HTGR TECHNOLOGY ECONOMIC / BUSINESS ANALYSIS AND TRADE STUDIES

TASK 1.3: IMPACTS OF HTGR COMMERCIALIZATION ON THE U.S. ECONOMY

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Technology Insights

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ACRONYMS

Acronym	Description
FOAK	First-Of-A-Kind
CTL	Coal To Liquid
CTG	Coal To Gasoline
GDP	Gross Domestic Product
Gen	Generation
GTL	Gas To Liquid
GTG	Gas To Gasoline
HTGR	High Temperature Gas Cooled Reactor
NGNP	Next Generation Nuclear Plant
NPP	Nuclear Power Plant

1 INTRODUCTION

The NGNP Industry Alliance's market analysis in the HTGR Commercialization Business Plan (Reference 1) indicated that, within the first 25 years of application in the U.S., up to a trillion dollars in Gross Domestic Product (GDP) could be generated. Further, the modular HTGR is particularly well suited for small to medium and developing countries, with its scalable modular deployment and superior safety characteristics that do not rely on operator intervention or the use of any AC-powered systems to avoid major off-normal events that could disturb the normal day-to-day activities of the public. Altogether, this translates into profitable growth in new market sectors for the nuclear energy system and for equipment suppliers, owner/operators and energy end-user industries with many thousands of highly skilled, high-paying jobs. This growth is good for industry and good for the U.S., North America, and other countries that choose to participate and engage in this technology

The purpose of this report is to describe and update the impacts that commercialization of the modular HTGR could have on the U.S. economy in terms of GDP, jobs, supply chain, vendor capability, and U.S. competitiveness in the nuclear industry.

1.1 Scope of Impacts Assessment

Given the expected penetration into the spectrum of markets from Task 1.1 (Reference 2), the following impacts are assessed:

- Projected increase in the U.S. Gross Domestic Product within the first 25 years
- Job creation within the U.S
- Increased U.S. competitiveness in the nuclear industry
    - HTGR supply chain development
    - Increased nuclear power plant vendor capability

1.2 Impacts Assessment Approach

The approach to this task was to initially review the 2012 Business Plan and supporting analyses for the above impacts. With that understanding as a base, the Business Plan impacts are updated in terms of the GDP and job creation as a result of additional studies and inputs such as the revised market assessment from Task 1.1. For the impacts on U.S. competitiveness, the NGNP Industry Alliance team members have been utilized to provide inputs on supplier infrastructure development and on vendor capability.

1.3 Organization of Report

Section 2 of this report reviews the basis for the US GDP increase provided in the 2012 business plan and updates it with inputs from other subtasks in this project. Section 3 addresses the assessment of each of the other impacts listed in Section 1.1. Summary observations, conclusions and recommendations are provided in Section 0.

2 HTGR COMMERCIALIZATION IMPACTS ON U.S. GROSS DOMESTIC PRODUCT

This section examines the overall impact on the Gross Domestic Product (GDP) in the US for two levels of market penetration:

1) 50 4-reactor module plants, as assumed in the Business Plan Appendix A and

2) 200 4-reactor module plants as a projected build-out potential, as discussed in the Business Plan.

This is followed by the regional economic impacts in two states based on INL studies performed since the issue of the Business Plan.

2.1 National Economic Impacts

The impact on the U.S. GDP has been estimated for a 25 year period from 2025-2050 with the expenditure profile of a single 4-reactor module plant shown in Figure 2-1 which assumes a five year construction period.

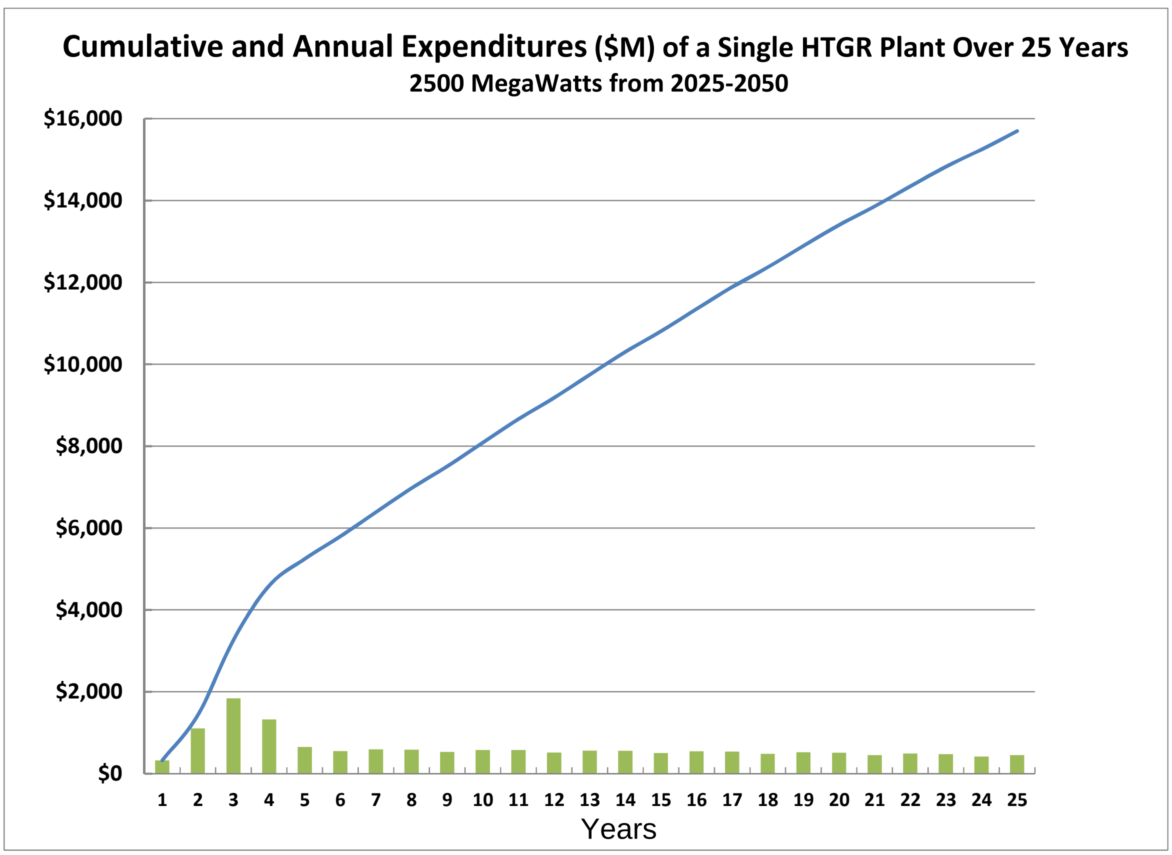

FIGURE 2-1 EXPENDITURE PROFILE OVER 25 YEARS OF A SINGLE 4-REACTOR MODULE HTGR PLANT

In the economic analyses of Appendix A in the NGNP Business Plan, a market penetration of 50 4-module HTGR plants was assumed within North America. Figure 2-2 shows the GDP accumulation of taking the single profile from Figure 2-1 and assuming that 50 plants, each with a five-year construction period, are sequentially brought on line over a 25 year period. As indicated in the top right portion of the summation curve, the national increase in the GDP over this period is over half a trillion dollars.

Further, the business plan also indicated a build-out potential for 200 modular plants (800 reactor modules), which if deployed results in a GDP increase of over 2 trillion dollars in the first 25 years of the introduction for HTGR plants. The impact on the GDP would be increased still further if the evaluation period was increased from 25 years to the full 60 year design lifetime of each of the 200 modular plants.

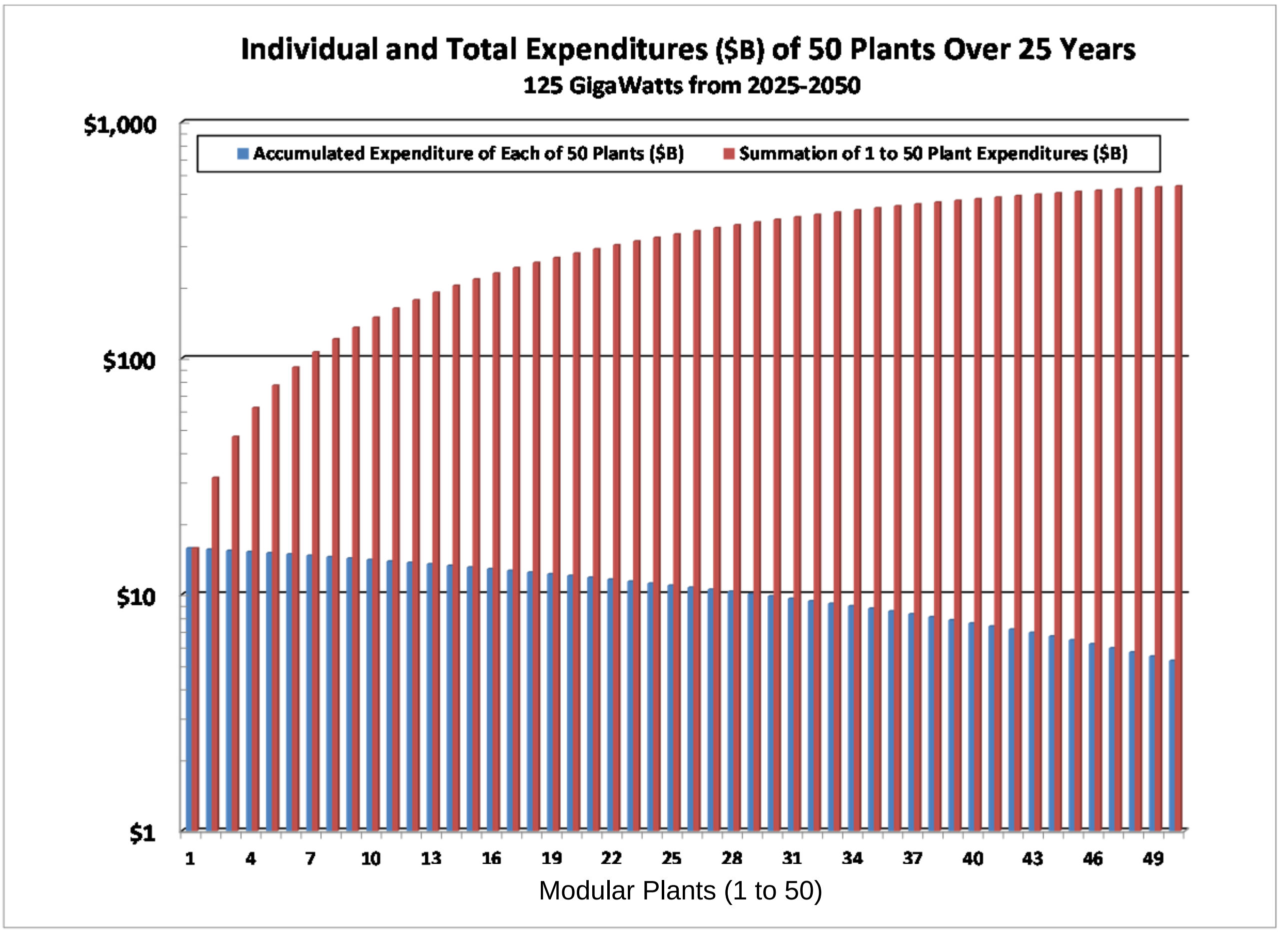

FIGURE 2-2 INDIVIDUAL AND TOTAL EXPENDITURES FOR 50 MODULAR HTGR PLANTS (200 REACTOR MODULES) OVER AN INITIAL 25 YEAR TIME FRAME

2.2 Regional Economic Impacts

Considerable progress has been made since the NGNP Business Plan was issued in 2012 in assessing the impacts of potential applications in two states. INL, working with the NGNP Industry Alliance, has interacted with the Wyoming and Kentucky governments and industries on integrating advanced modular HTGR plants with their respective coal industries (References 3 and 4). The following sections have been taken from those respective studies to provide the significant positive impact on the economies in terms of GDP of those states.

2.2.1 Economic Impacts from Energy Development Opportunities for Wyoming (Reference 3)

In Wyoming, an industry is projected for converting coal to higher value petro-chemical products Figure 2-3 provides a notional schedule for deployment of the Wyoming carbon conversion industry including integration of advanced HTGR plants providing heat and electricity to the processes and base-load electricity to the Wyoming grid. This is judged to be a non-aggressive schedule that does not require excessive annual expenditures or large labor forces that could strain the Wyoming infrastructure.

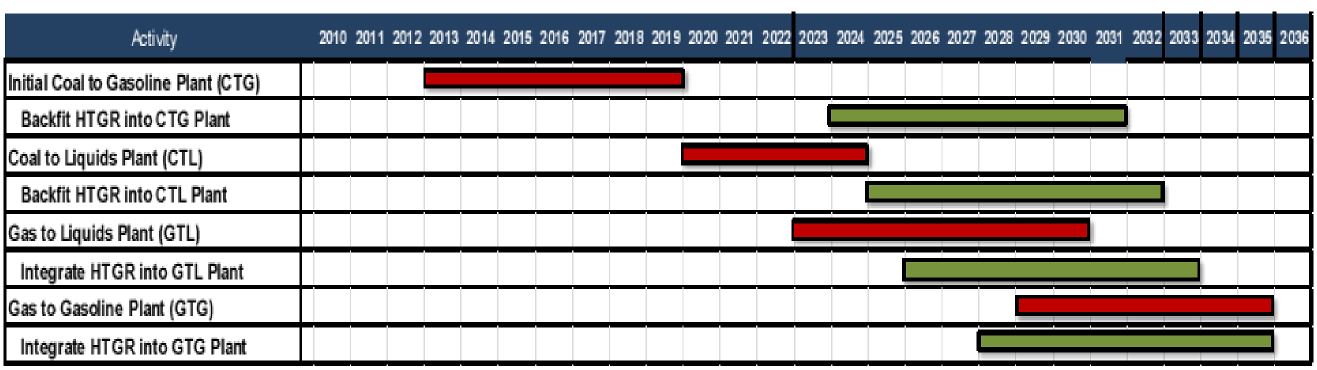

FIGURE 2-3 CARBON CONVERSION SCHEDULE FOR DEPLOYMENT IN WYOMING

Figure 2-4 summarizes the projected annual contributions to the Wyoming GDP and accumulative expenditures for this deployment. The total projected cost of $35.53 Billion is spread over 22 years and the highest annual expenditure is in the range of $3.0B. These are judged to be reasonable for the benefit to be accrued from this deployment; an addition of ~$7B in revenue from sales of the products. The annual contributions of these expenditures to the Wyoming GDP are also significant; reaching 7% of the Wyoming GDP in 2011$ in peak years. The ~150,000 man-years required to complete the construction over the 22 year period would also be of benefit to the local and state economies.

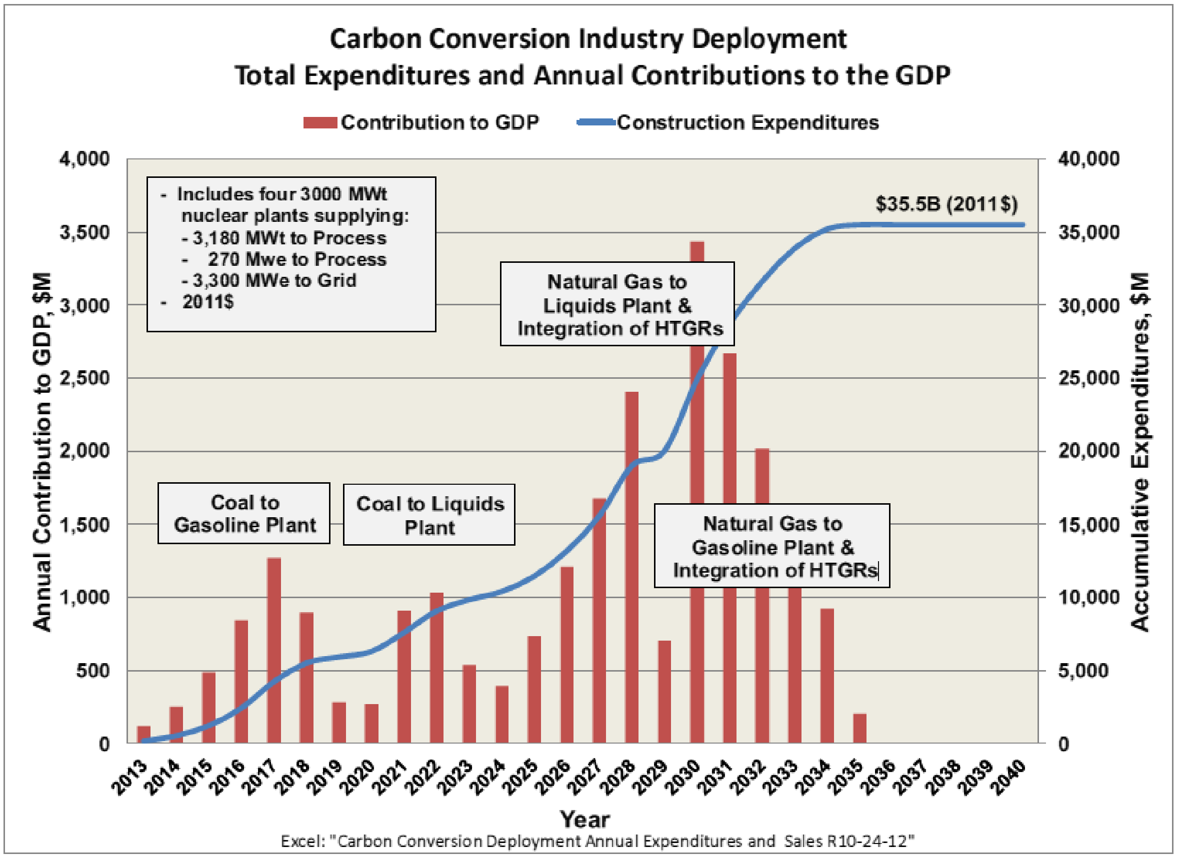

FIGURE 2-4 CARBON CONVERSION INDUSTRY DEPLOYMENT EXPENDITURES AND ANNUAL CONTRIBUTIONS TO THE WYOMING STATE GDP

2.2.2 Economic Impacts from Development Options for Kentucky's Energy Future (Reference 4)

The deployment of a carbon conversion industry in Kentucky will have a positive effect on state's economy by providing a continuing demand for indigenous coal and natural gas resources and increasing the value of these resources by transforming them into higher value products. The investment in constructing the facilities that will make up this industry will also add value to the GDP during construction, and the construction activity and operation of the facilities will provide lasting job growth. The same is true of the investment required to transform the electricity generation sources in Kentucky. During construction of the new generation and upgrade of the emissions control equipment of the retained generation, the investment will add value to the GDP. Figure 2-5 provides the projected contributions from these two initiatives and the total annual contribution to the GDP in 2011$.

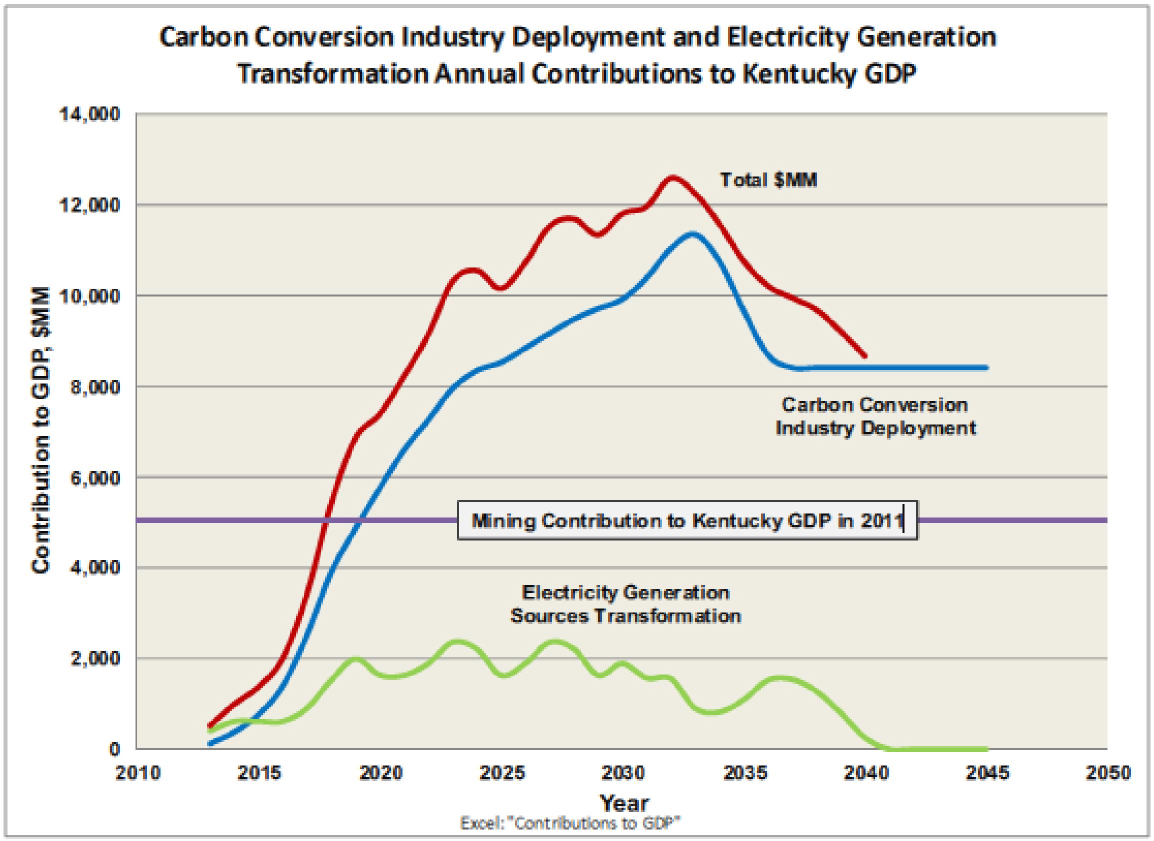

FIGURE 2-5 CARBON CONVERSION INDUSTRY DEPLOYMENT EXPENDITURES AND ANNUAL CONTRIBUTIONS TO THE KENTUCKY STATE GDP

In 2011, the mining industry contributed ~3% of the total Kentucky GDP or about $5B. At the peak of construction, the deployment of the carbon conversion industry and the transformation of the electric generation industry will be on the order of $12B (2011$), or more than twice that of the mining contribution in 2011. Once the initial carbon conversion industry is fully deployed, it will add ~$8.5B to the annual GDP or 70% more than the mining industry contributed in 2011. These are substantive contributions on a real dollar basis and support the Commonwealth's objectives of revitalizing the coal and natural gas production industry in eastern Kentucky and providing a viable sustainable mix of electricity generation over the long term. Also, it should be noted that economic multiplier effects of business growth (e.g., real estate, retail sales growth) that accompanies such industry development and transformation have not been included. An important consideration in evaluating the long term effect is the extent to which the carbon conversion industry may continue to grow beyond the notional assumptions evaluated. As an example, if the carbon conversion industry were to continue to grow to utilize the entire current coal production in Kentucky, the effect on the GDP would be an order of magnitude larger.

2.3 Summary of Impact on Gross Domestic Product

At a national level, introduction of steam cycle modular HTGR plants for process heat and cogeneration of electricity has a similar highly positive impact: for a 25 year time period, 50 plants (200 reactor modules) projects to an increase in the GDP of $530 Billion and, at 200 plants (800 reactor modules), provide a GDP increase that exceeds 2 Trillion dollars. The impact over the full 60 year design lifetimes of these modular plants is even higher.

However, if the modular HTGR plant development is jointly developed with another country, these impacts are lessened and, as suggested by recent trends from Gen 3 reactors, can be expected to decrease with time. This occurs as the partner country takes over the commercialization of a US-developed Gen 4 NPP that caters to not only the electricity generation needs, but also to the needs of the process industry for expanding the availability of safe, reliable, economic energy.

The recent studies on the commercialization of an advanced modular HTGR in conjunction with the development of a carbon conversion industry in the states of Wyoming and Kentucky indicate significant economic impacts:

- In Wyoming, ~$35 Billion over 22 years with the highest annual expenditure in the range of $3.0B or 7% of the Wyoming GDP

- In Kentucky, the highest annual contribution is ~$12 Billion or >6% of the Kentucky GDP.

3 OTHER U.S. HTGR COMMERCIALIZATION IMPACTS

This section examines the additional commercialization impacts of U.S. job creation and the competitiveness of the U.S. nuclear industry.

3.1 Job Creation within the U.S.

Several studies in recent years have addressed the U.S. readiness for a general nuclear resurgence. Reference 5 performed by Bechtel in 2004 examined job creation in the ten year time frame of 2014-2024 associated with the order of large LWRs (41 1200 MWe and 33 1500 MWe plants). The study characterized the job categories excerpted below:

> **Repatriated Manufacturing Jobs**
> This job category refers to those jobs previously lost to either offshore companies or industry attrition due to the lack of nuclear plant orders in the United States.
>
> **Construction Jobs**
> This category is the labor needed to construct a new nuclear power plant.
>
> **Operations Jobs**
> These jobs include the higher-paying permanent plant operators, technicians, plant engineers, and managers involved in the day-to-day-operations of a nuclear power plant.
>
> **Indirect Jobs**
> The indirect employment effects were based on actual operations expenditures for all outside goods, services, and taxes. Examples of indirect expenditures include nuclear fuel; maintenance and repair services; personnel supply services; management and consulting services; industrial machinery; pipes, valves, and pipe fittings; research and testing services; engineering-architectural services; steam supply and sewage services; computer and data processing services: insurance premiums; and state and local taxes.
>
> **Induced Jobs**
> This job category contains new jobs created in the nonnuclear industry due to the new jobs added in the categories above. These types of jobs include the additional grocery store checkers, elementary school teachers, home construction craft workers, postal carriers, etc. that are added to the community as a result of new nuclear power plant employment.

The LWR resurgence job estimates for these categories for the assumed large LWR mix and timeline in the reference are shown in Figure 3-1. As indicated, the indirect and induced job categories dominate.

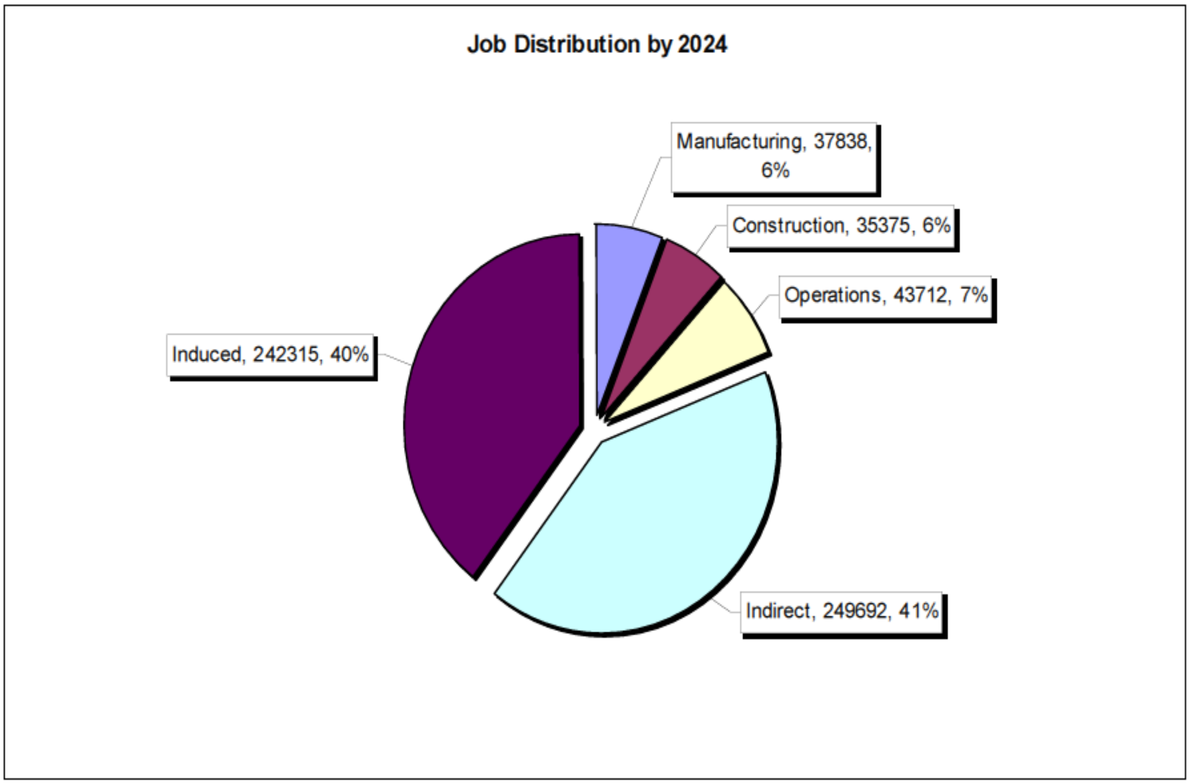

FIGURE 3-1 JOB CREATION ESTIMATES BY JOB CATEGORY FOR LARGE LWR RESURGENCE AT END OF 10-YEAR PERIOD

A more recent HTGR-specific study from 2011 performed by URS (Reference 6) provided input for the NGNP estimates of job creation. It is estimated that 50 modular HTGR plants of 4 reactor modules each rated at 625 MWt could be economically deployed in North America generating a total of 125 GWt for process steam cogeneration supporting a wide range of industrial applications. These include petrochemical processing, petroleum refining, fertilizer and ammonia production, coal to liquids conversion, tar sands and oil shale oil recovery. Estimates have been made of the number of jobs that would be created during the design, manufacture of equipment, construction, commissioning and operation of the HTGR plants as an alternative to the construction and operation of traditional fossil plants, with equivalent thermal ratings, burning natural gas. For the purposes of this evaluation, 20 year and 30 year periods for deployment of the 50 plants were investigated. Although there is uncertainty in the estimate of 50 plants, it is considered conservative and could be much higher if the government implements a substantive program for reduction of carbon emissions that provides an economic incentive for industry to remove the source of carbon emissions in their processes.

A total of ~13,500 man-years is estimated to be required to complete the design, manufacture of equipment, construction and commissioning of a single 4-reactor module plant of 2500 MWt.

This estimate does not include the indirect and induced impacts noted in the large LWR study above.

Accordingly, over the period of deployment of 50 plants, a total of approximately 674,000 man-years will be expended in design, manufacture of equipment, construction and commissioning of the plants. For the purposes of analysis, it has been assumed that the plants would be completed in a number of groups (e.g., 14 groups for a 20 year deployment period, 24 groups for 30 years) with initiation of the development of each group staggered by a year. For the 20 year deployment period, the largest group comprises 6 plants. At the peak of the development, 30 plants will be in some phase of development and ~62,000 man-years will be expended in a single year. For the 30 year deployment period, the largest group comprises 3 plants. At the peak of the development, 18 plants will be in some phase of development and ~39, 000 man-years will be expended in a single year. The number of man-years is equivalent to the number of jobs that would be created by these efforts.

Based on current estimates, each plant will require approximately 270 personnel for operations, maintenance, engineering, security, quality assurance, support and supervision. Accordingly, upon the completion of deployment ~ 13,400 new highly-paid jobs will be in place to support the 50 plants.

Table 3-1 summarizes the results for a single plant of four modules and for 50 modular plants as assumed in Appendix A of the Business Plan for 20 and 30 year time frames. Also shown are the results for 200 plants for the same two time frames, consistent with the Business Plan's potential market, as discussed in the main body.

TABLE 3-1 SUMMARY OF JOB CREATION IN THE US FOR HTGR FLEETS OF 50 AND 200 PLANTS

Item	Single Plant	50 Plants in 20 years	50 Plants in 30 years	200 Plants in 20 years	200 Plants in 30 years
Total man-years	13,486	674,300	674,300	2,697,200	2,697,200
Average man-years per year	1,927	33,715	22,477	134,860	89,807
Number of permanent plant jobs created after full deployment	400	20,000	20,000	80,000	80,000

As with the impact on GDP, if a joint project is implemented with a foreign country, the above favorable U.S. job creation estimates are negatively affected, depending on the particulars of siting, scope share, and ultimate location(s) of HTGR commercialization.

3.2 Increased U.S. Competitiveness in the Nuclear Industry

The U.S. competitiveness in the nuclear industry as a result of the modular HTGR commercialization can be conveniently grouped into the favorable impacts for the development of the supply chain and for the nuclear power plant vendors.

3.2.1 HTGR Supply Chain Development

The supply chain for the supply of materials and equipment for the construction of nuclear power plants in the U.S. has deteriorated considerably since the construction of 100plus nuclear power plants (including the supply of foreign plants) in the 1970s and 1980s. For the construction of 50 4-reactor module HTGR plants over 25 years, the supply chain would have to re-established and further developed. This applies in particular, to the supply of the major equipment items required by the HTGR that include, but are not limited to, reactor pressure vessels, steam generator vessels, steam generator tube bundles, reactor core graphite components and reactor fuel. Major material supply requirements include concrete, rebar, structural steel, wire and cabling.

Quantity requirements for the supply of the major equipment items and core graphite material are as given in Table 3-2.

TABLE 3-2 QUANTITY REQUIREMENTS, MAJOR EQUIPMENT ITEMS AND GRAPHITE

Major Equipment Items	Quantity per Module	Weight per Module, MT	No. Per 4 Module Plant	Weight per Plant, MT	Average*** Quantity per Yr, MT
Reactor Pressure Vessel	1	825	4	3300	6600
Steam Generator Vessel	2	320	8	1280	2560
Cross Vessel	2	16	8	64	128
Steam Generator Tube Bundle	2	105	8	420	840
Reactor Internals	1	100	4	400	800
Total Major Metallic Equip		1366		5464	10928
Initial Core Graphite					
Active Core Bulk Graphite*	1	92	4	368	736
Refector Core Bulk Graphite*	1	527	4	2108	4216
Total Initial Core Bulk Graphite		619		2476	4952
Replacement Core Graphite**					
Active Core Bulk Graphite* per year	1	53	4	212	
Refector Core Bulk Graphite* per year	1	11	4	44	
Replacement Bulk Graphite* per year				256	
Replacement Graphite* per year (10 plants)				2560	
Replacement Graphite* per year (25 plants)				6400	
Replacement Graphite* per year (50 plants)				12800	
* Bulk Graphite refers to quantity produced finished to exterior dimensions					
** Normalized to per year basis					
** * Average quantitiy refers to 50 plants deployed over 25 years, or, 2 plants per year					

As indicated in Table 3-2, commercialization of the HTGR involving deployment of 50 plants over 25 years would require substantial manufacturing capacity for the supply of the major equipment items. For the first plant, the major metallic equipment supply requirement is about 5,500 MT but would have to expand, on average to about 11,000 MT per year. These types of equipment items were typically supplied during the 1970s and 1980s by companies in the business to supply pressure vessels and large components. From the survey in Reference 7 the U.S. supply capability for these components is currently very limited indicating the supply capacity has contracted considerably. The supply requirements in Table 3-1 should be sufficient to invigorate re-establishment of the supply capability which leads to significant job creation and economic improvement benefits.

A similar situation exists for the supply of graphite. At present, there is very limited graphite supply capacity in the U.S. Graphite suppliers have indicated that graphite would be supplied for the first HTGR plants deployed by using manufacturing capacity in foreign countries. But, they also indicate that if a fleet of HTGR plants were deployed, they would re-establish or expand manufacturing capacity in the U.S. Of particular note in Table 3-2 is the on-going requirement for graphite supply. A considerable amount of graphite in the form of prismatic blocks is required for replacement fuel element assemblies and for replacement graphite reflector elements. For 50 4-reactor module plants, this replacement supply requirement exceeds 12,000 metric tons per year. This demand should be sufficient to attract investment in either new or expanded graphite production facilities.

4 OBSERVATIONS, CONCLUSIONS AND RECOMMENDATIONS

This report confirms, amplifies, and expands on the favorable impacts to the U.S. economy discussed in the HTGR Business Plan from the commercialization of the steam cycle HTGR issued by the NGNP Industry Alliance in 2012. The conclusions are as follows:

Gross Domestic Product

At a national level, introduction of steam cycle modular HTGR plants for process heat and cogeneration of electricity has a highly positive impact: for a 25 year time period, 50 plants (200 reactor modules) projects to an increase in the GDP of $530 Billion and at 200 plants (800 reactor modules) the GDP increase exceeds $2 Trillion. The impact over the full 60 year design lifetimes of these modular plants is even higher.

The recent studies on the commercialization of an advanced modular HTGR in conjunction with the development of a carbon conversion industry in the states of Wyoming and Kentucky indicate significant economic impacts:

- In Wyoming, ~$35 Billion over 22 years with the highest annual expenditure in the range of $3.0B or 7% of the Wyoming GDP
- In Kentucky, the highest annual contribution is ~$12 Billion or >6% of the Kentucky GDP.

Job Creation

It is estimated that a single 4-reactor module HTGR plant results in ~13,500 total man years. Based on this estimate, the number of man-years for a fleet of 50 plants is ~670,000. Estimates for a 200 plant fleet and for the full 60 year design lifetime of the plants are appreciably higher.**Supply Chain Development**

The impacts on the nuclear industry- and HTGR-specific supply chains are very significant as indicated by the impact in weights and quantities of vessels, heat exchangers, and graphite.

Nuclear Vendor Capability

It is noted that these impacts are lessened to the degree to which the commercialization effort of this U.S.-developed Gen IV advanced reactor is a joint effort with another country.

5 REFERENCES

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2. “Market Analysis for HTGR Technologies and Applications, USNC-NIA-G00001, Revision 0, September 2013.

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5. “U.S. Job Creation Due to Nuclear Power Resurgence in the United States - Volume 1,” INEEL/EXT-04-02384, Volume 1, November 2004.

6. “NGNP HTGR-Assisted Conventional Processes Jobs Creation and Energy Security Report,” URS Report prepared for INL, November 2011.

7. “U.S. Job Creation Due to Nuclear Power Resurgence in the United States - Volume 1,” INEEL/EXT-04-02384, Volume 2, November 2004.