INDUSTRY ALLIANCE

Clean Sustainable Energy for the 21st Century

Modular High-Temperature Gas-Cooled Reactor Technology
An Essential Option for the Global Energy Future

A SUMMARY BUSINESS PLAN FOR COMMERCIALIZATION

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A BUSINESS PLAN FOR HIGH-TEMPERATURE GAS-COOLED REACTOR (HTGR) COMMERCIALIZATION

This business plan prepared by the NGNP Industry Alliance Limited (NIA) includes the following summation:

1. **HTGR Technology**
   A brief introduction to HTGR technology and its most important attributes

2. **Market and Economics**
   A characterization of the potential market and the associated economics

3. **Investment Perspectives**
   Why HTGR technology is a well-founded investment for industry, equity, and national policymakers

4. **Commercialization Strategy**
   Steps necessary for commercialization and deployment

5. **Enterprise Structure**
   A description of the major activities and organization to implement the commercialization strategy

6. **Enterprise Risk Perspective**
   A summary characterization of the most important risks associated with completion of the commercialization strategy
AN INTRINSICALLY SAFE, NEAR-ZERO CARBON SOURCE OF PROCESS HEAT AND ELECTRICITY

The HTGR’s intrinsic safety permits its colocation with industrial installations, allowing it to address the industrial sectors which are responsible for more than 20% of energy usage in North America and Europe and above 25% in Asia\(^1\). Refining, chemical processing, and iron and steel industries rely on fossil fuels for high temperature process heat and account for over 40% of the industrial sector energy usage.

Today, there are limited options for near-zero carbon dioxide (CO\(_2\)) emission high temperature process heat. HTGR technology provides a promising option in the near term that addresses industry’s CO\(_2\) emissions, regional energy stability, supply security, and price volatility.

HTGR technology is the most mature advanced form of nuclear energy that can provide a near-zero emission source of both process heat and electricity for industry. Along with proven long term fuel supply availability and price stability, each plant can store fuel for more than a year of operation eliminating fuel availability and delivery uncertainties that lead to price volatility of fossil fuel energy source alternatives. HTGRs deliver reliable energy in the form of process heat and electricity that does not depend on external factors such as time of day or weather conditions. The capability to switch between process heat and electricity generation and the ability to increase or decrease the amount of delivered energy provides a flexible low carbon source of energy unattainable with other renewable sources of energy.

The potential market for HTGRs is only limited by the market acceptability and industrial demand — hundreds of reactor modules in North America alone and hundreds more in other regions across the globe including the Middle East, Japan, the Republic of Korea (ROK), Europe, and Asia. China and Russia are pursuing HTGR designs and are working to bring their systems to market world-wide.

Investment in the development or deployment venture will be negotiated to ensure the terms are equitable and acceptable to all parties. Arrangements regarding intellectual property (IP) ownership, rights, and use would be made between the specific IP holder and the interested investor.

HTGR — THE GAME CHANGER

1. **Intrinsic Safety** — The Intrinsic safety characteristics and passive safety features in the design of HTGRs eliminate failure scenarios that result in significant release of radionuclides.
   - Fission products are contained within ceramic-coated tristructural-isotropic (TRISO) fuel particles.
   - The reactor shuts itself down well below temperatures that damage TRISO fuel.
   - Passive reactor cooling requires no fluids (e.g. water or helium) post-accident.
   - Spent fuel will be air-cooled without external power.
   - No powered systems or operator intervention is needed to safely shut down or cool the reactor.

2. **Process Heat** — HTGR technology is the only near-term energy source capable of displacing the use of fossil fuels for high temperature process heat and/or electricity generation while emitting almost no CO\(_2\).
   - Process heat and electricity can be supplied for petrochemical refining, chemical processes and extraction, and upgrading of bitumen from oil sand and shale, replacing or supplementing premium fossil fuels.
   - HTGRs, with low CO\(_2\) emissions, enable premium fossil fuels to be used as feedstock for higher-value products, such as chemicals and synthetic fuels that add multiples of gross returns instead of simply burning as fuel.

3. **Economics** — HTGR technology competes today for process heat and electricity at about $6-$10/MMBtu equivalent natural gas price, or less if carbon costs are internalized.
   - HTGR is competitive now in parts of the world that rely on liquefied natural gas (LNG) or oil products for process heat and electricity.
• In North America, NIA concludes HTGR will be competitive within the target time frame for commercial availability of 2030. In fact, it is competitive for electricity in some areas of the NorthEast today that rely on natural gas for electricity and heating.

• NIA estimates that the first 25-year buildout with a 25% market penetration in North America will create over $115 billion in Gross Domestic Product (GDP). Application of the technology in other countries and its application in electricity-only production would significantly increase and accelerate this GDP contribution.

• HTGR manufacturing, construction, and operation will create high-paying jobs in supply chain industries (large industrial forgings and other ancillary equipment), construction and operation. Construction will average ~3000 full time construction and fabrication jobs per four module plant. With only a 35% market penetration (50 four module plants) in North America, the buildout will reach an equilibrium level of 60,000 jobs within 15 years.

• HTGRs will help assure energy security by providing long-term stable energy costs and enabling conversion of carbon (e.g., coal, pet coke, solid waste) to synthetic fuels and chemicals via nuclear-assisted conversion processes.

4. Business Model — There are two primary business efforts necessary to fulfill the Commercialization Strategy described later in this Business Plan. The first effort involves a consortium of investors, including the primary Nuclear System Supplier, partnered with government and other sovereign investors. This partnership: 1) completes technology development; 2) establishes the necessary regulatory framework for licensing HTGR technology through pre-application activities with a regulatory agency, for example, the US Nuclear Regulatory Commission (NRC); 3) completes the reference design; and 4) develops the supply chain of the equipment and materials for construction of a plant.

The second effort is multiple consortia of investors that build HTGR plants using technology developed in the first stage. Major financing (e.g., government loan guarantees) is not anticipated to be required; instead, large industrial end-users would provide long-term purchase agreements and multi-investor ownership would provide capital for technology development and deployment:

• Third-party fenceline commercial long-term agreements with the process heat and power off-takers, to serve as collateral and eliminate the need for loan guarantees.

• Many installations as joint venture (JV) structures with 80/20 debt to equity financing enabling many participants in financing. A $4.6 billion four reactor nth-of-a-kind (NOAK) installation with four partners would only require a $230 million cash infusion by each partner.

• Multiple modules may be required to meet the needs of an application. The number of modules will be dependent on the specific application.

5. Key Challenge — The key challenge centers not on the HTGR or its commercial phase economics, rather it is the financial lift required to bring this game-changing technology to market. The business risks of a time frame of more than two decades for an initial economic return on investment (ROI) are difficult for private industry to make alone. Potential approaches to address this risk include public-private partnerships between industry investors, sovereign investors and government(s), or risk sharing among multiple international industrial investors. Particularly important risks are those introduced by government regulatory processes (not standard world-wide) coupled with the need for regulatory support of HTGR (a non-light water reactor technology). Developing the necessary regulatory framework for licensing HTGR technology can build on the pre-application activities with the NRC already conducted in the NGNP Program.
Today, process heat requirements for energy-intensive industries are provided almost entirely by fossil fuels. Electrical power for these industries are hostage to evolving environmental concerns, unpredictable government policies, uncertainty of supply, and price volatility. Modular HTGR nuclear technology provides an important option that addresses these issues head on. It provides process heat at the temperatures needed by industry and electricity with competitive economics, compelling safety, and minimal environmental concerns.

For those markets that rely on premium fossil fuels, commercializing the HTGR makes available a game-changing technology that can address the overarching and global energy policy goals of energy and feedstock security, economic growth (jobs) and CO2 emissions. In addition, trends in fossil fuel prices suggest that modular HTGR technology integrated with modified versions of conventional carbon conversion technologies provides an economic approach to production of synthetic transportation fuel, chemical feedstock, and chemicals with minimal CO2 emissions.

Several variations of modular HTGRs have been proposed, including pebble bed and prismatic core technologies. In all modern HTGR designs, TRISO fuel is a key part of the modular HTGR concept. Each fuel particle consists of a fuel kernel surrounded by four layers of three isotropic materials which provide the primary fission product retention barrier under all licensing basis conditions. TRISO fuel particles are designed not to crack and can support temperatures of 1600°C and beyond. A single core includes roughly 10 billion such particles.

In a prismatic core, the TRISO fuel particles are distributed in graphitic cylindrical compacts and the compacts are placed in holes drilled in the graphite fuel blocks. The core is made up of a mix of fueled blocks and unfueled graphite reflector blocks. The basic core structure is entirely ceramic.
NIA selected AREVA NA’s prismatic core modular HTGR with conventional steam cycle (SC-HTGR) in February of 2012 as the initial reference design for near-term development and deployment. The AREVA design provides the best match to near-term energy needs with competitive economics and acceptable risks for investment readiness, while also laying the foundation for more advanced modular HTGR concepts. Key 625 megawatt-thermal (MWt) reactor module performance parameters are summarized in Table 1:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor outlet temperature</td>
<td>750°C</td>
</tr>
<tr>
<td>Reactor inlet temperature</td>
<td>325°C</td>
</tr>
<tr>
<td>Primary coolant pressure</td>
<td>6 MPa</td>
</tr>
<tr>
<td>Main circulator power</td>
<td>4 MW electric (each)</td>
</tr>
<tr>
<td>Main steam temperature</td>
<td>566°C</td>
</tr>
<tr>
<td>Main steam pressure</td>
<td>16.7 MPa</td>
</tr>
</tbody>
</table>

The nuclear steam supply system is based on a nominally 625 MWt annular reactor core in a large steel reactor vessel. It is a two-loop system with the reactor connected to two parallel steam generators and helium circulators.

The schematic pictured here illustrates a typical configuration which can simultaneously deliver both high- and low-pressure process steam as well as electricity.
FULFILLS THE ENERGY NEEDS OF ENERGY-INTENSIVE INDUSTRY

It is envisioned that the reference concept module will be incorporated in multi-module plants that can provide over-the-fence supplies of energy analogous in capacity and reliability to conventional cogeneration facilities used by industry. For example, a large industrial complex might typically have four to six modules for reliable process heat and power supply.

The initial fleet will adapt multiple standard reactor modules with application-specific process steam and/or power generation energy utilization systems to serve a range of plant sizes for the target applications discussed above.

COMPELLING SAFETY

The superior intrinsic safety characteristics of modular HTGR technology provide a nuclear energy system design that protects the owner’s investment, the investment of the industrial entity receiving the process heat and electrical power, the public, and the environment. The safety case clearly supports acceptable business risk for colocation at the energy end-user's facility. It addresses extraordinary events such as interruption by natural causes (e.g., flood or earthquake), human error, or equipment failure that may affect the plant normal operations. During extreme case accident response, reactor power and heat generation can be managed through intrinsically self-limiting reactor passive shutdown features without operator action and without the need for fluids or fluid management systems (e.g., water or gas) or power.

No explosive gases can be produced by fuel materials or core infrastructure — the materials were selected and designed to preclude this. Used nuclear fuel from an HTGR requires no cooling water or active systems for heat transfer, relying instead on natural air convection.

The safety case has been demonstrated in the German Arbeitsgemeinschaft Versuchsreaktor (AVR) and recently in the 10 and 30 MWT HTGR designs in China and Japan, respectively. In those tests, the self-limiting reactor shutdown was demonstrated. This was done by stopping the normal operation of the helium forced cooling system. The reactor heated up to a temperature where the nuclear fission reaction naturally shut itself down without any damage to the reactor or the ceramic fuel.

Nearby public and industry need not shelter or evacuate for any internal or external event challenging reactor operation. This translates into a close-in siting capability needed for process steam/heat loads, and improved public and investor acceptance. Long-term investment risk due to safety concerns is minimized for both the reactor plant itself and for colocated industrial facilities.

- No need to evacuate or shelter the public and no threat to food or water supplies for all potential events.
- Multiple assured barriers to the release of radioactive material are provided.
- Reactor power levels are limited and the nuclear reactor shuts down if reactor temperatures exceed intended operating conditions.
- No actions by plant personnel or backup systems are required to either ensure reactor shutdown or ensure reactor heat removal.
- No power, water or other cooling fluid is required to ensure post-accident safe shut down or post-accident reactor heat removal.
- Reactor materials including fuel are chemically compatible and in combination will not react or burn to produce heat or explosive gases.
- Achievable levels of air or water intrusion do not result in substantive degradation of the capability to contain radioactive materials.
- Spent or used fuel is stored in casks or tanks in underground dry vaults that can be cooled by natural circulation of air and shielded by steel plugs and concrete structure.
EXTENSIVE DEVELOPMENT HISTORY

The basis for the HTGR technology was first developed over 50 years ago in the UK, the United States, and Germany. Seven experimental and demonstration reactors have been built worldwide, including US commercial-scale demonstrations of specific HTGR concepts for electric power generation at the Peach Bottom Atomic Power Station, Unit 1 (rated at 200 MWe), located in Delta, Pennsylvania, that was operated from June of 1967 to its final shutdown on October 31, 1974, and the Fort St. Vrain plant (rated at 842 MWe), located in Colorado, that operated from 1976 through 1989.

Commercial-Scale Demonstration Plants

<table>
<thead>
<tr>
<th>Plant</th>
<th>Type</th>
<th>Rating</th>
<th>Temperature</th>
<th>Location</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEACH BOTTOM 1</td>
<td>115 MWe prismatic</td>
<td>(US)</td>
<td>750°C</td>
<td>1967-1974</td>
<td></td>
</tr>
<tr>
<td>THTR</td>
<td>750 MWe pebble bed</td>
<td>(FRG)</td>
<td>750°C</td>
<td>1986-1989</td>
<td></td>
</tr>
<tr>
<td>FORT ST. VRAIN</td>
<td>842 MWe prismatic</td>
<td>(US)</td>
<td>750°C</td>
<td>1976-1989</td>
<td></td>
</tr>
</tbody>
</table>

Experimental Reactors

<table>
<thead>
<tr>
<th>Reactor</th>
<th>Type</th>
<th>Rating</th>
<th>Temperature</th>
<th>Location</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAGON</td>
<td>20 MWe prismatic</td>
<td>(UK)</td>
<td>750°C</td>
<td>1963-1976</td>
<td></td>
</tr>
<tr>
<td>AVR</td>
<td>40 MWe pebble bed</td>
<td>(FRG)</td>
<td>850-950°C</td>
<td>1967-1988</td>
<td></td>
</tr>
<tr>
<td>HTTR</td>
<td>30 MWe prismatic</td>
<td>(Japan)</td>
<td>750-950°C</td>
<td>1998-present</td>
<td></td>
</tr>
<tr>
<td>HTR-10</td>
<td>10 MWe pebble bed</td>
<td>(China)</td>
<td>700-950°C</td>
<td>2003-present</td>
<td></td>
</tr>
</tbody>
</table>

Current HTGR system-related development efforts exist in China, ROK, Japan and Russia, and there has been recent revived interest from the process heat industry in Europe. NIA is actively involved and communicating with industry leaders in Europe, Japan, ROK, and the Kingdom of Saudi Arabia (KSA) to identify technology requirements and work to promote commercialization of the HTGR. International Gen IV meetings and technical conferences also continue to provide opportunities for shared work and collaboration activities.

Through 2011, $500 million has gone into confirmatory research and development for HTGR technology by the US Department of Energy under the Next Generation Nuclear Plant (NGNP) program. Activities currently underway to complete qualification and codification for fuel, graphite and high temperature materials will complete in five to six years if sustained funding is provided. These activities are being conducted at the Idaho National Laboratory (INL) and Oak Ridge National Laboratory (ORNL).

In complementary activities over the past decade, industry has invested more than $1,000 million in advancing design concept and pre-licensing work with the vision for completing a commercial-scale demonstration project.
MARKET AND ECONOMICS CHARACTERIZATION

Substantive evaluations comparing the technology and economics of HTGR technology with conventional options have been completed for about 20 different industrial processes including cogeneration supply of steam and electricity to industrial plants, electricity generation as a merchant or regulated power generator, non-conventional oil extraction and upgrading, production of hydrogen, conversion of coal and natural gas to transportation fuel and chemical feedstock, production of ammonia and ammonia derivatives, seawater desalination, and coke and steel production. These evaluations addressed applications where the high temperature capabilities of HTGRs extend the use of nuclear energy beyond the traditional role of conventional light water reactors to supply electricity only.

For purposes of this business plan, the initial target market is limited to three broad market sectors around the world: 1) petrochemical, chemical, petroleum, and other processing facilities; 2) oil sands recovery operations; and 3) electrical power generation. This initial target market is selected based on the functional and performance capabilities of the reference reactor module concept described earlier, configured for the production of steam and electricity, and assessment of preliminary economics for the associated applications. Each sector is summarized in the following with the estimated production capacity that could be installed, the cumulative contribution to the economy for the period 2025 through 2050, and a preliminary characterization of economics.

PETROCHEMICAL, CHEMICAL, PETROLEUM, AND OTHER PROCESSING FACILITIES
These production facilities have large energy demands typically addressed via fossil fuel burning on-site power generation and high temperature steam supply for combinations of process heating, mechanical drivers and direct steam injection. In support of assessing representative potential applications, a recent site-specific report, “Evaluation of Siting an HTGR Cogeneration Plant on an Operating Commercial Nuclear Plant Site” has been prepared by INL with the support of Entergy Louisiana, LLC, Entergy Nuclear, Inc., and The Dow Chemical Company concludes:
- Installed rating of plants for potential market — 75 GWt or ~125 modules
- Cumulative contribution to the economy — $330 billion
- Competes with natural gas at an energy equivalent price of ~$6/MMBtu
In addition, as noted above there is a potential market for displacement of oil used for steam production in KSA equivalent to 5 GWt or ~8 modules.

OIL SANDS RECOVERY OPERATIONS IN ALBERTA, CANADA
These operations have modest electrical demands for on-site generation but require large process steam loads in the form of distributed injection of steam for bitumen recovery. In support of assessing this potential application, a recent report “Integration of HTGR Technology with Oil Sands Processes” has been jointly prepared by INL and the Petroleum Technology Alliance Canada that represents the leading petroleum companies who operate on an international scale and are heavily involved in the oil sands industry in Canada. This report addresses the technical feasibility and economic viability of using a central HTGR cogeneration plant to provide the energy needs of multiple bitumen recovery sites over a period of several decades, and upgrading the extracted bitumen to premium synthetic crude.
- Installed rating of plants for potential market — 18 GWt or ~30 modules
- Cumulative contribution to the economy — $95 billion
- Competes with natural gas at an energy equivalent price of ~$10/MMBtu
ELECTRIC POWER GENERATION
Adding power generation units often involves unique siting constraints such as geographic locations close to load centers, transmission capacity, or availability of cooling water. In addition to addressing these issues, the modular HTGR is an ideal technology for replacing small to medium coal-fired plants scheduled to be retired in the time frame of interest due to tightening environmental requirements.

- Installed rating of plants for potential market\textsuperscript{12} — 110 GWt or 180 modules
- Cumulative contribution to the economy — $480 billion
- Competes with natural gas at an energy equivalent price of \textasciitilde$6/MMBtu

As noted previously, there are potential markets for electricity generation in Hawaii, KSA, Japan, and ROK for a total of 80 GWt or \textasciitilde130 modules.

In addition to the three sectors identified above, direct heating growth applications are emerging for industrial manufacturing processes such as ethane cracking, steam methane reforming, and water splitting for hydrogen production using high-temperature electrolysis or thermochemical processes. These growth areas can extend the market potential for the above target applications by using the reference steam reactor module and developing an advanced process heat reactor module that fully uses the high temperature capability of the fuel and reactor. New market applications such as carbon conversion for production of synthetic transportation fuel and chemical feedstock are other areas that are expected to emerge prior to mid-century. In addition, a higher temperature capability can be applied to advanced energy conversion cycles for more efficient and cost-effective power generation. Serving these growth areas requires further high temperature materials qualification, development of high temperature heat exchange capability, and commercialization of highly efficient hydrogen production technology. The groundwork for these growth areas has been established in previous development work by industry and INL. This area for advancement is identified later in the Enterprise Structure section below as part of the Technology Expansion Program.

PRICE OF CARBON
For every $10 per ton of CO2, the cost-effectiveness of HTGR technology improves by $0.50/MMBtu equivalent natural gas price. A $50 price per ton of CO2 improves the competitiveness of the HTGR from $6/MMBtu to $3.50/MMBtu for Natural Gas Combined Cycle (NGCC) plant with Carbon Capture and Storage or to the range of $8-$10/MMBtu for an Advanced NGCC.
INVESTMENT PERSPECTIVES

HTGRs can produce competitively priced electric power and high temperature process heat/steam that assures energy security and stabilization of energy prices for more than half of global energy needs. Of these energy needs, over half of associated applications have been evaluated at a conceptual level and show promising economics.

For markets that rely on premium fossil fuels, have limited water supply for electrical power generation, or see a need to reduce CO2 emissions tied to process heat requirements, HTGR technology provides an option to use a viable, safe, environmentally friendly, and sustainable technology that can address energy policy goals of energy and feedstock security, economic growth, jobs, water conservation, and CO2 emissions. Using HTGR produced process heat dramatically reduces CO2 emissions from petrochemical production and petroleum refining facilities. It is economically competitive today in many parts of the world where gas prices are tied to oil, such as Europe, Japan, and the Middle East. NIA concludes that even US natural gas prices are likely to emerge in a range that will make this technology competitive for process heat and power in the 2030 time frame as utilities, transportation, and LNG exports compete to arbitrage the current US price advantage. If cost of oil reaches $130+ per barrel, modular HTGR technology integrated with carbon conversion processes provides an economic approach to production of synthetic transportation fuel or an alternative source of chemical feedstock.

HTGRs can create an expanding marketplace beyond electricity generation and enable industrial growth that is today solely reliant upon a natural gas supply. HTGR-produced energy can be a hedge that can insulate industry from energy price volatility. Unlike natural gas energy production, HTGR is largely immune to fuel price swings. For HTGRs, 70% of the cost is driven by the capital investment; fuel cost are <20%. This is directly opposed to natural gas where about 70% of the cost of energy is directly tied to the cost of fuel and the enormous volatility this brings with it.

Game Changer for Industry
HTGR can effectively use air-cooled condensing for electric power production, making it an efficient alternative in many arid regions of the world.

Energy Supply
The HTGR:
- Competes today in many parts of the world
- Creates a new market for nuclear energy within industrial heat applications and a brand-new energy option using indigenous carbon to produce synthetic fuels and feedstock
- Supports requirements of industry that are not serviceable from lower temperature light water reactors and other non-carbon emitting energy sources
- Provides for higher-efficiency power production, especially where water supply is limited
- Provides stable energy price uncoupled from volatile pricing for natural gas — a fungible global commodity tied to oil parity

When used in a cogeneration mode for industrial process and power, the HTGR can provide incremental power to the grid in a distributed mode precluding additional transmission grid investments.
WHY WOULD AN ENERGY END-USER BE INTERESTED IN THIS TECHNOLOGY?
Current industrial plants are using one primary source of energy, natural gas, to provide process heat. Modular HTGR technology provides an important option based on 1) intrinsic safety; 2) high-temperature output; 3) competitive and stable long-term energy prices; and 4) air-cooling.

Intrinsic Safety
Intrinsic safety allows a facility to be colocated near any manufacturing complex. HTGRs provide an energy system at a size and scale that will meet the needs for commercial applications and provide intrinsic safety protecting personnel, the public, and the environment. The robust fuel design makes it possible for close-in siting capability needed to expand existing industrial capacities.

High-Temperature Output
HTGR technology is capable of delivering process heat at the temperature and pressure ranges required by manufacturing and processing plants. Reliable and sustainable supply can be offered through multiple HTGR modules, or a combination of HTGR and gas-fired units to leverage the best cost characteristics of both technologies, with 100% availability. The output produced is several hundred degrees above what is possible with conventional light water reactor technology and is produced with little CO2 emissions.

Competitive and Stable Long-term Energy Prices
Because HTGR nuclear fuel cost is projected to be consistent with today’s commercial nuclear fuel (accounting for <20% of total production costs13) and is purchased for multi-year capabilities, it is largely immune to volatility in pricing and market swings; largely in opposition to natural gas for industrial production where ~70% of the operational costs are tied to fuel.

Air-cooling
The HTGR can effectively use air-cooled condensing for electric power generation as return temperatures are high enough that reasonable power generation efficiencies can be sustained in arid, high ambient temperature regions of the world where water is a critical limiting factor.

In many places, natural gas price is indexed to oil price and, even in North America, higher natural gas prices are likely by the mid-2020s based upon several important considerations. Projects are underway to export US LNG by reconfiguring import terminals to export capabilities — increased demand and export will eventually result in higher US prices due to international arbitrage. Additional natural gas-fired base load power generation and growth in industrial use will likely create an inelastic demand and associated volatile pricing. A move to natural gas as a transportation fuel is yet another likely inelastic demand that can lead to increased price volatility over the next decade.

WHY WOULD A NATIONAL POLICYMAKER BE INTERESTED IN THIS TECHNOLOGY?
Growth in the Economy and Jobs
NIA’s market analysis indicates that within the first 25 years of application in the United States and the Alberta oil sands industry, nearly $1 trillion in GDP could be generated. HTGRs are particularly well suited for both small to medium and developing countries, with scalable modular deployment and superior safety characteristics that do not rely on intervention of any systems or people to safely avoid major events during operation. It would be an obvious stepping stone for application of nuclear technology in countries that do not have the same infrastructure (academic, regulatory, etc.) that the United States, Europe, Japan and ROK have. Altogether, this translates into profitable growth in new market sectors for the nuclear energy system and 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 United States and other countries that choose to participate and engage this technology. China is already working toward deployment of a modular HTGR design that may compete globally. The
longer the United States delays the development of the HTGR technology, the greater the likelihood that countries like China become the world leaders in HTGR technology and take the majority of the economic benefits from this Intrinsically safe nuclear technology.

**Energy Price Stability**
The HTGR energy pricing is expected to be stable over an operational plant life of more than 60 years because <20% of the energy cost is tied to the fuel. By supplanting natural gas and other fossil fuels for producing heat, the modular HTGR provides insulation from energy price variability.

**Alternative Uses for Indigenous Carbon Resources and Improving Energy Security**
HTGR technology provides an attractive path to take advantage of indigenous carbon (coal, pet coke, municipal solid waste, etc.) by gasifying the carbon with coproduction of hydrogen, all using an advanced process heat version of HTGR technology, resulting in chemical feedstock or transportation fuels. For example, 31 coal to liquids conversion plants (50 Kbbbl /day/plant) can convert the entire annual Kentucky coal output to displace US import demand today with minimal CO2 emissions\(^\text{14}\). This improves both energy security and independence.

**Minimizes CO2 Emissions**
Unique within nuclear, the modular HTGR is the only CO2-reducing technology on the foreseeable horizon for supplanting fossil fuels in the production of high temperature process heat. The end-user community within NIA envisions a path that would eliminate as much as 80% of its CO2 emissions with HTGR technology. Substantially lower CO2 emissions cannot be achieved without bold technology advances. Environmental factors range from incremental advantages associated with fuel use, waste management, land use, and cooling water requirements.

**Minimizes Water Usage**
The high thermal efficiency of modular HTGR technology can make use of dry cooling as an economic alternative where water is limited.

**Waste Water Cleanup and Desalination**
Fresh, clean water using SC-HTGR heat can provide a sustainable water supply in regions of the world where water is limited or contaminated. Desalination using SC-HTGR technology provides a near-term approach using existing technology to cleanup or expand the existing water capacity. Cogeneration of electricity can also provide a source of power for remote locations using micro-grids or traditional electric transmission grids to transport power to load centers.
COMMERICALIZATION STRATEGY

To achieve a commercially viable energy supply technology, several actions must take place: 1) completing HTGR technology development; 2) completing design development; 3) establishing licensing and regulatory requirements; 4) developing supply infrastructure; and 5) constructing and deploying demonstration module and the first-of-a-kind (FOAK) plant.

COMPLETING HTGR TECHNOLOGY DEVELOPMENT
The development activities for nuclear fuel, graphite structural materials, high temperature metals and composite materials, and contemporary analytical methods must be completed. Current development activities are being led by INL and are founded on the past design and qualification work on similar nuclear technologies.

COMPLETING DESIGN DEVELOPMENT
The development activities for the reference prismatic reactor concept and a Rankine cycle steam plant capable of cogenerating process heat (as steam) and electricity must be completed.

ESTABLISHING LICENSING AND REGULATORY REQUIREMENTS
A licensing plan is needed that continues the pre-application iterative process of collaboratively working with the NRC to establish the regulatory performance and design requirements for modular HTGRs. Licensing efforts continue into the preparation of a license application for a selected site based on the design being developed for the reference concept.

DEVELOPING SUPPLY INFRASTRUCTURE
Establish a supply chain for nuclear fuel, graphite, and other major equipment to support construction and operation of the demonstration and follow-on plants.

CONSTRUCTING AND DEPLOYING DEMONSTRATION MODULE AND FOAK PLANT
The demonstration will consist of the initial single reactor module to confirm technology and licensing implementation. This is then expanded to a multiple module FOAK plant.
NIA is leading the industry effort to develop modular HTGR technology and anticipates a structure for the enterprise to commercialize this technology as a small modular reactor (SMR) concept summarized below. This structure includes equity investment opportunities that are expected to realize long-term and continuing returns as the HTGR technology is widely adopted across the globe. Each of the activities envelopes some or all of the components of the commercialization strategy described above.

**OVERALL STRUCTURE**

**Development Venture**
A joint venture led by the Nuclear System Supplier (NSS) with the Prospective Owner/Operator (Owner). Equity investors are anticipated to include NSSs, energy producers (e.g., utilities, power-generating companies, independent power/energy producers), vendors of major equipment and materials, governments, industrial energy end-users, and other equity investors. The NSS will lead completion of technology development and perform design development through preliminary design. The Owner will lead completion of pre-application activities with the NRC and lead and implement the licensing plan including: preparation of license application; supporting the Deployment Project (e.g., an Early Site Permit application, environmental and safety report submittals); construction permits and field applications; and other required application submittals, including FOAK HTGR licensing documents and a reference combined Construction and Operating License Application (rCOLA)\(^5\), if 10 CFR Part 52 is the chosen licensing approach.

**Deployment Project**
A joint venture led by the Owner for procurement, construction and operation of the FOAK plant. Equity investors are anticipated to include energy producers, municipalities, architect-engineers/constructors (AE/C) and industrial energy end-users. The Owner and/or the designated Operator will lead and implement the project management plan. They will lead final site and plant licensing submittals and hold the operating license; the NSS and the AE/C will complete the final design; and the AE/C will manage construction.

**Infrastructure Framework**
Activities to establish a supply chain for nuclear fuel, graphite and major equipment that can be matured to support construction and operation of the demonstration and follow-on HTGR plants. The structure of this procurement management plan and the activities will depend on the extent to which the NSS elects to be the supplier versus purchasing from others. It is anticipated that nuclear fuel production capability will be developed as part of the Development Venture. Initial indications are that the graphite and major equipment vendors will make the necessary investments.

**Technology Expansion Program**
Activities to pursue advanced and alternative technologies to broaden the initial market for HTGR technology. This could include alternate HTGR designs, engineered improvements and technology advances such as higher temperature materials, gas-to-gas heat exchangers, and a high-efficiency hydrogen production capability. Advanced HTGR plant designs will support higher temperature process heat needs and the production of hydrogen, essential to the carbon-conversion technologies. There are several carbon-conversion technologies that could be economically integrated with HTGRs. This is envisioned as a separate and subsequent investment after the successful demonstration and deployment of the SC-HTGR, thus not an integral component to the initial Development Venture.

**Program Direction**
Activities led by NIA to ensure appropriate direction and overall integration for commercialization of HTGR technology. NIA will lead activities to improve the understanding of market opportunities and associated economics. We anticipate that membership will expand to include at least each of the entities represented in the above activities.
Investment in the development or deployment venture will be negotiated to ensure the terms are equitable and acceptable to all parties. Arrangements regarding IP ownership, rights, and use would be made between the specific IP holder and the interested investor. Other arrangements, including contributions in kind (materials, components, applied time) would be considered as a part of any negotiation.

**ESTIMATED COSTS**

The estimated costs (2014 USD) to complete each of the Enterprise activities are summarized as follows:

<table>
<thead>
<tr>
<th>Development Venture</th>
<th>$ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology development</td>
<td>245</td>
</tr>
<tr>
<td>Conceptual/preliminary design</td>
<td>280</td>
</tr>
<tr>
<td>Final design</td>
<td>200</td>
</tr>
<tr>
<td>Licensing through preparation of application[^16]</td>
<td>165</td>
</tr>
<tr>
<td>Inspections, testing, and modifications</td>
<td>75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deployment Project</th>
<th>$ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete site-specific design</td>
<td>100</td>
</tr>
<tr>
<td>Construction permit/license application/review</td>
<td>65</td>
</tr>
<tr>
<td>Equipment procurement</td>
<td>432</td>
</tr>
<tr>
<td>Construction</td>
<td>625</td>
</tr>
<tr>
<td>Startup and testing[^17]</td>
<td>55</td>
</tr>
<tr>
<td>Initial operations (3 years)</td>
<td>348</td>
</tr>
<tr>
<td>Revenue (initial 3 years)</td>
<td>-265</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infrastructure Framework</th>
<th>$ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear fuel production facility</td>
<td>440</td>
</tr>
<tr>
<td>Equipment and infrastructure development</td>
<td>648</td>
</tr>
<tr>
<td>Graphite production facility</td>
<td>150</td>
</tr>
<tr>
<td>Technology Expansion Examples[^18]</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Future—Second-Generation Product</th>
<th>$ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intermediate HX</td>
<td>100</td>
</tr>
<tr>
<td>Hydrogen production</td>
<td>200</td>
</tr>
<tr>
<td>Higher-temperature materials</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Program Direction</th>
<th>$ millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program support</td>
<td>90</td>
</tr>
</tbody>
</table>

These costs were developed by: 1) reconciliation of cost estimates prepared by several NIA pre-conceptual design teams; 2) incorporation of modifications to those estimates made over the subsequent years wherein the objectives for the HTGR were redefined; and 3) utilization of historical cost estimates for similar plants. Subsequently, AREVA North America performed an independent estimate for the specific design concept selected by NIA. AREVA’s estimate validated the costs with a confidence level of 95%.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>HTGR Development and Deployment</td>
<td></td>
</tr>
<tr>
<td>Research and Development</td>
<td></td>
</tr>
<tr>
<td>Licensing - FOAK Plant and DC</td>
<td></td>
</tr>
<tr>
<td>Pre-application Review</td>
<td></td>
</tr>
<tr>
<td>CP Application and Review</td>
<td></td>
</tr>
<tr>
<td>CP Issued</td>
<td></td>
</tr>
<tr>
<td>OL Application and Review</td>
<td></td>
</tr>
<tr>
<td>Fuel Load and Initial OL Issued (Module 1)</td>
<td></td>
</tr>
<tr>
<td>Test and Verification of Safety Features</td>
<td></td>
</tr>
<tr>
<td>Full OL Issued (Module 1)</td>
<td></td>
</tr>
<tr>
<td>DC Application and Review</td>
<td></td>
</tr>
<tr>
<td>DC Issued</td>
<td></td>
</tr>
<tr>
<td>Ref COL Application and Review (Module 2,3,4)</td>
<td></td>
</tr>
<tr>
<td>COL Issued</td>
<td></td>
</tr>
<tr>
<td>ITAAC Review</td>
<td></td>
</tr>
<tr>
<td>FOAK Plant Deployment</td>
<td></td>
</tr>
<tr>
<td>Conceptual Design</td>
<td></td>
</tr>
<tr>
<td>Preliminary Design</td>
<td></td>
</tr>
<tr>
<td>Final Design</td>
<td></td>
</tr>
<tr>
<td>Procurement</td>
<td></td>
</tr>
<tr>
<td>Construction and Startup Testing (Module 1)</td>
<td></td>
</tr>
<tr>
<td>First Module Operational</td>
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<tr>
<td>Second Module Deployment</td>
<td></td>
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<tr>
<td>Third Module Deployment</td>
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</tr>
<tr>
<td>Fourth Module Deployment</td>
<td></td>
</tr>
<tr>
<td>HTGR Plant Fully Operational</td>
<td></td>
</tr>
</tbody>
</table>
The potential consequences for three key areas of overall risk that are critical to the success of the Enterprise are identified below. Executing risk mitigation activities and managing residual risk are essential for success.

TECHNOLOGY DEVELOPMENT
This includes the ongoing development of fuel and materials, and design support activities, such as codification in consensus technical standards and providing technical support for development of a regulatory framework via pre-application licensing activities. Currently, only about one-half of the Research and Development (R&D) necessary to support licensing and commissioning of the first module is scheduled and funded.

Risk mitigation
- Use INL/EXT-11-23907, NGNP Project — 2011 Status and Path Forward, December 2011, and detailed development plan references therein. This constitutes a comprehensive plan for the remaining technical technology development activities.
- Full funding for the remaining R&D

Residual risk probability and impact are classified as low
- Unanticipated technical issues or untimely processing and acceptance of code cases by consensus standards committees and/or NRC

NUCLEAR FACILITY LICENSING
While the safety attributes of the HTGR represent an important asset that argues for ultimate success, there are a number of risks that must be considered. This includes ongoing pre-licensing application interactions with the NRC developing the regulatory technical requirements and review processes for HTGR technology. The development of this licensing framework for the HTGR requires changes to existing regulatory frameworks that have evolved primarily for light water reactor technology. The framework is needed for certification of the HTGR reactor design as well as site licensing requirements for location of the reactor near industrial facilities. Progress on and the credibility of this developing framework is essential to beginning detailed design work with an acceptable business risk.

Risk mitigation
- Next Generation Nuclear Plant Licensing Strategy — a report to Congress, August 2008. This report, prepared jointly by NRC and DOE, summarizes the preferred licensing development approach and necessary regulatory resources.
- PLN-3202, NGNP Licensing Plan, June 26, 2009. A detailed implementation plan prepared by INL for DOE that was in effect through 2012.
- Aggressive pre-application activities with NRC to adapt/augment current regulatory requirements for applicability to HTGR technology continued from 2009 through the first quarter of 2013.
- NIA conducted a regulatory risk assessment in 2013 that prioritized licensing risk mitigation measures based on a hybrid strategy that utilized 10 CFR Part 50 and 10 CFR Part 52 to obtain construction permit and commercial licensing of an initial four reactor module plant in addition to design certification for subsequent commercial units.
- NRC Assessment of Key HTGR Licensing Issues (ML-13220A176) — The NRC issued an assessment report on several white papers prepared by DOE/INL on key HTGR licensing issues. It concluded that “the NRC staff believes that DOE/INL's proposed approaches to the respective key issues are generally reasonable and are responsive to the Commission's Policy Statement on advanced reactors.”
- A licensing plan will be formulated under the Development Venture to incorporate the above risk mitigation information into a comprehensive plan. This plan will enable preparation of design and licensing documents and determine the licensing application requirements. It will provide
the approach that can best share the investment risk during technology development and for investors in the deployment projects.

**Residual Risk Probability And Impact Are Classified As High**
- While there is reasonable technical agreement with NRC staff, most of the most important issues require changes to extant NRC policies (e.g., emergency planning basis and use of risk-informed methodology for license basis event selection). These policies have not yet been taken to and addressed by the NRC Commissioners.
- NRC finalization of the requirements framework will not be fully complete until an operating license is issued.
- There is exposure to public hearings during the licensing and permitting process.
- Outstanding cross-cutting issues that impact commercialization for modular SMR designs.

**SUCCESSFUL EXECUTION OF INTERDEPENDENT ENTERPRISE ACTIVITIES**
Success in three of the Enterprise activities is highly interdependent (e.g., Development Venture; Deployment Project; Infrastructure Framework). As a consequence, investment, execution, and coordination among these activities and the involved companies and investors are paramount. A strong program management plan will be required and has been envisioned by NIA to support and direct program coordination.

**Risk mitigation**
- Preparation of this Business Plan for Commercialization
- Development of prospectus for Enterprise activities that provide a conceptual approach to an investment model and characterization of alternatives for return on investment
- Contractual vehicles and business arrangements are anticipated between the companies that lead each of the Enterprise activities and describe coordination between the investment ventures

**Residual risk probability and impact is classified as high**
- If assured funding path is not established comprising a barrier to investment, coordination, planning and execution of program activities will not move forward and the modular SC-HTGR will not reach commercialization.
Post-Fukushima, the HTGR is the first true Generation IV intrinsically safe and efficient reactor design that allows colocation with other industrial installations and the public. It dramatically reduces CO2 emissions from petrochemical production, petroleum refining, and extraction of bitumen from oil sands and shale, and in the production of electricity where it replaces traditional carbon fuels. It is economical today in Europe, Asia and the Middle East where natural gas price is tied to oil parity. NIA concludes that even US natural gas prices are likely to emerge in a range that will make this technology competitive for process heat and power in the 2020+ time frame as utilities, transportation and natural gas compete to arbitrage the current US price advantage. A carbon cost in the $50/ton range makes the HTGR competitive today in North America. Further, if the cost of oil reaches $130+ per-barrel in the 2020+ time frame, the HTGR also provides an economic approach to production of synthetic fuels from indigenous carbon sources with virtually no CO2 emissions. HTGR is a game-changing technology that can address energy policy goals of energy and feedstock security, economic growth, jobs, and CO2 emissions. Based on the current trajectory, if funding were sufficient to implement this business plan, HTGR technology could be deployed initially in the mid-2025 time frame increasing North American manufacturing and adding an estimated 60,000 jobs.

THE NORTH AMERICA SC-HTGR POTENTIAL MARKET IS:
- Petrochemical, Refinery, Fertilizer-Ammonia Plants, and Others
  Process: Cogeneration of electricity and process steam
  Market = 75 GWe (~125 steam cycle modules)
- Oil Sands/Oil Shale Gas
  Process: Steam, electricity, and water treatment
  Market = 18 GWe (~30 steam cycle modules)
- Electricity Generation
  Process: Independent Power Production Supply of Electricity
  Market: 110 GWe (~180 steam cycle modules)
- Hawaii Electricity Generation
  Market: 1 GWe (~2 steam cycle modules)
- Future Higher-Temperature Markets Utilizing Advanced Process Heat HTGRs:
  - Process: Hydrogen Merchant Production
    Market: 36 GWe (~6 steam modules and ~52 advanced process heat modules)
  - Process: Synthetic Fuels and Feedstock Production—US Transport Fuels
    Market: 249 GWe (~40 steam cycle modules and ~361 advanced process heat modules)
EXAMPLES OF THE INTERNATIONAL STEAM CYCLE POTENTIAL MARKET ARE REPRESENTED BY:

- Petrochemical, Refinery, Fertilizer/Ammonia Plants, and Others
  Process: Cogeneration of electricity and process steam
  Location: KSA Process Steam
  Market: 5 GWt (~8 steam cycle modules)

- Electricity Generation—Displacement of oil and LNG
  Location: KSA Electricity Generation
  Market: 12 GWt (~20 steam cycle modules)
  Location: Japan Electricity Generation
  Market: 51 GWt (~82 steam cycle modules)
  Location: ROK Electricity Generation
  Market: 16 GWt (~26 steam cycle modules)

FUTURE HIGHER-TEMPERATURE MARKETS UTILIZING ADVANCED PROCESS HEAT HTGRS:

- Location: Japan Process Heat
  Market: 40 GWt (~13 steam cycle modules and 51 advanced process heat modules)
- Location: ROK Process Heat
  Market: 20 GWt (~6 steam cycle modules and 26 advanced process heat modules)

INVESTMENT OPPORTUNITIES
Example investment scenarios and potential approaches are developed around the Enterprise Structure and described in more detail in the appendices of this plan.

Specifics regarding breakdown of scope, the investment framework, the interaction and interdependencies of these activities, investment risk, and the character of IP and other returns on investment are the subjects for detailed discussions with interested equity investors.
END NOTES

1 According to Organization for Economic Cooperation and Development (OECD).

2 Owned and operated by the Philadelphia Electric Company (later shortened first to PECO Energy and later to just PECO) NRC docketed by NRC (License No.: DPR-12 Docket No.: 50-171)

3 Owned and operated by Public Service Company of Colorado and granted an operating license by the Atomic Energy Commission (AEC) on December 21, 1973 (initial criticality on January 31, 1974)

4 INL/EXT-11-23907, NGNP Project. 2011 Status and Path Forward, December, 2011

5 Historical investment by the industry — see Next Generation Nuclear Plant Implementation Strategy (11/30/2009 section 3.3.1 attachment to letter to DOE Secretary Chu dated 11/30/2009 from NIA in response to FOA DE-FOA-0000149 issued 9/18/2009)

6 Report No. INL/EXT-11-23282, Revision 1 (October 2011), Next Generation Nuclear Plant Project Evaluation of Siting an HTGR Cogeneration Plant on an Operating Commercial Nuclear Power Plant Site

7 Assumes replacement of 50% of the existing cogeneration facilities with ratings in excess of 900 MWt (125 operating facilities) as they are retired due to increased natural gas prices and/or CO2 emission costs/regulation over the period 2025-2050

8 Report No. INL/EXT-11-23282, Revision 1 (October 2011), Next Generation Nuclear Plant Project Evaluation of Siting an HTGR Cogeneration Plant on an Operating Commercial Nuclear Power Plant Site

9 Report No. INL/EXT-11-23239 (October 2011), Integration of High Temperature Gas-cooled Reactor Technology with Oil Sands Processes

10 Assumes installation of six central energy facilities to provide the energy needs for 25% of the growth in the oil sands in-situ production that is projected over the period 2025-2050

11 $10/MMBtu equivalent natural gas price (higher than previously noted $6/MMBtu) is based on a capital construction cost multiplier for the Alberta oil sands region of ~1.7x

12 Assumes installation of ~45 GWe capacity over the period 2025-2050. This is about 10% of the nuclear electricity generation that would be required as replacement and/or alternatives to coal and natural gas based generation plants to meet emissions regulations such as those recently issued by EPA

13 Fuel cost includes: conversion — 2%; fabrication — 50%; waste fund — 8%; enrichment — 16%; uranium — 23%. Ref: AREVA

14 INL/EXT-12-26710, Revision 1, Options for Kentucky’s Energy Future, February 2013

15 The licensing plan prepared in the Development Venture will determine licensing requirements under NRC Regulations 10 CFR Part 50 (Domestic Licensing of Production and Utilization Facilities) or 10 CFR Part 52 (Licenses, Certifications, and Approvals for Nuclear Power Plants)

16 The licensing plan prepared in the product Development Venture will determine licensing requirements under NRC Regulations 10 CFR Part 50 (Domestic Licensing of Production and Utilization Facilities) or 10 CFR Part 52 ( Licenses, Certifications, and Approvals for Nuclear Power Plants)

17 Design certification is planned following first plant demonstration

18 Some funds may come through government DEVELOPMENT programs
ABOUT THE NGNP INDUSTRY ALLIANCE LIMITED AND ITS CURRENT MEMBERS

Member companies have joined in this alliance with the primary purpose to promote the development and commercialization of HTGR technologies through support of, and participation in, the DOE’s Next Generation Nuclear Plant (NGNP) Project. Our alliance represents the interests and views of our members that intend to mutually support and direct project plans to design, build, operate, and use the HTGR technology. We provide a forum and focus to communicate industry needs and requirements, and work in concert with the INL and others to seek out and promote industrial uses for HTGR technologies within the United States, North America, and other continents around the world.

AREVA supplies solutions for carbon-free power generation. Its expertise and know-how in this field are setting the standard, and its responsible development is anchored in a process of continuous improvement. As the global nuclear industry leader, AREVA’s unique integrated offer to utilities covers every stage of the fuel cycle, nuclear reactor design and construction, and related services. AREVA has designed, built, and operated HTGRs and is active in further development of the prismatic graphite block HTGR.

AREVA Federal Services offers a single face to the Department of Energy and other agencies for federal business, providing access to the full suite of AREVA competencies and global experience. Leveraging AREVA’s nuclear life cycle experience, AREVA Federal Services matches the evolving needs of the U.S. government with current and first-of-a-kind technologies that help meet the nation’s cleanup and closure needs, along with engineering solutions for dealing with used nuclear fuel, radioactive waste and advanced reactors and fuels.
ConocoPhillips is the world’s largest independent exploration and production (E&P) company based on production and proved reserves. ConocoPhillips explores for, produces, transports, and markets crude oil, bitumen, natural gas, natural gas liquids, and liquefied natural gas on a worldwide basis. Key focus areas include safely operating producing assets, executing existing major projects, and exploring for new resources in promising areas. Our portfolio includes legacy assets in North America, Europe, Asia, and Australia; growing North American shale and oil sands businesses; a number of major international development projects; and a global exploration program. ConocoPhillips conducts exploration activities in 18 countries and produces hydrocarbons in 13 countries as of December 31, 2013.

The Dow Chemical Company was founded in 1897 and combines the power of science and technology with the “Human Element” to passionately innovate what is essential to human progress. The company connects chemistry and innovation with the principles of sustainability to help address many of the world’s most challenging problems such as the need for clean water, renewable energy generation and conservation, and increasing agricultural productivity. Dow’s diversified industry-leading portfolio of specialty chemical, advanced materials, agro-sciences, and plastics businesses delivers a broad range of technology-based products and solutions.

Entergy Corporation is an integrated energy company engaged primarily in electric power production and retail distribution operations. Entergy owns and operates power plants with approximately 30,000 megawatts of electric- generating capacity, and it is the second-largest nuclear generator in the United States. Entergy delivers electricity to 2.8 million utility customers in Arkansas, Louisiana, Mississippi, and Texas. Entergy has annual revenues of more than $11 billion and approximately 15,000 employees. In 1999, as a part of the company’s unregulated growth strategy, Entergy began to grow the nuclear fleet by acquiring the first of six additional operating nuclear plants that provide electric power via long- term power agreements. Entergy has been one of the fastest-growing and successful nuclear companies in the nation and was recently ranked 7th in the world for nuclear electricity generation. Additionally, in 2003, a long-term management services contract was signed with Nebraska Public Power District for Entergy to support the management of the Cooper Nuclear Station in Nebraska. The Cooper contract was extended in 2010 to provide management support through 2028. Through its TLG Services Company, Entergy also provides decommissioning services for the industry. Other management, technical, and engineering services for the nuclear industry are provided by Entergy Nuclear Incorporated.

Excel Services Corporation specializes in providing operations, engineering, safety and regulatory services for energy and environmental projects worldwide. These specialized services include: License Renewal, Power Uprate, 24 Month Fuel Cycle Conversions, ITS Conversions, QA Solutions, Training, Spent Fuel Storage Licensing, New Plant Site Licensing, and Decommissioning. In its 30-year distinguished history, Excel has worked with every nuclear plant and most nuclear facilities in the United States, and has worked with many international facilities and organizations.

High Expectations International is a project management consulting company. We are focused on bringing our capabilities to the world by leveraging our experiences through collaborative endeavors with others. We provide support and expertise for projects, project management, business planning and management in a variety of business sectors and based upon sound management principles. Our consulting services are intended to pass along ‘lessons learned’ from years of experience that will enable others. We incorporated HEI with the mission to pass along what we’ve learned and help others continue to be successful and set high expectations for themselves and the people they live and work with. Strategic. Smart. Innovative. It is what we do! www.hei-llc.com

Manufacturing Excellence Consulting, Inc. specializes in helping companies improve their safety and reliability performance through assessment of and improvements in both culture and management systems. MEC Inc. also actively supports the efforts to commercialize the HTGR technology in the process heat and power industries.

Mersen is a global expert in materials and equipment for extreme environments and for the safety and reliability of electrical equipment. They are focused on serving expanding markets: energy, electronics, chemicals and pharmaceuticals, transportation, and process industries. Major product offerings are in: graphite anticorrosion equipment for the chemicals and pharmaceuticals industries; fuses for power semiconductors brushes and brush holders for electrical machinery; and high-temperature applications of isostatic graphite. Mersen has sales and/or manufacturing base in more than 40 countries.
The SGL Group—The Carbon Company is one of the worldwide leading manufacturers of carbon-based products. The company has an in-depth materials, production, applications, and engineering expertise; a comprehensive graphite and carbon fiber-based product portfolio; and an integrated value chain from carbon fibers to composites. SGL Group operates close to customers through a global sales network and state-of-the-art production sites in Europe, North America, and Asia.

StarCore Nuclear is a Canadian manufacturer of Small Modular Reactors designed for off-grid applications, including remote communities and mines. Our plant contains two independent cogeneration High-Temperature Gas Reactor units each producing (nominally) 10 MWe and 5 MWt super-heated steam, although these can be traded for specific applications. They use TRISO fuel in a Prismatic Core design, the same as the larger NGNP plant, and have a helium/nitrogen energy transfer system to an air-breathing load following turbine. Each StarCore plant also produces potable water, and StarCore's long-term mission is to bring clean safe energy, water, and hope to remote communities throughout the world.

Technology Insights is a consulting firm that specializes in assessing and supporting the development and deployment of emerging technologies related to energy generation, distribution, utilization, and management. The primary focus of the company is development and engineering support of the HTGR dating back to the late 1970s with its predecessor company, Gas-Cooled Reactor Associates.

Toyo Tanso Co., LTD. produces and sells isotropic graphite, other specialized carbon products, and carbon products for general industries. They also manufacture for-sale composite materials made from carbon and ceramic, metal, or organic materials. In addition, the company produces for-sale carbon electrode for fluorine electrolysis and business of surface treatment on various materials with fluorine gas.

Ultra Safe Nuclear Corporation (USNC) is participating in the development and commercialization of new “Ultra Safe” technology to enhance the robustness of nuclear reactors and nuclear fuels, including the Fully Ceramic Micro-encapsulated (FCM) TRISO-based fuel for advanced reactors. The company provides design and analysis services for fuel, core, and reactor systems on gas- and water-cooled reactors and has representation and technical contributors in the United States, Europe, and Asia.

Westinghouse Electric Company LLC is the world’s pioneering nuclear energy company and is a leading supplier of nuclear plant products and technologies to utilities throughout the world. Westinghouse supplied the world’s first pressurized water reactor in 1957 in Shippingport, PA, US. Today, Westinghouse technology is the basis for approximately one-half of the world’s operating nuclear plants, including 60% of those in the United States. Worldwide, the nearly 14,000 employees of Westinghouse Electric Company continue to pioneer value-added engineering and services creating success for our customers in their increasingly demanding markets. The four core product lines of Westinghouse—Nuclear Automation, Nuclear Fuel, Nuclear Services, and Nuclear Power Plants—support this mission. Through these core businesses, Westinghouse aims to serve the needs of utility, government, and industrial customers in nuclear power-related industries. Through alliances with customers, Westinghouse plays a key role in the design and implementation of integrated solutions.

The State of Wyoming: Wyoming’s mineral commodities include coal, natural gas, coal bed methane, crude oil, and trona. Wyoming is a major exporter of coal and natural gas in the United States. The HTGR presents a possible pathway for the state to grow its GDP by extracting more value from its mineral resources while being responsible stewards in managing carbon emissions.
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