclear Adoption Case	$ 878.0	$ 1,756.1	$ 2,195.1	$ 2,508.7	$ 3,010.5	$ 3,324.0	$ 3,825.8	$ 4,390.2	$ 5,142.9	$ 5,456.5

Earnings (Payroll) Economic Impacts (dollars in Billions)	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Low Nuclear Adoption Case	$ 80.9	$ 80.9	$ 80.9	$ 80.9	$ 80.9	$ 80.9	$ 121.4	$ 121.4	$ 161.9	$ 121.4
Moderate Nuclear Adoption Case	$ 283.2	$ 323.7	$ 445.1	$ 526.0	$ 647.4	$ 728.3	$ 849.7	$ 971.1	$ 1,133.0	$ 1,254.4
High Nuclear Adoption Case	$ 202.3	$ 445.1	$ 566.5	$ 647.4	$ 768.8	$ 849.7	$ 1,011.6	$ 1,133.0	$ 1,335.3	$ 1,497.1
Disruptive Nuclear Adoption Case	$ 566.5	$ 1,133.0	$ 1,416.2	$ 1,618.5	$ 1,942.2	$ 2,144.6	$ 2,468.3	$ 2,832.4	$ 3,318.0	$ 3,520.3

Employment Economic Impacts	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Low Nuclear Adoption Case	13,849	13,849	13,849	13,849	13,849	13,849	20,774	20,774	27,699	20,774
Moderate Nuclear Adoption Case	48,473	55,398	76,172	90,021	110,795	124,645	145,419	166,193	193,892	214,666
High Nuclear Adoption Case	34,624	76,172	96,946	110,795	131,570	145,419	173,118	193,892	228,516	256,214
Disruptive Nuclear Adoption Case	96,946	193,892	242,365	276,989	332,386	367,010	422,408	484,730	567,827	602,450

Indirect Business Taxes Economic Impacts (dollars in Billions)	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Low Nuclear Adoption Case	$ 7.2	$ 7.2	$ 7.2	$ 7.2	$ 7.2	$ 7.2	$ 10.7	$ 10.7	$ 14.3	$ 10.7
Moderate Nuclear Adoption Case	$ 25.0	$ 28.6	$ 39.3	$ 46.5	$ 57.2	$ 64.4	$ 75.1	$ 85.8	$ 100.1	$ 110.8
High Nuclear Adoption Case	$ 17.9	$ 39.3	$ 50.1	$ 57.2	$ 67.9	$ 75.1	$ 89.4	$ 100.1	$ 118.0	$ 132.3
Disruptive Nuclear Adoption Case	$ 50.1	$ 100.1	$ 125.1	$ 143.0	$ 171.6	$ 189.5	$ 218.1	$ 250.3	$ 293.2	$ 311.1

Appendix C: Projected Economic Impacts of SMR Manufacturing and Construction of SMRs in Year 2030

Scenario	Sales Economic Impacts
Low Nuclear Adoption Case	$ 3,914,523,909
Moderate Nuclear Adoption Case	$ 40,450,080,396
High Nuclear Adoption Case	$ 48,279,128,214
Disruptive Nuclear Adoption Case	$ 113,521,193,369
Scenario	**Value-Added Economic Impacts**
Low Nuclear Adoption Case	$ 1,881,534,775
Moderate Nuclear Adoption Case	$ 19,442,526,011
High Nuclear Adoption Case	$ 23,205,595,561
Disruptive Nuclear Adoption Case	$ 54,564,508,481
Scenario	**Earnings (Payroll) Economic Impacts**
Low Nuclear Adoption Case	$ 1,213,904,459
Moderate Nuclear Adoption Case	$ 12,543,679,408
High Nuclear Adoption Case	$ 14,971,488,326
Disruptive Nuclear Adoption Case	$ 35,203,229,307
Scenario	**Employment Economic Impacts**
Low Nuclear Adoption Case	20,774
Moderate Nuclear Adoption Case	214,666
High Nuclear Adoption Case	256,214
Disruptive Nuclear Adoption Case	602,450
Scenario	**Indirect Business Taxes Economic Impacts**
Low Nuclear Adoption Case	$ 107,261,435
Moderate Nuclear Adoption Case	$ 1,108,368,157
High Nuclear Adoption Case	$ 1,322,891,026
Disruptive Nuclear Adoption Case	$ 3,110,581,602

Appendix D: Projected Economic Impacts of Cumulative Operations of SMRs in Year 2030

Economic Impact Projections Year 2030	
Scenario	**Sales**
Low Nuclear Adoption Case	$ 1,927,975,993
Moderate Nuclear Adoption Case	$ 14,995,368,837
High Nuclear Adoption Case	$ 23,028,602,142
Disruptive Nuclear Adoption Case	$ 57,089,511,358
Scenario	**Value-Added**
Low Nuclear Adoption Case	$ 1,229,395,516
Moderate Nuclear Adoption Case	$ 9,561,965,126
High Nuclear Adoption Case	$ 14,684,446,444
Disruptive Nuclear Adoption Case	$ 36,403,767,231
Scenario	**Earnings/Payroll**
Low Nuclear Adoption Case	$ 499,181,990
Moderate Nuclear Adoption Case	$ 3,882,526,592
High Nuclear Adoption Case	$ 5,962,451,552
Disruptive Nuclear Adoption Case	$ 14,781,333,381
Scenario	**Employment**
Low Nuclear Adoption Case	$ 6,739
Moderate Nuclear Adoption Case	$ 52,413
High Nuclear Adoption Case	$ 80,491
Disruptive Nuclear Adoption Case	199,543
Scenario	**Indirect Business Taxes**
Low Nuclear Adoption Case	$ 164,305,314
Moderate Nuclear Adoption Case	$ 1,277,930,221
High Nuclear Adoption Case	$ 1,962,535,696
Disruptive Nuclear Adoption Case	$ 4,865,262,911

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