OXFORD ECONOMICS

The Economic Impacts of LIFE

November 2012

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Executive Summary

Laser inertial fusion energy (LIFE) has been under development by a global team of researchers for many years. With the recent successful construction of the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL), demonstration of laser fusion with energy gain is anticipated in the near future. If successful, this could open the door to the development of commercial LIFE power plants, which would have profound implications for global energy supply, the environment, non-proliferation and economic growth in the U.S.

In this study, we assess the likely impacts for the U.S. economy if the commercialization of LIFE were successful. We estimate that the construction and operation of a domestic fleet of LIFE plants could support an average of **152,200 to 417,400 jobs** in the U.S. over the period 2014 to 2050, depending on the speed of rollout, and generate, on average, **$17.7 to $47.7 billion of GDP a year.**

The domestic commercialization of LIFE would have three phases:

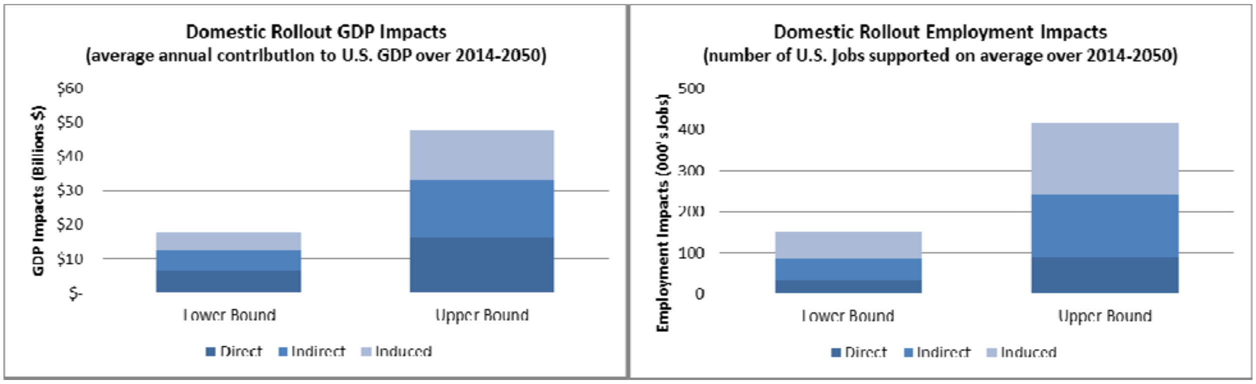
- ***The Construction Phase* –** the construction of LIFE power plants and associated off-site fuel plants.
- ***Technology Demonstration Phase* –** investment in the technology supply-chain to manufacture the equipment needed in commercially viable LIFE plants.
- ***The Operations Phase* –** the annual operations of both the LIFE power plants and off-site fuel plants to produce electricity.

The economic benefits generated by each of these phases have three components:

- **Direct impacts** – how many people are employed in the construction, manufacturing and operation of LIFE plants, and how much GDP do they create?
- **Indirect impacts** - how many jobs and how much GDP are supported down the supply chain to LIFE plants, in each of the three phases of the project?
- **Induced impacts** – how much do the direct and indirect employees spend in the U.S. economy, and how many jobs and how much GDP are supported by that spending?

The lower and upper bound direct, indirect and induced employment and GDP impacts of the domestic LIFE rollout scenarios that we have considered are set out in the charts below. To put the employment impacts into perspective, the number of jobs that would be supported by LIFE is potentially greater than the direct employment today in, for example, the machine shop (246,000), aircraft manufacturing (230,000) or semiconductor manufacturing (182,000) industries.

Figure 1: Economic impacts of the domestic commercialization of LIFE in the U.S.



Source: Oxford Economics

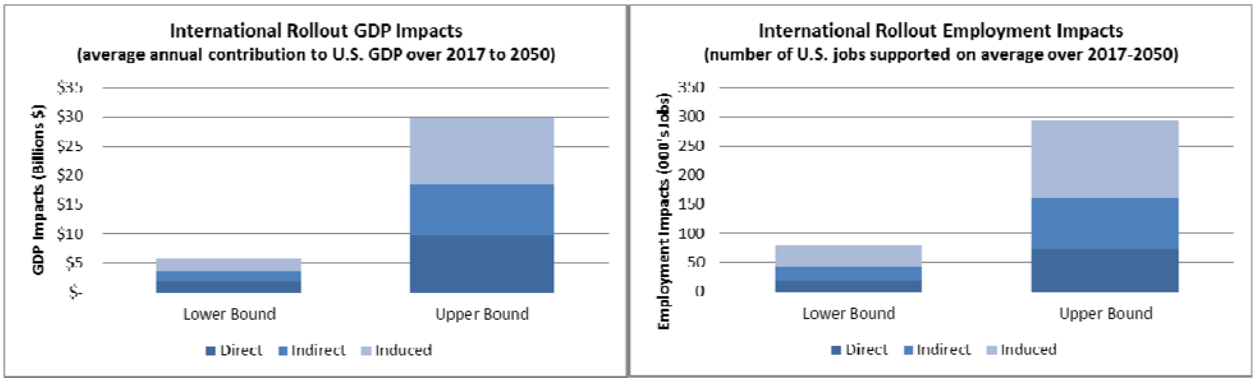
Without the investment in the domestic rollout of LIFE, these employment benefits would not occur. Of course, the electricity that would have been generated by LIFE would have to be generated by some other source. The construction and operation of these conventional plants would generate employment impacts that are likely to be similar in magnitude to the development of LIFE plants.

Compared to fossil fuel power plants, however, many of the employment impacts generated by the domestic rollout of LIFE plants are likely to be **high-skilled jobs in the U.S. manufacturing sector**. These include jobs in high-tech industries, such as laser diode manufacturing, laser optic fabrication and computer programming. We estimate that the domestic rollout of LIFE will support between **8,100 and 21,500 jobs** on average over the period 2014 to 2050 in these high-tech industries alone. Alternative ways of meeting U.S. electricity generation needs would be unlikely to create so many high productivity manufacturing jobs.

But there are a number of additional channels through which the development of LIFE could generate benefits for the U.S. economy on top of those from its domestic commercialization.

As LIFE plants are developed globally, this will create **export opportunities for U.S. companies**. The U.S. has much to gain if it can position itself as a “first mover” in certain LIFE-specific industries, capturing a large share of future global demand for fusion lasers and the design and engineering of LIFE plants overseas. U.S. manufacturers have the potential to generate up to **$20.6 billion in increased export revenues** per annum over the 2017 to 2050 period, supporting up to **295,400 additional jobs,** of which up to 48,400 could be in high-tech manufacturing industries.

Figure 2: Economic impacts from increased U.S. exports for the global commercialization of LIFE



Source: Oxford Economics

Building LIFE plants, instead of fossil fuel and conventional nuclear power plants, to replace current generating capacity when it retires and to meet new energy growth needs would **reduce the pollution associated with fossil fuels** (carbon dioxide, carbon monoxide, sulfur and nitrogen oxides, particulate matter and mercury) and reduce the amount of nuclear waste. We estimate the benefits from this avoided pollution will total between **$106 and $268 billion** over the 2020 to 2050 period when compared to an alternative scenario in which most new electricity generation capacity comes from natural gas plants.

In addition, fusion energy is a threshold process, so it has an inherently low marginal cost of electricity and high temperature operation. This makes LIFE particularly well-suited to dry cooling and water purification, which is a significant advantage for water-poor areas where conventional power plants are a major burden on water supply, such as the Southeastern U.S.

It is also important to note that the economic contribution of power generation by coal or natural gas could still be maintained even when there is substantial roll-out of LIFE plants. Some of the coal or gas that would otherwise have been used in U.S. electricity generation could be used in other sectors or exported, and so continue to support U.S. jobs. The extent to which the latter would occur would depend on worldwide demand, the price of the commodity, and development of the necessary export infrastructure.

Finally, the R&D undertaken to develop LIFE is projected to have important applications or “spillovers” in other industries, generating further economic benefits for the U.S. Our analysis suggests these spillovers could generate some **$40 billion** in cumulative GDP impacts over the course of the LIFE project. An example of where this is likely to be significant is laser based manufacturing, which is used to strengthen metals, increase component lifetime and mitigate corrosion in the aerospace, transportation and petrochemical industries.

The construction and operation of LIFE plants, and associated R&D, will generate significant economic impacts over the 2013 to 2050 time period. The economic benefits from the domestic and international rollout of LIFE power plants total some **$995 to $2,926 billion in cumulative GDP** impacts and **8.6 to 26.4 million job years** over the course of the project to 2050, including effects from some R&D prior to 2013.

1 Introduction

1.1 LIFE Background[1]

Fusion, the process that powers the sun and the stars, is the reaction in which two atoms of hydrogen combine together to form an atom of helium. In the process some of the mass of the hydrogen is converted into energy. One way to accomplish this is by combining the hydrogen isotopes deuterium and tritium to make helium and a neutron. Deuterium is plentifully available in ordinary water. Tritium can be produced by combining the fusion neutron with the abundant light metal lithium.

A laser fusion power plant operates in a pulsed manner like a car engine. Fuel is injected (in the form of a small capsule of hydrogen isotopes) to the center of the fusion chamber where a pulse of laser energy is used to compress and heat the fuel to the point of ignition. The energy released is absorbed in the walls and structures of the fusion chamber and also directly in the molten lithium that flows through the blanket of the chamber. In addition to breeding the tritium fuel, lithium is used as the heat transfer fluid to produce steam which drives electric turbines. Repeating the injection and ignition process at repetition rates of ~15 times per second (similar to an idling car engine) is sufficient to produce a gigawatt of electrical power from an inertial fusion energy plant.

Fusion energy is reaching a turning point, as the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) may soon demonstrate fusion with energy gain, or ignition, expected by the end of 2012 for the purposes of this study. Ignition will resolve the question of whether fusion energy is possible. This clears the way for the engineering and technology work needed to establish commercial feasibility. The laser inertial fusion energy (LIFE) effort takes the next step, providing a blueprint for progressing from scientific feasibility to commercial fusion energy in a time frame that is relevant to satisfying the world's ever-increasing need for abundant, sustainable energy.

The LIFE approach builds upon the technology advances achieved in building and conducting ignition experiments on NIF. Adopting a modular design and construction, building on proven physics and laser technology, and pursuing concurrent integration of required technologies, a LIFE power plant could offer safe, cost-effective, and reliable baseload power.

1.2 Purpose of the Study

Laser inertial fusion has been under development by a global team of researchers for the past 50 years. Testing currently underway at LLNL in California may soon demonstrate fusion with energy gain. This would open the door to development of commercial fusion energy on a wide scale basis.

After proof of concept, early commercialization of fusion energy would have profound implications for global energy supply, the environment, non-proliferation and economic growth. As such, the Howard Baker Forum

[1] Additional background information on the LIFE project, including a detailed description of the technology, the general design of the plants, the additional benefits of LIFE and the status of ignition can be found on the LIFE website (https://life.llnl.gov/what_is_life/index.php).

(HBF) commissioned Oxford Economics to undertake a study of the likely impacts for the U.S. economy if fusion energy were commercialized in the relatively near future.

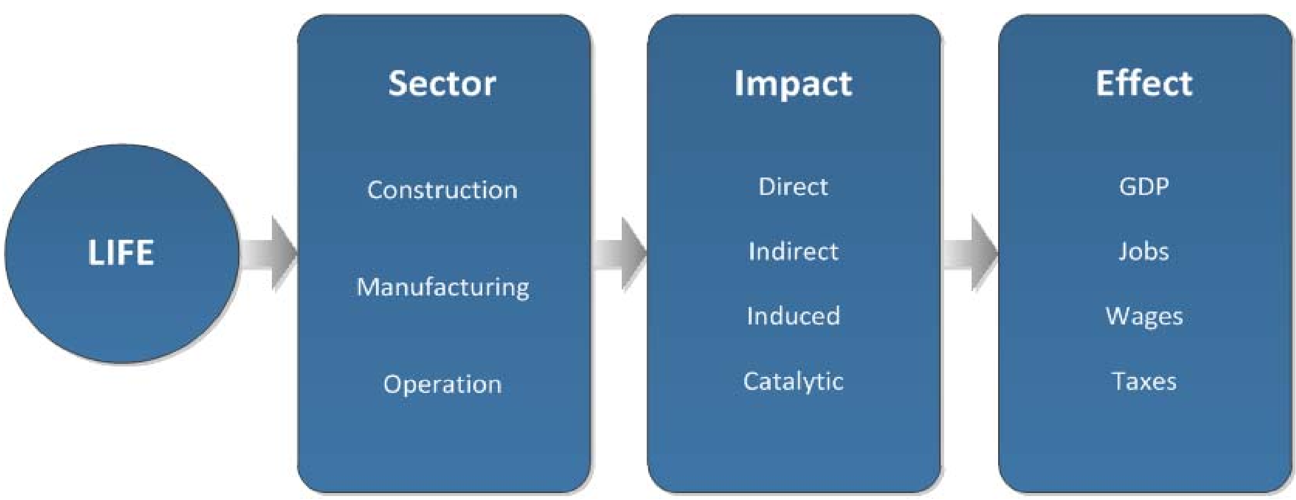
LLNL has developed a design concept and commercialization delivery plan that outlines the path from successful fusion demonstration on the NIF to the construction of the demonstration power plant (the "market-entry plant" or "MEP") and commercial-scale plants. This study takes the LLNL estimates for power plant costs, time-to-market and market penetration as inputs, and projects the likely impacts for the U.S. economy if commercialization of laser fusion were successful.

1.3 Study Approach

The commercial development of LIFE technologies to generate electric power will produce economic benefits across a number of areas (see Figure 1.1), including:

- The domestic rollout of LIFE, including the construction of LIFE plants and the plants that manufacture the fusion fuel;
- The investments associated with research and development (R&D) and in the technology base to supply the equipment needed in commercially viable LIFE plants;
- The annual operations of both the LIFE power plants and the associated fuel plants; and
- Increased exports related to the supply by U.S. manufacturers of equipment used in LIFE power plants constructed overseas and being a "first-mover" in the development of key LIFE technologies.

Figure 1.1: Framework for assessing the economic impact of the LIFE program



Source: Oxford Economics

The key channels through which this activity will generate economic benefits include[2]:

- **Direct impacts** – the economic impacts and employment associated with LIFE power plants themselves. During the construction period, this includes the on-site construction labor as well as the impacts associated with the design and engineering of the plant, the construction management and the commissioning of the plant. During the annual operations, this includes the impacts associated with operation and maintenance of both the LIFE power plants and the off-site fuel plants.
- **Indirect impacts** - the economic impacts and employment supported via the supply chain purchases of materials and equipment from U.S.-based suppliers. During the construction period, this includes the spending on the materials and equipment needed to construct the plant such as steel, concrete, turbines, electrical transformers, the fusion laser, etc. During the annual operations of the plant, this includes the spending on replacement parts and equipment as well as other supplies needed to operate both the LIFE power plants and the fuel plants.
- **Induced impacts** – the economic impacts and employment supported by the individuals involved directly or indirectly with LIFE spending their incomes on goods and services in the wider U.S. economy. This spending helps to support jobs in the industries that supply these purchases and includes jobs in real estate, retail and companies producing a variety of consumer goods and services.
- **Catalytic Impacts -** these impacts include:
    - **R&D spillovers -** The R&D investment that is planned for the LIFE program, as well as the R&D that has already occurred, will enhance the U.S. stock of knowledge. This could have applications in other sectors and have broader commercial economic impacts. These include using the technology developed for LIFE in applications such as laser-based manufacturing, which is used to strengthen metals, increase component lifetime and mitigate corrosion in the aerospace, transportation and petrochemical industries.
    - **Traditional exports -** The development of LIFE power plants internationally offers export potential for conventional U.S. companies who are well-placed to take advantage of selling their goods overseas as the LIFE plants are rolled out globally. These include the producers of the equipment used in traditional power plants, such as pumps, air compressors, heat exchangers, turbines, power transformers, electrical switch gear and similar equipment.
    - **"First mover" exports -** In addition, if the U.S. can be a "first mover" in some of the key fusion industries, then U.S. firms have the potential to gain a relatively large share of global revenues from the international rollout of LIFE. In particular, development of the fusion laser appears to be a likely case where the U.S. could benefit from this first mover advantage.

Finally, LIFE may also generate additional benefits due to reductions in adverse environmental and health impacts compared to other electricity generating technologies.

[2] The impacts reported in this report represent undiscounted gross impacts which do not take into account the economic impacts that would be generated if the money that would be invested in a LIFE plant were invested elsewhere in the economy (e.g. constructing a coal-fired power plant).

We used the IMPLAN[3] economic impact model developed by the Minnesota IMPLAN Group Inc. to calculate the size of each of these channels of impact across the following metrics:

- Gross Domestic Product (GDP)[4] - all references to GDP in this report are to GDP at "basic prices", also known as gross value added or GVA. This measure excludes the impact on measured values of taxes on products, in contrast to the "headline" or "market price" measure of GDP which includes this impact;
- Employment;
- Labor Income; and
- Federal and State Tax Impacts.

The economic impacts generated by the development of LIFE power plants in the U.S. depend on the speed and scale of the actual rollout. In our analysis, we considered a range of domestic rollout scenarios. In this report, however, we only present the results corresponding to the lower and upper bounds of the scenarios considered (see Box 2.2 for a detailed description of the lower and upper bound scenarios).

Box 1.1: Economic Impact Explanations

The economic impact estimates for employment presented in this report represent the number of jobs that would be supported or sustained, on average, during each year of the LIFE rollout and do not represent new jobs supported or sustained each year. For example, the lower bound estimate that the domestic rollout of LIFE will support 152,200 jobs means that on average between 2014 and 2050 there will be 152,200 jobs in total supported by LIFE.

1.4 Structure

The rest of paper is organized as follows:

- Section 2 summarizes the economic impacts of the development of a fleet of commercial-scale LIFE power plants in the U.S.;
- Section 3 details the expected economic impact for the U.S. resulting from the development of LIFE power plants abroad;
- Section 4 offers some conclusions; and
- A separate Appendix details the assumptions and calculations underpinning the economic impacts presented in this report.

[3] Please see the Appendix for a description of the IMPLAN model.

[4] All dollar values reported throughout the report are in 2012 prices and are undiscounted.

2 The Economic Impact of the Development of LIFE in the U.S.

Box 2.1: Key Points – The Gross Economic Impact of the Development of LIFE in the U.S.

- The domestic rollout of LIFE will require an average annual investment of between **$9.0 and $25.7 billion** per annum between 2014 and 2050. This is in addition to the $1.8 billion in total spending during the technology demonstration phase.
- This will generate an estimated total impact on U.S. GDP of between **$17.7 and $47.7 billion** per annum from 2014 to 2050.
- The average annual employment impacts are estimated to range between **152,200 and 417,400** jobs – including between **33,200 and 89,800** direct jobs.
- The project will also generate between **$4.6 and $12.1 billion** in average annual federal and state taxes and **$9.7 and $25.6 billion** in average annual labor income.
- The widespread commercialization of LIFE power plants will require the expansion of many high-tech industries to meet the increased demand, resulting in the creation of new high-skilled, well-paying jobs.
- The catalytic impacts associated with LIFE are estimated to amount to approximately **$40 billion** in cumulative additional GDP through 2050.
- Finally, LIFE has the potential to generate between **$106 and $268 billion** in aggregate pollution reduction benefits over the 2020 to 2050 period, compared to the Status Quo counterfactual.

The economic impacts associated with the domestic rollout of LIFE power plants[5] can be grouped into three phases: the construction phase, when LIFE plants and the off-site fuel manufacturing facilities are built; the technology demonstration phase (which includes the impacts associated with investments in R&D and the supply chain); and the operations phase when LIFE power plants are used to produce electricity. Below we consider each of these phases in turn.

The economic impacts generated by the development of LIFE power plants in the U.S. depend on the speed and scale of the actual rollout. In our analysis, we considered a range of domestic rollout scenarios. The results presented below correspond to the lower and upper bounds of the scenarios considered (see Box 2.2 for a description of the lower and upper bound scenarios).

[5] In this section we only consider the impacts resulting from the construction and operation of LIFE plants in the U.S. We discuss the impacts resulting from increased exports and being a "first-mover" in Section 3.

Box 2.2: LIFE Domestic Rollout Scenarios

The economic impacts generated by the development of LIFE power plants in the U.S. depend on the speed and scale of the actual rollout. The lower and upper bound scenarios that we considered are as follows:

- **Lower Bound** – the lower bound involves the construction of 51 total plants (including the MEP) and 75 GW of nameplate capacity. The doubling time[6] is assumed to be ten years. The capacity added under the lower bound scenario will satisfy approximately one-third of the approximately 250 GWe of new-build capacity required to fill the "generation gap" to meet projected U.S. electricity demand in 2050.
- **Upper Bound** – the upper bound involves the construction of 136 total plants (including the MEP) and 211 GW of nameplate capacity. The doubling time is equal to five years. LIFE capacity additions are capped at 50% of the needed U.S. generating additions. The capacity added under the upper bound scenario will almost satisfy the approximately 250GWe of new-build capacity required to fill the "generation gap" to meet projected U.S. electricity demand in 2050.

Table – LIFE Domestic Rollout Scenarios

	Lower Bound	Upper Bound
Market Entry Plant	1	1
First of a Kind 1 GWe	1	1
Nth of a Kind 1 GWe	9	9
Nth of a Kind 1.6 GWe	40	125
Total Plants	51	136
Total Nameplate Capacity GW	74.6	210.6

Source: LLNL

The rollout scenarios are all dependent on the assumption that successful ignition will lead to a well-funded effort to complete technical risk reduction and vendor development activities and Nuclear Regulatory Commission (NRC) approval.

The domestic rollout scenarios assume that the preconstruction spending begins in 2014 and the MEP begins construction in 2016 and begins operation in 2020, with the first of a kind 1GWe plant beginning construction in 2022 and commercial operation in 2027. (See the Appendix for additional details on how the aggregate impacts of the domestic rollout scenarios were calculated.)

We assume that the construction period for each LIFE plant is six years, which include five years of on-site construction plus an additional year of materials procurement that begins

[6] Doubling time refers to the amount of time that it takes for the number of plants under construction to double. For example, a doubling time of five years implies that if one plant is able to be constructed in year one, in year five two plants will be able to be constructed per year and by year ten four plants will be able to be constructed per year.

before the initiation of on-site construction activities, and the construction period for each fuel plant is two years. We further assume that each LIFE plant requires the construction and operation of one fuel plant.

It is important to note that the construction of LIFE plants will likely continue past the 2050 timeframe as additional conventional power plants are retired and electricity demand increases. For the purposes of this study, we only consider the plants constructed or under construction between 2014 and 2050.

2.1 The Construction Phase

The commercialization of LIFE power plants will involve the development of the market entry plant (MEP) to test and refine the technologies and the construction of a fleet of commercial scale plants.[7] The economic and employment impacts generated by the construction of each plant depend on how much of the supply chain is located in the U.S. [8] – this is especially important with regards to the location of the manufacturing of several key fusion-related components, most notably the laser diode and laser optics.[9]

The domestic fleet rollout will require an annual average investment[10] of between $9.0 and $25.7 billion between 2014 and 2050, depending on the speed and scale of the rollout (see Box 2.2 for a description of the likely rollout scenarios). This will amount to an aggregate investment of between $333 and $951 billion through 2050.

Overall, Oxford Economics estimates that the construction of the fleet of LIFE plants will generate an average of $11.3 to $32.3 billion of GDP annually between 2014 and 2050 (See Figure 2.1 and Table 2.1). This includes between:[11]

- $1.8 and $5.2 billion in Direct GDP impacts;
- $5.1 and $14.4 billion in Indirect GDP impacts; and
- $4.5 and $12.7 billion in Induced GDP impacts.

This, in turn, will generate between 127,000 and 362,600 jobs on average over the 2014 to 2050 period and between $7.4 and $20.9 billion in average annual labor income. This includes:

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[7] The Appendix includes the construction period estimates for each individual plant type.

[8] The multipliers developed by IMPLAN assume that some portion of the spending in each industry is met by domestic suppliers and the remainder is imported from overseas. The portion that is imported from outside of the study area is referred to as "leakage."

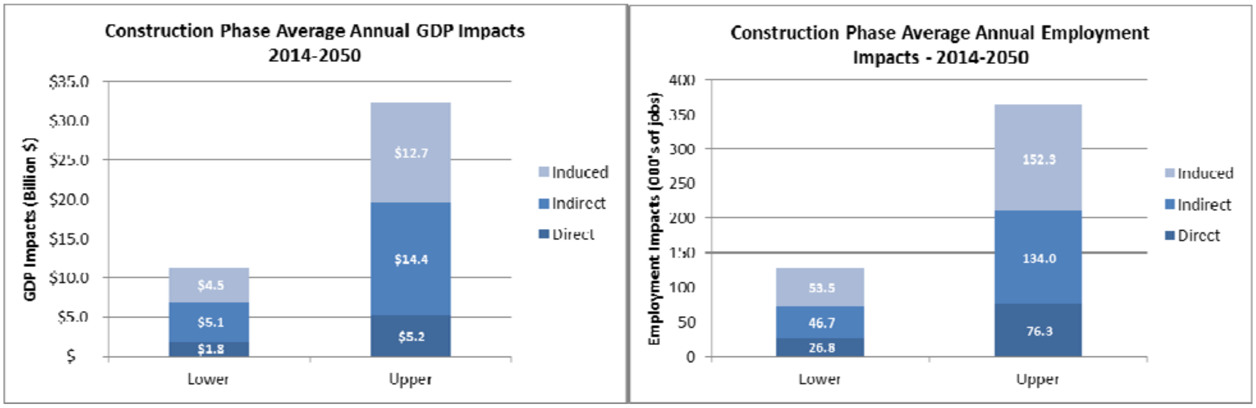
[9] Box 1.1 in the Appendix illustrates the effect that different spending leakage assumptions can have on the impact estimates.

[10] This includes costs related to both the construction of the individual LIFE power plants as well as the offsite fuel plants.

[11] Figures may not sum due to rounding.

- 26,800 to 76,300 Direct jobs and $2.1 to $5.9 billion in average annual Direct labor income;
- 46,700 to 134,000 Indirect jobs and $2.8 to $7.9 billion in average annual Indirect labor income; and
- 53,500 to 152,300 Induced jobs and $2.5 to $7.1 billion in average annual Induced labor income.

Figure 2.1: Construction Phase GDP and Employment Impacts



Source: Oxford Economics

2.2 Technology Demonstration Spending

Unlike the supply chains associated with the construction of other types of power plants (coal, natural gas, nuclear and renewables) which have well-established supply chains, many of the industries associated with LIFE plants are not currently large enough[12] to support the increased demand that would result from the domestic rollout.

It is estimated that that the technology demonstration spending will require an investment of $1.2 billion in R&D spending and an additional $0.6 billion in capital/equipment spending for a total supply chain investment of $1.8 billion.

This represents an initial investment and should begin quickly after successful ignition and continue up to the construction of the first commercial scale (1 Gigawatt sized) LIFE plant. In total, the technology demonstration spending will generate a total impact on GDP of $2.5 billion over the entire pre-construction period.

In addition, the technology demonstration spending will support total labor impacts of 2,690 jobs during an average year of the pre-construction phase. This will generate approximately $1.8 billion in total labor income

[12] For example, it is estimated that to manufacture the laser diodes needed to assemble the lasers for one LIFE plant would require approximately 100-times the current global supply. See Box 1.3 in the Appendix for additional information on the Laser Diode Industry.

over the entire pre-construction period. We further estimate that the technology demonstration spending will generate $540 million in total federal and state taxes.

This represents only an initial investment in the supply chain. As the construction of LIFE plants increases, both domestically and internationally, additional investments in the supply chain will likely need to be undertaken.

2.3 Annual Operations

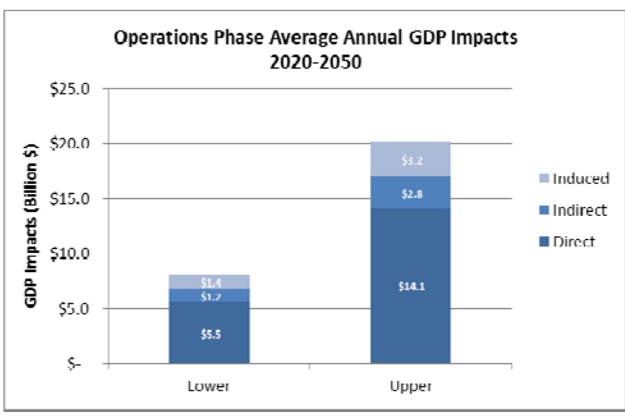
Oxford Economics estimates that the annual operations of the fleet of LIFE plants and the associated off-site fuel plants will generate total GDP impacts between $8.1 and $20.1 billion per annum between the beginning of operations of the MEP plant in 2020 and 2050[13] (see Figure 2.2 and Table 2.2). This includes between:

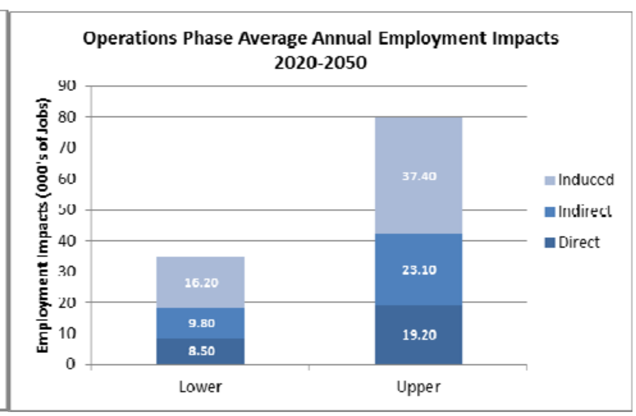
- $5.5 and $14.1 billion in Direct GDP impacts;
- $1.2 and $2.8 billion in Indirect GDP impacts; and
- $1.4 and $3.2 billion in Induced GDP impacts.

This will in turn generate between 34,500 and 79,700 jobs on average over the period 2020 to 2050 and between $2.6 and $4.8 billion in average annual total labor income. This includes:

- 8,500 to 19,200 Direct jobs and $0.8 to $0.7 billion in average annual Direct labor income;
- 9,800 to 23,100 Indirect jobs and $0.7 to $1.6 billion in average annual Indirect labor income; and
- 16,200 to 37,400 Induced jobs and $1.1 to $2.5 billion in average annual Induced labor income.

Figure 2.2: Average Annual Operations Phase GDP and Employment Impacts





Source: Oxford Economics

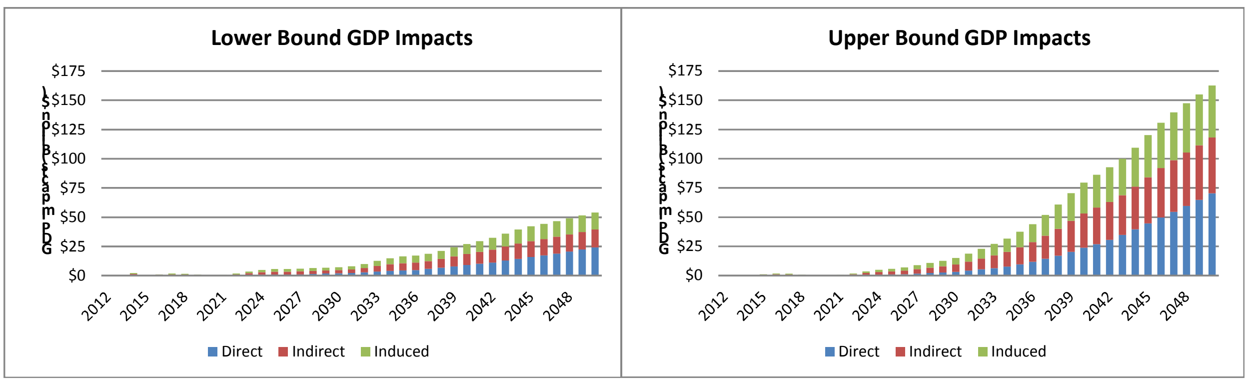
[13] It is important to note that these benefits will continue well into the future, but in this study we only consider the annual impacts that will be generated between the 2020 and 2050

2.4 The Total Economic Impact of the Domestic LIFE Rollout

Figures 2.3 and 2.4 present the upper and lower bound year-by-year GDP and employment impacts from 2014 to 2050. The impacts in any given year include the impacts related to both the LIFE power plants and the off-site fuel plants that are under construction or operating in that year.

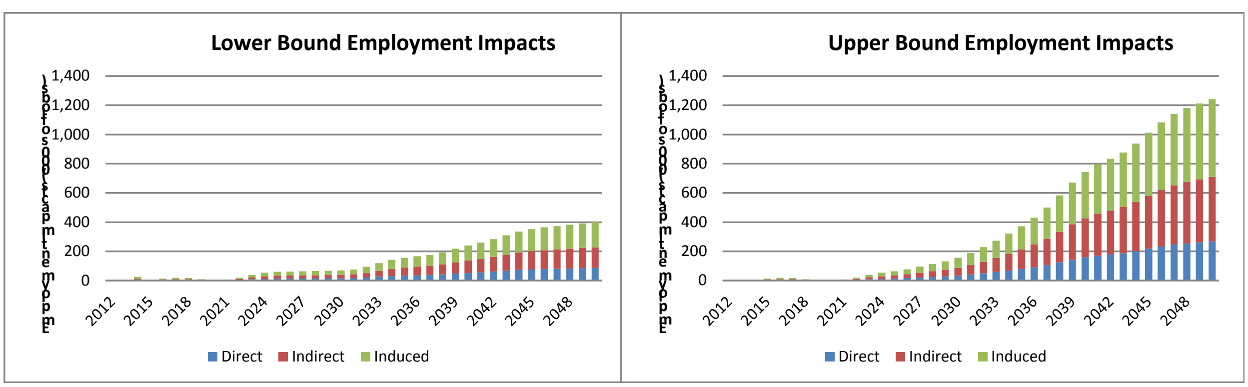
For example, the impacts in 2030 include the operation and maintenance impacts related to all the LIFE and fuel plants that are operating in that year. In addition, the impacts also include the construction period impacts associated with the LIFE plants that will begin operation in 2031-2036 (due to the assumed six-year construction period), as well as the fuel plants associated with LIFE plants that begin operation in 2031 and 2032 (two-year construction period).

Figure 2.3: Year-by-Year GDP Impacts of the Domestic LIFE Rollout



Source: Oxford Economics

Figure 2.4: Year-by-Year Employment Impacts of the Domestic LIFE rollout



Source: Oxford Economics

Due to the construction period associated with each LIFE plant, the results for the later years also include a portion of the construction period impacts for the plants that begin operations beyond 2050. For example, during 2049 there are plants under construction that will begin operations in 2050-2054

The impacts included in Figures 2.3 and 2.4 could be thought of as the upper and lower bound impacts that would result in a given year. For example, in 2050, the total impacts on GDP are estimated to range from $53.9 billion (lower bound) to $162.7 billion (upper bound). Similarly, the employment data included in the charts could be thought of as the number of jobs that can be attributed to LIFE in a given year. For example, in 2050, the upper bound employment impact is approximately 1.2 million jobs, compared to the lower bound estimate of 400,000 jobs.

Table 2.1 presents the average annual upper and lower bound GDP and employment impacts. The total impacts on GDP are estimated to range from $17.7 to $47.7 billion on average over the 2014 to 2050 period. This will amount to cumulative total impacts on GDP of between $655 and $1,765 billion over the entire period.

The domestic rollout of LIFE is estimated to generate an average of between 152,200 and 417,400 jobs over the 2014 and 2050 period taking the direct, indirect and induced jobs together. This results in average annual labor income impacts between $9.7 and $25.6 billion over the 2014 to 2050 period. Finally, this results in average annual federal and state tax collections between $4.6 and $12.1 billion annually over the same period

Table 2.1: Average Annual Economic Impacts of the Domestic LIFE Rollout Over the Period 2014 to 2050

	GDP (Billions, $)		Employment (Thousands)		Labor Income (Billions, $)		State and Federal Tax Impacts (Billions, $)	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Direct	$ 6.3	$ 16.5	33.2	89.8	$ 2.8	$ 7.3	$ 4.6	$ 12.1
Indirect	$ 5.9	$ 16.3	53.5	149.1	$ 3.4	$ 9.2		
Induced	$ 5.5	$ 14.9	65.5	178.5	$ 3.5	$ 9.1		
Total	**$ 17.7**	**$ 47.7**	**152.2**	**417.4**	**$ 9.7**	**$ 25.6**	**$ 4.6**	**$ 12.1**

Source: Oxford Economics

Box 2.3: Comparison of LIFE Impacts to Other Industries

To help put the estimates of the economic impacts of LIFE into perspective, the average upper bound employment impact of 417,400 jobs (taking Direct, Indirect, and Induced effects together) represents more jobs than directly generated today in the machine shop (246,000); aircraft manufacturing (230,000); mining (234,000); and semiconductor manufacturing (182,000).[14]

In addition, the upper bound estimate of $47.7 billion in average GDP per annum is more than the value added directly generated on an annual basis by the aircraft manufacturing ($40.8 billion); machine shop ($17.4 billion); petrochemical manufacturing ($16.8 billion); computer manufacturing ($6.3 billion); tool and die manufacturing ($4.2 billion); computer circuit board manufacturing ($3.8 billion); and power transformer manufacturing ($3.5 billion) industries.

2.5 The Counterfactual

It is important to consider what would happen in the event that the commercialization of LIFE power plants does not occur as expected. U.S. demand for electricity would not diminish, which would require that the electricity that would have been produced by the LIFE power plants would have to be produced by some other source. The likely source is a mix of coal, natural gas, nuclear and renewable power plants.[15] The construction and operation of each of these will, in and of themselves, generate economic impacts. However, it is beyond the scope of this study to assess in detail the economic impacts of the development of each alternative plant type.

Regardless of the exact mix of generating technologies that would be constructed/operated under the counterfactual, the gross economic impacts associated with the construction/operation of the counterfactual are likely to be of a similar magnitude to LIFE plants. But the manufacturing jobs that will be generated are likely to be larger under LIFE given the industries that will need to be significantly expanded in order to commercialize LIFE power plants (e.g. laser diode, laser optic glass, etc.). In addition, compared to fossil fuel plants, the jobs generated by LIFE plants are likely to be high-skilled, well-paying jobs in the technology sector.

These include jobs in high-tech industries, such as laser diode manufacturing, laser optic fabrication and computer programming. We estimate that the domestic rollout of LIFE will support between 8,100 and 21,500 jobs on average over the period 2014 to 2050 in these industries. Alternative ways of meeting U.S. electricity generation needs would be unlikely to create so many high productivity manufacturing jobs.

The advanced nature of many of the manufacturing jobs that will result from the materials and equipment spending on the LIFE program mean that those jobs will have a higher labor productivity (GDP per employee)

[14] The employment and value added data represent the IMPLAN estimates for each industry in 2010.

[15] It is unclear what the exact mix of generating technologies would make up the counterfactual. It depends on a number of factors that are unable to be known at this time. These include the long-term price of natural gas, carbon taxes, the U.S. attitude towards nuclear energy and a number of other factors. However, for the purposes of this analysis we consider four different counterfactual scenarios. See Box 2.4 for a description of each scenario.

than the average for the U.S. economy as a whole or for the overall manufacturing sector (See Table 2.2). In addition, the average labor income is higher for the jobs associated with LIFE plant equipment manufacturing than for the U.S. economy in general and the manufacturing sector in particular.

Table 2.2: Productivity and Labor Income Generated by LIFE-Related Manufacturing Jobs

	GDP Per Employee	Labor Income per Employee
LIFE Manufacturing Jobs	$ 147,350	$ 86,890
All Manufacturing Jobs	$ 139,350	$ 76,000
U.S. Economy	$ 83,700	$ 51,990

Source: Oxford Economics

Many of the manufacturing jobs will likely require an associate's degree or higher from a technical or community college. Similarly, the on-site construction labor will be high-skilled craft labor positions that will require advanced training and/or certifications. Finally, many of the direct jobs at each LIFE plant will require advanced training compared to the direct jobs at fossil fuel plants; while the direct jobs associated with the off-site fuel manufacturing facility will be similar to the type of jobs associated with the semiconductor industry.

It is important to note that the realization of these benefits depends on different policy choices – for example, whether or not the U.S. decides to invest in the laser diode industries can have profound impacts on the number and types of jobs generated by the construction of each LIFE plant.[16]

It is also important to note that not all of the economic contribution of power generation by coal or natural gas would necessarily be lost if they were replaced by LIFE plants. Some of the coal or gas that would otherwise have been used in U.S. electricity generation could then potentially be exported, and so continue to support U.S. jobs. The extent to which that would occur would depend on worldwide demand, the price of the commodity and development of the necessary export infrastructure (LNG processing plants, LNG ports, etc.).

2.6 Other Impacts

2.6.1 Catalytic/Spillover Benefits

The LIFE project in the U.S. will involve significant research and development activity in its early stages. The knowledge gained during the R&D phase could be transferred to other industrial sectors. This would generate substantial spillover benefits that would boost the productivity that could be achieved by other sectors of the U.S. economy.

[16] As illustrated in Box 1.1 in the Appendix.

Since the 1970s, the economics literature has emphasized the potential for R&D to generate external benefits to society in excess of the private returns to the investing businesses and their suppliers.[17] This can occur because innovations developed to match the specific demands of a business can sometimes be applied more widely in other firms and sectors of the economy, generating additional benefits to society as a whole beyond those captured in the commercial return to the innovators.

In the case of LIFE specifically, potential spillover impacts could include those associated with laser-based manufacturing. This process is used at present to strengthen the metal in jet engines, but the laser technology required for LIFE will enable that technique to be applied much more extensively and at a much lower cost. Scientists involved with the project have also identified a host of further potential applications of fusion technology and techniques, the majority of which could – in Oxford Economics' view – be expected to deliver spillover benefits for the wider economy.

The rollout of LIFE will result in additional R&D spending[18] of $593 million per annum (at today's prices) over the 2013-2020 period.[19] This is in addition to the total of $7.3 billion that was spent between 1992 and 2012. The total annual R&D impact on GDP, including the impacts derived from R&D activity to date, would peak at close to $1.7 billion in 2021, before easing back gradually. The total cumulative spillover benefit on GDP would approach $40 billion, with the vast bulk of the benefits occurring before 2030.[20] It is important to note that most of these impacts are not dependent on the successful commercial development of LIFE power plants.

[17] Please see the Appendix for additional details on the economics of spillover impacts.

[18] This does not include the R&D spending related to the technology demonstration period or the additional R&D spending that is likely to occur to the construction of the MEP plant and the first commercial scale plant.

[19] No allowance is made for additional R&D spending beyond 2020, even though it is likely that some additional spending would occur over that period (albeit on a diminishing basis).

[20] Please see the Appendix for year-by-year R&D impact estimates.

Box 2.4: Counterfactual Scenario Descriptions

The counterfactual scenarios that we considered in our analysis are defined as follows:

• **Status Quo –** this counterfactual scenario is based on the distribution of new generation additions expected by the Energy Information Administration (EIA) in their 2011 Energy Annual Report[21] which contains projections of new power plant construction out to 2035. We assume that the mix of plant types built over the period to 2035 will continue out to 2050. This implies that the generating capacity that would otherwise be provided by LIFE plants will be generated by a mix consisting of 67% natural gas plants, 20% renewables, 8% coal and 5% conventional nuclear plants.

• **High Natural Gas** – this scenario assumes that no new coal or nuclear plants are built and that 80% of the generating capacity that would otherwise be provided by LIFE plants will be generated by natural gas plants and the remaining 20% will be generated by renewable plants.

• **High Nuclear** – this scenario assumes that there no new coal plants are constructed and that 50% of the generating capacity that would otherwise be provided by LIFE plants will be generated by conventional nuclear plants, 30% by natural gas plants and the remaining 20% from renewables.

• **High Renewables** – this scenario assumes that there is a significant investment in renewable generating capacity and that no new coal or nuclear plants are constructed. This results in 40% of the generating capacity that would otherwise have been provided by LIFE plants being generated by renewable technologies and 60% by natural gas plants.

Table: Counterfactual Scenarios

	Status Quo	High Natural Gas	High Nuclear	High Renewables
Coal	8%	0%	0%	0%
Natural Gas	67%	80%	30%	60%
Nuclear	5%	0%	50%	0%
Renewables	20%	20%	20%	40%

Source: Oxford Economics

2.6.2 Fuel Use and Pollution Reduction Impacts

One of the other impacts expected to result from the domestic rollout of LIFE power plants is carbon-free electricity that is projected to be cheaper to generate than most other renewable technologies[22] (see Figure

[21] EIA (2011). "Annual Energy Outlook: 2011" Department of Energy's Energy Information Administration, Washington, DC. DOE/EIA 0383(2011) April 2011.

[22] Nicholson et al. (2010) "How carbon pricing changes the relative competitiveness of low-carbon baseload generating technologies." Energy 36(1): 305-313.

2.5). This could lead to other wider macro-economic benefits due to lower electricity prices, such as increased disposable income for individuals and reduced operating costs for businesses.

Replacing parts of the current U.S. fossil fuel and conventional nuclear generating fleet with LIFE power plants could reduce the amount of fossil fuels used for electricity generation compared to the mix of plants assumed under each counterfactual scenario (see Box 2.4 for a description of each counterfactual scenario).

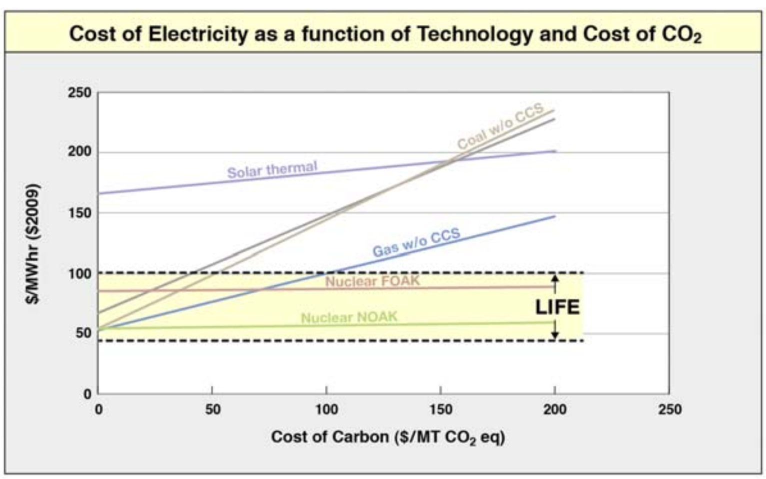
Fossil fuel savings were estimated by calculating the amount of fossil fuels that would be required to generate the electricity that would be produced by each of the LIFE rollout scenarios. The estimates were based on Btu per KwHr requirements for each fuel-type obtained from the EIA.

Compared to the Status Quo counterfactual[23], we estimate that LIFE would result in the following generating fuel reductions over the 2020 to 2050 time period:

- 186.1 to 472.2 million short tons of coal;
- 22.7 to 57.4 trillion cubic feet of natural gas; and
- 1.5 to 3.8 million pounds of UO_2 nuclear fuel.

In addition, the investment in LIFE power plants will also likely displace investment in conventional nuclear power plants, which would result in significant amounts of avoided high-level nuclear waste and plutonium production, which will generate environmental and non-proliferation benefits. Compared to the Status Quo counterfactual, LIFE will result in between 800 and 2,000 less metric tons of nuclear waste and between 9,200 and 23,400 less kilograms of plutonium.

Figure 2.5: Comparison of Electricity Costs



Source: Nicholson et al. (2010)[24]

[23] Please see the Appendix for the fuel reductions estimates for the other (High Natural Gas, High Nuclear and High Renewables) counterfactual scenarios.

[24] Nicholson et al. (2010).

The construction of LIFE plants would also reduce the amount of pollutants entering the atmosphere – such as carbon dioxide, carbon monoxide, sulphur and nitrogen oxides, particulate matter and mercury – from the U.S. compared to what would be emitted by the mix of plants assumed to be developed in the counterfactual scenarios. Some of this avoided pollution, such as carbon dioxide, contributes to the long-term problem of climate change, while others such as particulate matter and mercury have more localized health impacts.

We estimate that LIFE would result in the following amounts of avoided pollution compared to the Status Quo counterfactual:[25]

- 1,735 to 4,400 million tons of carbon dioxide;
- 0.8 to 2.1 million tons of carbon monoxide;
- 1.9 to 4.8 million tons of Nitrogen oxides;
- 4.8 to 12.1 million tons of Sulphur oxides;
- 5.1 to 13.0 million tons of Particulate matter; and
- 29 to 74 tons of mercury.

Based on pollution externality costs from the U.S. Environmental Protection Agency, we estimate that the benefits from this avoided pollution will cumulatively total between $106 and $268 billion over the 2020 to 2050 time period compared to the Status Quo counterfactual.[26] This amounts to average annual pollution reduction benefits of between $3.5 and $8.9 billion. Even when compared to a High Renewables scenario, the implementation of LIFE still generates between $37 and $95 billion in aggregate benefits over the lifetime of the project.

Finally, fusion energy is a threshold process, so it has an inherently low marginal cost of electricity, which means that it is relatively inexpensive to increase the generating capacity of a LIFE plant. This makes LIFE particularly well-suited to dry cooling because the low thermal-to-electric efficiency associated with dry cooling can be compensated for by adding additional plant capacity without unduly impacting the cost of electricity. This is a significant advantage for water-poor areas where conventional power plants are a major burden on water supply, such as the Southeastern U.S. [27]

[25] Please see the Appendix for the air pollution reduction estimates for the other (High Natural Gas, High Nuclear, and High Renewables) counterfactual scenarios

[26] Please see the Appendix for air pollution reduction benefit estimates for the other (High Natural Gas, High Nuclear, and High Renewables) counterfactual scenarios

[27] Please see the companion report “The Economic Impacts of LIFE in Southern States” for a detailed discussion of the impacts associated with the rollout of LIFE plants in the Southern States.

3 The Economic Impact for the U.S. of the Development of LIFE Abroad

Box 3.1: Key Points – The Economic Impact of the Development of LIFE Abroad

- As LIFE could ultimately be expected to be rolled out on a global basis, rather than being confined to the U.S., further benefits can be expected for U.S. industries in the form of new and additional export opportunities.
- Increased exports from traditional industries (such as the manufacturing of pumps, turbines, electrical transformers and the like) are projected to range from between **$2.1 to $8.0 billion** per year.
- These increased exports are estimated to be able to support total GDP impacts averaging between **$2.8 and $10.5 billion** per year, which will generate between **25,900 and 97,100** jobs on average over the period 2017 to 2050.
- If the U.S. developed the manufacturing capacity for key LIFE technologies (e.g. the fusion laser) ahead of potential international competitors, then U.S. manufacturers could benefit from a potentially high global market share as a result of "first mover advantage."
- The potential fusion laser export market is expected to range from **$5.7 to $20.6 billion** per annum and the design and engineering market from **$1.1 to $4.6 billion** per annum over the 2017 to 2050 period.
- If the U.S. is able to capture **25%** of the both markets, this will result in in total impacts on GDP between **$2.7 and $9.7 billion** on average a year from 2017 to 2050, generating between **26,800 and 99,100** jobs on average over that period.
- If the U.S. is able to capture **50%** of the both markets, this will result in in total impacts on GDP between **$5.3 and $19.5 billion** on average a year from 2017 to 2050, generating between **53,600 and 198,300** jobs on average over that period.

Given its potential advantages, it would seem reasonable to expect LIFE capacity and technology to be developed, in due course, not just in the U.S. but also abroad. This in turn could benefit U.S. manufacturers further by providing increased export opportunities.

The benefits that will accrue to U.S. manufacturers as the result of the development of LIFE plants abroad fall into two main categories:

- Increased exports opportunities for the producers of equipment used in the construction of LIFE power plants; and
- Being a "first mover" in several "new" industries that would need to be developed in order for LIFE plants to be constructed.

Box 3.2: LIFE International Rollout Scenarios

To assess the impact of the international rollout, we have developed two global scenarios that correspond with the lower and upper bound domestic scenarios. We assume that four international plants are built for every one domestic plant that is constructed under each of the domestic rollout scenarios.

By 2050 this will result in the construction of 544 plants and over 840 GWe under the upper bound and 204 plants and 298 GWe under the lower bound international rollout scenarios.

Table : LIFE International Rollout Scenarios

	Lower Bound	Upper Bound
Market Entry Plant	4	4
First of a Kind 1 GWe	4	4
Nth of a Kind 1 GWe	36	36
Nth of a Kind 1.6 GWe	160	500
Total Plants	204	544
Total Nameplate Capacity GW	298.4	842.4

Source: LLNL

3.1 Increased Exports

Some of the associated spending arising from the construction of LIFE plants abroad would naturally benefit local economies, through on-site employment impacts and purchases from local suppliers. However, spending on products that could potentially be purchased from U.S.-based manufacturers, such as pumps, air compressors, heat exchangers, turbines, power transformers, electrical switchgear and similar equipment, could also be significant. Oxford Economics estimates that total international spending in industries with export potential will average between $14.2 and $53.2 billion per annum over the 2017 to 2050 period.

These industries already have healthy export markets, with the U.S. share of world production ranging from 8.75% to 24%. Assuming that U.S.-based manufacturers in these sectors were able to capture 15% of their potential market in the future (in line with the approximate mid-point for these sectors at present), then the upper bound result would be an additional $8.0 billion of extra annual revenues for U.S.-based manufacturers. This in turn would generate an average of $10.5 billion of GDP, sufficient to support 97,100 jobs as well as $5.9 billion in total annual labor income per annum over the period 2017 to 2050.[28]

Even under the lower bound global rollout scenario, international spending on these products would total some $14.2 billion per annum over the 2017 to 2050 period. If the U.S. were able to capture 15% of those revenues –

[28] Just like with the development of domestic LIFE plants, it is likely that the international construction of plants will continue well past 2050, but for the purposes of this analysis we only consider the impacts over the 2014 to 2050 timeframe.

an average of some $2.1 billion annually – then that would be sufficient to generate an average of $2.8 billion of GDP, supporting 25,900 jobs as well as $1.6 billion in average annual labor income over the period 2017 to 2050.

3.2 "First Mover" Benefits

The additional export benefits for "new" industries most intrinsically linked to the development of LIFE capacity and technology – such as laser-related products and design and engineering – could vary considerably depending on the speed with which development is pushed in the U.S. relative to potential rivals. That is because of potential "first mover advantage" – i.e. the possibility that if the U.S. developed LIFE technology ahead of all other countries, then the U.S. could go on to enjoy a higher share of global revenues in LIFE-specific technologies long into the future.

A range of academic studies have analyzed this so-called "first mover advantage" issue, with many supporting the view that moving first does indeed boost future market share (see the Appendix for a summary of the studies). Topical "real-life" examples of first mover advantage include: the Apple iPad and iPhone, which have recently been the number 1 and number 2 best-sellers in the U.S. mobile and tablet market; the Toyota Prius, which in 2011 accounted for just over half of the total U.S. hybrid car market; and in Europe the Dyson bagless vacuum cleaner, which by 2005 had captured over a third of the UK vacuum cleaner market.

One example of how this would apply in practice, in the case of the LIFE project, concerns the manufacturing of the fusion laser. Significant production would be required to manufacture a sufficient number of laser diodes to allow a meaningful rollout of LIFE plants – in turn requiring significant investment in laser diode production capacity. If the U.S. were a first mover in terms of laser diodes, and undertook significant development of laser diode manufacturing capacity, then it would gain a clear competitive advantage over potential international rivals in manufacturing the fusion laser. This, in turn, would allow U.S. producers to capture not just a very large portion of the domestic market but also, potentially, a very large portion of the international market for fusion lasers.

To get an indication of the potential orders of magnitude involved here, our international rollout scenarios imply that the overseas market for lasers will average between $5.7 and $20.6 billion per annum over the period 2017-2050, and overseas spending on design and engineering will average between $1.1 and $4.6 billion per annum. We can then get an indication of the potential advantages to be had by acting quickly – and thereby achieving a higher share of the international market than otherwise – by looking at cases where the U.S. was able to capture a share of the market similar to high-tech examples cited above – between 25% and 50% of the total international market.

If the U.S. were able to capture 25% of the upper-bound global fusion laser market (comparable to the share of the British vacuum market captured by Dyson) then average impacts on GDP would be around $7.6 billion per annum over the 2017 to 2050 period, sufficient to support some 71,100 jobs and an average of $4.6 billion in annual labor income (see Table 3.1). And if the "first mover advantage" proved even more significant, enabling the U.S. to capture a 50% share of export markets (similar to the market share enjoyed by the Toyota Prius and the Apple iPhone and iPad), then these benefits would average $15.1 billion per annum in GDP over the 2017 to 2050 period, supporting around 142,300 jobs and an average of $9.2 billion in labor income.

The design and engineering of the plants is another area were the U.S. could develop an additional "first mover advantage." If U.S. firms were able to capture 25% of the upper bound estimate global design and engineering spending, then the average economic impacts on GDP would amount to $2.2 billion per annum over the 2017 to 2050 period. These impacts would support 28,000 jobs and an average of $1.8 billion in total labor income annually. If the U.S. was able to capture 50% of the upper bound estimate of the global market, then the upper bound impacts on GDP would amount to $4.3 billion per annum over the 2017 to 2050 period and support 56,000 jobs and an average of $3.6 billion in total labor income per annum.

Table 3.1: The Economic Impacts of Capturing High Export Market Shares

First mover Benefits of LIFE for select activities under different global market size and share scenarios 2017-2050												
	Laser-related activities				Design and engineering activities				Total			
	Lower		Upper		Lower		Upper		Lower		Upper	
Total global spending on products ($bn pa)	$5.7		$20.6		$1.1		$4.6		$6.9		$25.2	
US share of global market	25%	50%	25%	50%	25%	50%	25%	50%	25%	50%	25%	50%
GDP Impacts ($bn pa)	$2.1	$4.3	$7.6	$15.1	$0.5	$1.0	$2.2	$4.3	$2.7	$5.3	$9.7	$19.5
Employment Impacts (jobs)	20,100	40,200	71,100	142,300	6,700	13,400	28,000	56,000	26,800	53,600	99,100	198,300
Wage & Salary Impacts ($bn pa)	$1.3	$2.6	$4.6	$9.2	$0.4	$9.0	$1.8	$3.6	$1.7	$11.6	$6.4	$12.7
Federal and State Taxes ($bn pa)	$0.5	$0.9	$1.6	$3.2	$0.1	$0.2	$0.3	$1.0	$0.6	$1.1	$1.9	$4.2

Source: Oxford Economics

The total export market for laser-related spending and engineering and design services is expected to range between $6.9 and $25.2 billion per annum, depending on the size and speed of the international rollout. If U.S. firms are able to capture 50% of the international market in these two sectors, this will result in between $3.5 and $12.6 billion in increased annual exports; generate between $5.3 and $19.5 billion in GDP impacts per annum on average over the 2017 to 2050 period; and support between 53,600 and 198,300 jobs and $11.6 to $12.7 billion in wages and salaries per year. If U.S. firms are able to capture 25% of the global spending in these two sectors, this will result in between $1.7 and $6.3 billion in increased annual exports; generate annual GDP impacts on average of between $2.7 and $9.7 billion; and support between 26,800 and 99,100 jobs and $1.7 to $6.4 billion in wages and salaries per annum over the same time period. It is important to note that these impacts are in addition to the impacts that would be generated as part of the domestic rollout of LIFE plants.

3.3 Export Summary

The upper bound international rollout scenario will result in between $14.3 and $20.6 billion in increased exports per annum over the 2017 to 2050 time period, depending on how much of a first mover advantage U.S.-based firms are able to capture. These increased exports will result in between $20.2 and $30.0 billion in average GDP impacts and support between 196,200 and 295,400 jobs and $12.3 and $18.6 billion in wages and salaries per year over the 2017 and 2050 time period. This includes up to 48,400 jobs in high-tech industries, such as laser diode manufacturing, laser optic fabrication and computer programming.

The lower bound international rollout scenario will result in between $3.8 and $5.6 billion in increased exports per annum over the 2017 to 2050 time period, depending on how much of a first mover advantage U.S.-based firms are able to capture. This will result in between $5.5 and $8.1 billion in average GDP impacts and support between 52,700 and 79,500 jobs and $3.3 and $13.2 billion in wages and salaries per annum over the 2017 to 2050 time period.

4 Conclusions

Box 4.1: Key Points – LIFE Highlights

- This study assesses the likely impacts on the U.S. economy if the commercialization of laser fusion energy (LIFE) were successful. The domestic rollout of LIFE plants is estimated to result in a total impact on U.S. GDP of between **$17.7 and $47.7 billion** a year on average over the period 2014 to 2050, and to support between **152,200 and 417,400** jobs.
- The successful international roll out of LIFE plants would create export opportunities for existing U.S. manufacturing firms. This could amount to between **$2.1 and $8.0 billion** in annual exports, which would in turn support an average of **$2.8 to $10.5 billion of U.S. GDP** a year on average over the 2017 to 2050 period and between **25,900 to 97,100 jobs**.
- If the U.S. can be a "first mover" in certain LIFE-specific industries then U.S. firms have the potential to gain a relatively large share of revenues from the global rollout of LIFE. For example, if the U.S. were to capture a 50% share of the global market for fusion lasers and design and engineering then the additional annual benefits could average between **$5.3 and $19.5 billion** in **GDP a year**; supporting between **53,600 and 198,300 jobs** per annum over the 2017 to 2050 period.
- The widespread commercialization of LIFE power plants will require the expansion of many high-tech industries, including laser diode manufacturing, laser optic fabrication and computer programming. Many of the jobs that will be generated by this expansion will be high-skilled, well-paying jobs.
- The R&D undertaken to develop LIFE is likely to have important applications in other industries (e.g. laser-based manufacturing), which will generate further economic benefits for the U.S.
- LIFE offers the potential to provide a new abundant source of carbon-free baseload power, and the successful rollout of LIFE will lead to a reduction in fossil fuel use and air pollution. The cumulative air pollution benefits over the 2020 to 2050 period are estimated to amount to $**106 to $268 billion** compared to the Status Quo counterfactual scenario.

This study highlights the potential economic impacts that would accrue to the U.S. economy as a result of the domestic and international rollout of LIFE power plants. These impacts are contingent on the successful development of the key LIFE technologies on a commercially viable basis. Other factors that could affect the scale of the results include the size and speed of the LIFE rollout (both domestically and internationally) and the location of the manufacturing of the key components.

The domestic rollout of LIFE plants will result in an average **annual GDP impacts of between $17.7 and $47.7 billion** over the 2014 and 2050 period and will support between **152,200 and 417,400 jobs** and **$9.7 and $25.6 billion in labor income** per year.

Moreover, it holds the potential to generate significant wider economic benefits to the economy through the opportunities created for U.S. firms to sell goods and services overseas. This benefit is likely to be substantially larger if the U.S. can gain a first mover advantage by being the first country to develop the expertise and specialized supply chain to build LIFE plants.

Increased exports of traditional industries could amount to between **$2.1 and $8.0 billion** annually, which would support between **$2.8 and $10.5 billion of GDP** on average per annum, total employment impacts of between **25,900 and 97,100 jobs** and **$1.6 to $5.9 billion in labor income** over the 2017 to 2050 period. If the U.S. were to capture a 50% share of the global market for fusion lasers and design and engineering spending, then the average annual impacts on GDP could amount to an additional **$5.3 to $19.5 billion**; employment impacts to between **53,600 and 198,300 jobs**; and average annual impacts on labor income to between **$11.6 and $12.7 billion** over the 2017 to 2050 period.

The R&D spending associated with the development of LIFE will "spillover" into other industries in the U.S. generating further economic benefits. An example of where this has already happened is laser-based manufacturing, already used for jet engines but which could have much wider application if developed for LIFE. Our analysis suggests that some **$40 billion** in cumulative catalytic GDP benefits would be generated over the course of the LIFE project.

The construction and operation of LIFE plants, and associated R&D, will generate significant economic impacts over the 2013 to 2050 time period. The economic benefits from the domestic and international rollout of LIFE power plants total some **$995 to $2,926 billion in cumulative GDP** impacts and **8.6 to 26.4 million job years** over the course of the project to 2050, including effects from some R&D prior to 2013 (see Table 4.1).

Table 4.1 : The Economic Impacts of LIFE, 2013 to 2050

	GDP (Billions $)		Employment (000's of Jobs)	
	Average Annual	Aggregate	Average Annual	Aggregate (000's Job Years)
Domestic Rollout	$17.7 - $47.7	$655 - $1,775	152.2 - 417.4	5,700 - 15,500
R&D Spillovers	$0.60	$40	0	0
Traditional Exports	$2.8 - $10.5	$104 - $389	25.9 - 97.1	944 - 3,593
"First Mover" Exports	$5.3 - $19.5	$196 - $722	53.6 - 198.3	1,983- 7,337
Total		**$995 - $2,926**		**8,627 - 26,430**

Note: All figures include Direct, Indirect and Induced impacts. Supply chain investments are assumed to begin shortly after successful ignition and continue through to the completion of construction of the MEP plant. The Domestic Rollout includes the impacts related to the construction and the operations phase of the domestic rollout of LIFE plants. R&D spillover is based on the average R&D spend over the period 1992 to 2050. R&D spillovers are estimated to produce productivity improvements rather than employment gains. First mover advantage exports based on the U.S. obtaining and maintaining a 50% share of (combined) relevant laser-related and design and engineering activities. Traditional exports are based on maintaining market share over the period to 2050. These figures do not include pollution externalities estimates.

In addition to the economic impacts associated with the development of LIFE power plants, there are a number of other impacts that would result from the successful commercialization, including the development of high-tech/high-skilled industries and pollution-free electricity that is projected to be cheaper to generate than most other renewable technologies.[29]

Many of the jobs that will be created by the widespread commercialization of LIFE power plants will be high-tech and high-skilled jobs and will likely require an associate's degree or higher from a technical or community college. In addition, many of the on-site construction jobs will be high-skilled craft labor positions that require advanced training and/or certifications.

LIFE offers the potential to reduce the burning of fossil fuels for the production of electricity and associated harmful pollutants entering the atmosphere, including those which are associated with climate change such as carbon dioxide. Over the lifetime of the project, we estimate that the benefits from this avoided pollution will range from **$106 to $268 billion** compared to the Status Quo counterfactual. This represents an average annual benefit of between $3.5 and $8.9 billion. Even when compared to a High Renewables scenario (See Box 2.4), the implementation of LIFE still generates between **$37 and $95 billion** in cumulative pollution reduction benefits.

All told, the international and domestic rollout of LIFE has the potential to generate significant economic impacts for the U.S. economy. Without the investment required to develop the required technology, these economic and employment impacts would not occur. Of course, the electricity that would have been generated by LIFE would have to be generated by some other source. The construction and operation of those plants would generate employment impacts that are likely to be similar in magnitude to the development of LIFE plants. However, compared to fossil fuel plants, many of the employment impacts generated by the domestic rollout of LIFE are likely to be high-skilled, well-paying jobs in the high-tech manufacturing sector. These high-skilled jobs will likely provide a significant boost to the productivity and competitiveness of the manufacturing sector. Not only will this enable U.S. manufacturers to open up new markets as they will be well-positioned to benefit from increased exports to supply the roll-out of LIFE internationally, but it is also likely to enhance their ability to compete in related high-tech markets. A more highly skilled workforce is also likely to attract increased domestic investment. LIFE is therefore likely to result in a significant benefit to the wider U.S. economy. Alternative ways of meeting future electricity generation needs would be unlikely to create similar levels of high-skilled, high-tech manufacturing jobs.

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[29] Nicholson et al. (2010) "How carbon pricing changes the relative competitiveness of low-carbon baseload generating technologies." Energy 36(1): 305-313.

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