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Identification and Significance of the Problem or Opportunity.

A recent study ordered by the Pentagon warns that the rising cost and dwindling supply of oil -- the lifeblood of fighter jets, warships, and tanks -- will make the US military's ability to respond to hot spots around the world "unsustainable in the long term."[1] The Pentagon's Office of Force Transformation and Resources, which is responsible for addressing future security challenges, commissioned LMI[2], a government - consulting firm, to produce the report. Called "Transforming the Way DoD Looks at Energy," the study is intended as a potential blueprint for a new military energy strategy and includes a detailed survey of potential alternatives to oil -- including synthetic fuels, renewable biofuels, ethanol, and biodiesel fuel as well as solar and wind power, among many others. The study concludes that all four branches of the military must "fundamentally transform" their assumptions about energy, including taking immediate steps toward fielding weapons systems and aircraft that run on alternative and renewable fuels. It is "imperative" that the Department of Defense "…apply new energy technologies that address alternative supply sources and efficient consumption across all aspects of military operations," according to the report.

Another study, by the JASONs, also reported on the need to reduce DoD fossil fuel dependence[3]. The JASON report states that: *a.) Even though fuel is only a relatively small fraction of the total DoD budget, there are several compelling reasons to minimize DoD fuel use. b.) Fuel use is characterized by large multipliers and co-factors: at the simplest level, it takes fuel to deliver fuel. c.) Fuel use imposes large logistical burdens, operational constraints and liabilities, and vulnerabilities: otherwise capable offensive forces can be countered by attacking more-vulnerable logistical-supply chains. Part of this is because of changes in military doctrine. In the past, we used to talk of the "front line," because we used to talk of the line that was sweeping ahead, leaving relatively safe terrain behind. This is no longer true.* ***The rear is now vulnerable, especially the fuel supply line.*** *d.) There are anticipated, and some already*

[1] Bryan Bender, Boston Globe May 1, 2007
[2] LMI Government Consulting 2000 Corporate Ridge, McLean, Virginia 22102-7805
[3] Reducing DoD Fossil-Fuel Dependence, JSR-06-135, The MITRE Corporation, 7515 Colshire Drive, McLean, Virginia 22102-7508 September 2006

imposed, environmental regulations and constraints. Not least, because of the long life of many DoD systems. e.) Uncertainties about an unpredictable future make it advisable to decrease DoD fuel use to minimize exposure and vulnerability to potential unforeseen disruptions in world and domestic supply." (The emphasis above is added.)

Together, fuel and water account for more than 80% of all logistics delivered to troops in Operation Iraqi Freedom. Certainly, *in-situ* production of potable water and transportation fuel would be a very effective means to reduce the logistic needs of Army at Forward Operating Bases. The principal objective of this SBIR project is to investigate means to produce potable water and liquid hydrocarbon fuel from atmospheric CO_2 and water with energy sources that do not generate any net CO_2 emissions. The purpose is to provide an independent supply of water and liquid fuels for military vehicles and equipment in the field, using transportable process equipment.

Phase I Technical Objectives.

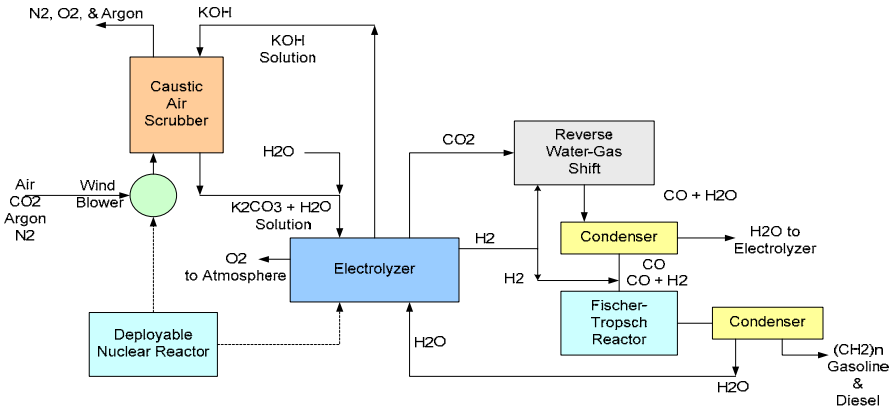
Background

The ability to generate liquid hydrocarbon transportation fuels, i.e. gasoline and diesel, from air and water has a very compelling strategic value and several methods have been proposed to accomplish this. The following describes three of the methods and discusses their applicability to the Army strategic requirements.

1. **Absorption of atmospheric CO_2 in alkaline solution**. Carbon dioxide can be absorbed in aqueous alkaline sodium or potassium hydroxide (NaOH or KOH) to form sodium or potassium carbonate (Na_2CO_3 or K_2CO_3)[4]. Early discussion of this method assumed a nuclear power system would be used as an external energy source[5]. The aqueous carbonate solution would be subjected to electrolysis to recover the CO_2 and to produce hydrogen. Carbon dioxide and oxygen would be generated in the anode compartment of the electrolytic cell and hydrogen in the cathode compartment. The hydrogen and CO_2

[4] M. M. Halmann and M. Steinberg, "Greenhouse Gas Carbon Mitigation, Science and Technology", pp136-9, Lewis Publishers & CRC Press LLC, Baton Rouge, FL (1999).
[5] M. Steinberg, "Synthetic Carbonaceous Fuels and Feedstocks", U.S. Patent 4,197,421 (April 8, 1980).

could then be catalytically converted to gasoline type $(CH_2)_n$ fuel for Army vehicles. An advantage of the electrolysis of carbonate solution is that hydrogen and CO_2 are produced efficiently in one unit operation.



	REACTIONS	ΔH, kcal/g mol
1) Caustic/Air Absorber	2KOH + CO2 = K2CO3 + H2O	-
2) CO2 Separation from Air	K2CO3 + CO2 + H2O = 2KHCO3	-
3) Electrolysis of Carbonate Solution	K2CO3 + 4H2O = 2KOH + 3H2 + CO2 + 1.5O2	+ 204.0
4) Reverse Shift Reactor	CO2 + H2 = CO + H2O	0.0
5) Fischer-Tropsch Synthesis	CO + 2H2 = CH2 + H2O	- 49.0
OVERALL REACTION	CO2 + H2O = CH2 + 1.5O2	+ 155.0

Figure 1. Synthetic liquid hydrocarbon transportation fuel from nuclear power, air and water (integrated process).

However, for Army use there are several disadvantages to this method. Because this method is a condensed liquid absorption system, the requirement of contacting large quantities of air through aqueous media can result either in evaporation from or condensation to water in the carbonate solution, depending on the humidity of the air. Water management thus becomes a most important factor for Army applications. At low air humidity (25% or less) and moderate temperature, water will evaporate and will have to be made up by other methods for extraction from the atmosphere.

An example of the magnitude of the evaporative loss is estimated as follows. Assume the average relative humidity and air temperature is 23% and 100° F, respectively (average summer Iraq conditions). To produce a minimum of 5000 gpd of liquid hydrocarbon fuel

requires 50 t/d CO_2 recovered from air at 400 ppm CO_2 concentration and 60 t/d H_2O recovered from air for producing the necessary hydrogen. The volume of air needed to recover the 50 t/d CO_2 is equal to 180 million lbs of air/day. The water content in air at 100° F and 23% relative humidity is 0.0099 lbs water/lb dry air while the saturated content at 100° F is 0.04305 lbs water/lb dry air.

Thus the amount of water evaporated,

= 180 x 106 lbs air/day x (0.04305 - 0.0099/2000 lbs,
= 2,850 tons/day.

With evaporation cooling of the aqueous solution and air to 80° F, it would still cause a loss of 1000 tons/day. This is at least 60 times more water lost than the water needed to generate the hydrogen from the process. The water evaporated would have to be recovered from the air and returned to the aqueous absorbing solution to prevent precipitation of the caustic solute, which greatly complicates the process.

2. **Enzyme extraction of atmospheric CO_2**[6,7]. Carbozyme, a New Jersey company, has developed a method for extracting and concentrating CO_2 from fossil fuel fired power plant stacks using a modified natural enzyme membrane. It is also recommending the application of this method to extraction of CO_2 from the atmosphere. In this method, the atmospheric humidity is again, a very important factor. There is some concern that at low humidity and low CO_2 concentration, the enzyme can be dried out and become inefficient in extracting CO_2. Methods for simultaneous recovery of water and CO_2 from the atmosphere while maintaining moisture content of the enzyme membrane need investigation and development.

3. **Adsorption of CO_2 on molecular sieves**. This method is used to remove both CO_2 and water vapor from the atmosphere in air liquefaction plants prior to cryogenic oxygen production from the air. First, alumina adsorbent is used to remove the water from the air

[6] Trachtenberg, M. C., Private Communication, Carbozyme, Inc., Monmouth Junction, New Jersey (2006).
[7] http://www.carbozyme.us/

and then a molecular sieve (zeolite) is used to extract the CO_2. It is necessary to remove the water first for assuring efficient removal of CO_2 from the air by the zeolite. However, in the air liquefaction plant, the CO_2 and water are not recovered in concentrated form. The water and CO_2 are desorbed from the adsorbent by blowing the effluent waste nitrogen through the beds, thus diluting the CO_2 and H_2O. In order to recover the adsorbed CO_2 and H_2O in concentrated form, it will be necessary to heat the beds to drive the water and CO_2 out of the bed without the use of the carrier diluent nitrogen gas. The advantage of this method compared to the other two is that the water management over a wide range of atmospheric humidity conditions is simpler and direct: There are no losses or gains. The water is directly recovered from the air and then the water is desorbed from the adsorbent and recovered. Excess water is separated from the CO_2 by condensation for general Army use. In the Phase I study, this method will be investigated in depth and compared to the enzyme extraction method to determine the best choice for further development for Army field use.

Technical Approach

Figure 2 illustrates one of the first attempts at extraction of CO_2 from the atmosphere and converting it to fuel. The method was first described in the 1980 patent by M. Steinberg[5]. The general process described in the patent is to utilize electrical power from a small nuclear reactor to: 1) capture and recover the 385 ppm by volume of CO_2 existing in the atmosphere using physical and chemical means; 2) electrolyze water to produce hydrogen; and 3) combine the H_2 and CO_2, to produce the synthetic liquid hydrocarbon fuel. The CO_2 would first be shifted to CO by the water gas shift reaction and then combined with H_2 to produce synthetic fuel using a catalyzed Fischer-Tropsch (F-T) reaction. An alternative to F-T is a catalytic methanol reactor and dehydration to the hydrocarbon synthetic fuel.

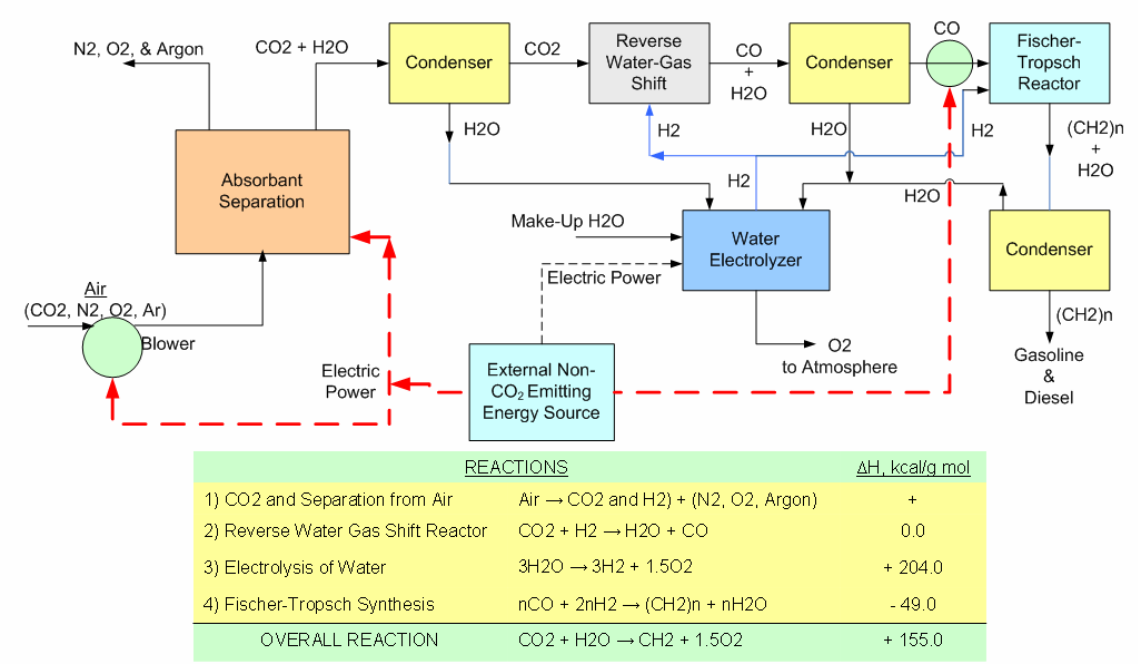


Figure 2. Synthetic liquid hydrocarbon transport fuel from external power, air and water. (From the patent by M. Steinberg.)

Figure 2 shows an integrated process where the CO_2 capture step is integrated with the electrolyzer operation for hydrogen production. The method uses the reverse water gas shift to convert CO_2 to CO by reaction with H_2. The feed stream to the Fischer-Tropsch reaction vessel is adjusted to a H_2/CO ratio of 2/1 for conversion to the liquid $(CH_2)_n$ hydrocarbon product (gasoline and diesel).

The minimum energy (100% thermodynamic efficiency) required to separate CO_2 from the atmosphere at 385 ppm CO_2 by volume, is given by the change of Gibbs Free Energy,

$$\Delta G = -RT\ln K,$$

where G is the Gibbs free energy, R is the gas constant, T is the temperature and $K = P_0/P_f$, the equilibrium constant for the reaction, is the ratio of initial and final concentration, P_0 and P_f, respectively. Inserting the initial and final concentrations into this equation gives,

$$\Delta G = - 4.575 \ln (385 * 10^{-6})$$
$$= 0.056 kWH / lbCO_2 .$$

A preliminary assessment of various methods of CO_2 separation from the relatively high concentrations found in power plant stack gases, based on actual energy requirements, is given in Table 1[8].

Table 1. Energy Requirements to Remove and Recover CO_2 from Coal Fired Power Plants. Basis = ~ 13 vol % CO_2 initial concentration 90% recovery of CO_2.

	Process	kWH/lb CO2
1.	Amine Absorption/Stripping	0.27
2.	Potassium Carbonate Absorption/Stripping	0.32
3.	Molecular Sieve Absorption/Stripping	0.40
4.	Refrigeration	0.40
5.	Membrane Separation	0.26

The values range from 0.26 to 0.40 kWH/lb of CO_2 recovered. The actual energy is thus as much as 5 to 10 times the thermodynamic value. Based on the thermodynamic log ratio of pressure between the CO_2 average concentration of ~ 13% for stack gases compared with 385 ppm in the atmosphere, the amount of energy to extract CO_2 from the atmosphere should be a factor of 3.8 times greater than the energy to extract CO_2 from stack gases. This results in an estimated 1.0 to 1.5 kWH/lb of CO_2 to extract CO_2 from the atmosphere.

For the non-liquid methods of extracting CO_2 from the atmosphere, the choices are the solid absorbent molecular sieve approach, membrane separation, or enzyme methods. An example of an industrial process where it is necessary to remove CO_2 from air before processing gas is the cryogenic air separation plant for liquid oxygen production. Prior to low temperature oxygen separation, to prevent ice formation the CO_2 and H_2O are separated from the air by molecular sieve absorption. The CO_2 is then discarded to the atmosphere by a nitrogen backflow stripping

[8] S. Stucki, A. Schuler, and M. Constantinescu, "Coupled CO2 Recovery from the Atmosphere and Water Electrolysis; Feasibility of a New Process for Hydrogen Storage", Int. J. Hydrogen Energy, 20, 653-666 (1995).

the CO_2 out of the absorbent. Liquid oxygen plants can generate as much as 3000 tons per day of liquid oxygen in one unit. This indicates that as much as 8.8 tons per day of CO_2 are removed in large oxygen plants. To produce liquid fuels based on combining CO_2 from the atmosphere with H_2 with a capacity of ~ 5000 gallons per day, a CO_2 separation system with about 6 times as much capacity would be required. Handling the large flows of air required may be accomplished with the help of natural wind movements in the field. Low pressure drop packing in natural convection towers is desirable to minimize electric power requirements by blowers for Army field operations.

A membrane extraction method has been used by NASA in space capsules to remove CO_2 for life support systems. A proprietary method based on the NASA approach for CO_2 recovery is under development by another company[7]. They are developing a technique for impregnating enzymes on nanotube carbon fibers to provide a large surface area for extracting the CO_2 and achieve rapid air flow. If BTG can obtain their approval to cooperate, we will evaluate the system they have under development together with the molecular sieve method discussed above. The result of the evaluation will determine the choice of method to be developed in the Phase II research.

In addition to CO_2 removal from the atmosphere, the other systems we will evaluate in the Phase I study are high efficiency high temperature electrolysis equipment and advanced F-T processor technology currently under development by Velocys Corporation of Plain City Ohio[9]. These three components will be studied in the Phase I research to determine their individual and system performance.

Phase I Work Plan.

The Phase I work plan is designed to:

1. Evaluate the power efficiency, system weight and system volume of the molecular sieve and enzyme methods of CO_2 extraction from the atmosphere.

[9] Velocys, Inc. 7950 Corporate Boulevard Plain City, Ohio 43064

2. Evaluate advanced high efficiency electrolysis systems and advanced F-T technology. The extraction methods will be evaluated based on weight, cost, efficiency, and readiness for Army field applications.
3. Determine minimum mission duration based on weight, volume and transportability.

Specific Tasks that will be performed are:

Task 1. Perform a detailed process design for extraction of CO_2 and water from the atmosphere based on process equipment data from available reports and suppliers. A process flowsheet will be produced. Mass and energy balances will be made. The process will be designed for production of a minimum capacity of 5000 gallons per day of liquid hydrocarbon fuel.

Task 2. An appropriate enzyme or alumina and zeolite adsorption reactor will be designed to separate CO_2 and H_2O from the atmosphere. A range of humidity conditions will be used from 10% R.H. to about 50% and temperatures from about -20° F to 100° F. A second, regenerative heat transfer method of heat transfer will be studied to determine if it offers advantages over the use of alumina.

Task 3. A detailed design of the CO_2 and H_2O adsorber will be made and estimates of the size and weight of the unit will be obtained. The adsorber will be optimized to minimize the weight of the unit for transportation of equipment to the field. The size and weight of the other units of the hydrocarbon fuel process will also be made. Computer programs will be used to model the process and verify the design. If the humidity is too high and the quantity of water removed is excessive, then consideration will be given to a head-end system of dehumidifying the air by a regenerative heat exchanger system recently developed.[4] Additional data on the alternative enzyme method of extraction will be obtained from the developer of that method and the results will be compared with the molecular sieve method of CO_2 extraction.

Task 4. Information on advanced electrolysis systems will be obtained from the literature. Detailed information on advanced F-T technology will be obtained by visiting the operation in Ohio to obtain a briefing on the readiness and important weight and size parameters. BTG will negotiate to obtain a Memorandum of Understanding with Velocys to cooperate in the Phase II research to develop a working scaled model of the complete fuel production system.

Task 5. Define experiments to be carried out in Phase II to verify operational capability of an adsorber demonstration unit for providing CO_2 and hydrogen for production of synthetic hydrocarbon fuel.

The Table below illustrates the proposed workflow.

	Month					
Description	1	2	3	4	5	6
Study extraction of CO2 and water						
Evaluate enzyme method of CO2 extraction						
Evaluate molecular sieve method of CO2 extraction						
Determine size, costs and weights of systems						
Compare methods						
Make process flowsheet						
Mass and energy balance						
Obtain information on advanced electrolysis systems						
Obtain information on advanced F-T systems						
Define experiments to be carried out in Phase II						
Write Final Report						

Based on the work performed in Phase I, the adsorber process will be further developed in the Phase II study. In particular, in the Phase II, a laboratory prototype demonstration unit of the adsorber unit developed in Phase I will be designed and constructed specifically for the production of CO_2 and water. These are the feedstock for the electrolyzer and shift reactor, which together produce the synthesis gas (CO and H_2) for the catalytic production of liquid hydrocarbon fuel. The high temperature electrolyzer and catalytic converter would be based on existing suppliers such as Ceramatec[10] and Velocys respectively. The main design, construction and operation effort in Phase II will involve tests for the extraction of CO_2 and water from the atmosphere.

The Phase I studies will be carried out at BTG offices in Long Island New York. There are several options for where the Phase II research will be carried out. The options include the

[10] http://www.ceramatec.com/

University of Texas at Austin where BTG has an ongoing collaboration on advanced energy systems for Army EM weapons program or we will utilize the facilities of Ktech Corporation, a partner company located in Albuquerque, NM that specializes in advanced technologies for the Defense Department. The choice of location for the Phase II research will be made based on the result of the Phase I research.

Related Work.

BTG is developing technologies for deployable nuclear reactors for use in remote locations, national disasters, and other emergencies. The sealed reactors are designed with an integral conformal shield that makes it possible to deliver and setup the power system in a matter of days and to completely remove it within a few days after it is shut down and allowed to cool. The availability of power produced by the reactor makes it possible to produce potable water, fertilizer, and transportation fuel. In addition, the energy from the reactor can be used as a driver for various forms of electromagnetic weapons, both defensive and offensive. A still open Phase II DOD Army SBIR funds the project.

Meyer Steinberg, an employee of BTG, has published more than 40 articles on capture and sequestration of CO_2 and co-authored the book titled, Greenhouse Gas Carbon Dioxide Mitigation: Science and Technology[11]. The company has filed for patents on the reactor designs and is currently seeking venture capital to commercialize the technology.

In addition, BTG has investigated the use of solar power to extract potable water from the atmosphere for use by deployed troops. That research project, which was submitted to the U.S. Army Research Laboratory, proposed to investigate means to produce a large portion of the potable water requirements of forward based troops using solar energy to generate electrical power, which in turn would operate dehumidifier equipment to directly condense water vapor from the atmosphere. The solar panels and condenser equipment would be lightweight, readily transportable by truck or helicopter to the forward base, and quickly set up. Preliminary estimates suggest that a photovoltaic panel area of ~ 2500 square meters (~150' x 150') could

[11] Martin M. Halmann, Meyer Steinberg, Greenhouse Gas Carbon Dioxide Mitigation: Science and Technology, Publisher: CRC Press, Pub. Date: November 1998, ISBN-13: 9781566702843.

supply potable water for 1000 soldiers at a rate of 10 liters per soldier per day, even in Iraq where air temperatures are 105° F and the relative humidity is only 23% (average summer conditions in Iraq).

Dr. Powell and Dr. Farrell have published more than five recent papers on production of essential supplies for use in military or emergency operations including water and transportation fuel. The company has filed preliminary patents to commercialize some of the technologies.

Relationship with Future Research or Research and Development.

For the past eight years, BTG has concentrated its DOD research activities on advanced high energy density systems for military and other National Security applications. Our projects include direct conversion of energy from nuclear isomers and radioisotopes and design and application of compact, deployable nuclear and solar-based energy systems. While these projects would provide a basic source of energy in the form of heat or electricity, the Army needs potable water and transportation fuel (JP8) produced on-site to fully exploit the availability of the large amounts of energy produced by these systems. Use of this energy to extract water and CO_2 from the atmosphere and convert it to potable water and fuel is a natural progression of our technology. If the proposed approach is successful in supplying up to 5000 gallons per day of transportation fuel using resources available everywhere and a non-CO_2 based energy source, it would greatly reduce the logistic requirements of fuel and water for certain brigade scale operations and in doing so, would save lives, free logistic support troops to perform other operations, reduce cost and improve reliability of water and fuel supply.

The Phase I research will model and analyze the enzyme extraction and molecular sieve processes for a range of atmospheric conditions to determine the expected efficiency, size, volume, cost and weights of components to achieve the specified goal. The minimum duration of mission to justify the transport and setup of the equipment based on the effort needed to transport conventional water and fuel will be studied. The results of these studies will determine which of the two candidate approaches will best serve the Army needs and under what conditions. This is an essential step to provide a foundation for the Phase II research and development effort.

Commercialization Strategy.

Assuming the lab and demonstration work in Phases I and II are successful and the Army need is justified, BTG will seek an industry partner to apply the process in the field for the Army. Commercial applications of the process may also have value, for example, in remote areas where the costs of hydrocarbon fuels are very expensive. The company is currently working with First American people in Nunavet, Canada with regard to deployable nuclear reactors. The ability to produce transportation fuel in addition to process heat and electricity is of great importance to them.

The process also has environmental benefits in eliminating net CO_2 emission from petroleum based fuels and thus fits in with the long-range goal of reducing global warming. CO_2 removal from the atmosphere followed by sequestration is another global warming justification for developing this technology.

BTG will file for patents on the technologies developed in this SBIR and will seek to either license the technology or develop it further through joint ventures with larger companies.

Key Personnel.

There are three key persons who will contribute in the Phase I study. They are James Powell, the Principal Investigator for the project, Meyer Steinberg, principal chemist and engineer, and Paul Farrell, physicist. Their CVs are presented below:

James R. Powell

Dr. Powell will serve as PI on this project.

Education

Carnegie Institute of Technology (CIT)	1953	B.S.Ch.E.
Massachusetts Institute of Technology (MIT)	1958	Sc.D. Nuclear Engineering

Biography

Dr. Powell joined Brookhaven Technology Group (BTG) as a Director of Science in 2004. Previously, he was on the staff of Brookhaven National Laboratory (BNL) since 1956 and later became a Senior Scientist and Head of Reactor Systems' Division in BNL's Dept. of Nuclear

Energy. There he carried out R&D on advanced fission and fusion reactor systems for terrestrial and space applications, plasma physics, and nuclear waste disposal. Jim retired from BNL in 1996. Currently, in addition to working at BTG, he is President of Plus Ultra Technologies, carrying out R&D on space nuclear power and propulsion systems. Powell has authored over 500 papers and reports, and holds over 20 patents. He was awarded the "Franklin Medal in Engineering" in 2000 AD together with Gordon Danby, for their invention of Superconducting Maglev.

Powell is the inventor of the Particle Bed Reactor (PBR), which was the basis for the SDI program to develop an ultra lightweight Nuclear Thermal Propulsion (NTP) engine for defense applications. The PBR NTP engine components were developed and tested by a National Laboratory Industry team (Brookhaven National Laboratory and Sandia National Laboratory, together with Grumman, Babcock & Wilcox, Garrett, Hercules, and General Dynamics). The PBR engine would have delivered 200,000 Newtons of thrust, with an engine weight of 500 kg and a specific impulse of 1000 seconds from its 3000 K hydrogen propellant. The PBR effort was carried out from 1987 to 1992 at a cost of 200 million dollars. The program was on track to ground test a full up engine, with a flight test in 1997, when the end of the Cold War caused the program to end.

Since then, Powell has continued to work on compact NTP engines for future robotic and manned NASA missions. Plus Ultra Technologies has published a number of papers on the compact MITEE (_MI_nature Reac_T_or _E_ngin_E_) and received several NIACNASA study contracts. The MITEE engine has a number of significant innovations over the PBR engine. It has bi-modal capability, with 14,000 Newtons of thrust in the NTP mode and 20 KW(e) in the electric generation mode, it uses a more durable nuclear fuel (the tungstenUO_2 cermet fuel developed for the 710 engine), and a modular easily scalable pressure tube construction. The total weight of the bi-modal engine is only 200 kilograms for 14,000 Newtons, 20 KW(e) output.

Plus Ultra has also developed a new approach for an ultra lightweight nuclear electric space power system that is based on existing navy reactor fuel and the standard steam power cycle. The SUSEE system achieves 25% cycle efficiency (thermal to electric) with a total system weight (reactor, turbine-generator, and radiator) of only 3 kg per KW(e). The key innovation for the

SUSEE system is a lightweight condensing radiator that can be launched as a compact rolled up package with subsequent deployment into a flat panel configuration after reaching orbit. SUSEE can be readily scaled over a wide range of power levels, from 10 KW(e) to 10 MW(e).

Related Presentations

1. A Compact Transportable Nuclear Power Reactor, Western Focus of the 30th Annual Canadian Nuclear Society (CNS) Conference in Calgary, Alberta, Canada, 31 May – 3 June 2009.
2. Compact Deployable Nuclear Power Systems for DOD/Army Applications, U.S. Army Deployable Nuclear Power Workshop, Adelphi, MD, October 17, 2008.
3. Compact Deployable Ultra Lightweight Multi-Megawatt Nuclear Power Systems for Very Long Range Electromagnetic Launchers, 14th Electromagnetic Launch Technology Symposium, Victoria, British Columbia, June 10-13, 2008.
4. MACE-A Compact Deployable Lightweight Electric Energy Storage System with Multi Megamp and Multi-Gigajoule Delivery Capacity, 14th Electromagnetic Launch Technology Symposium, Victoria, British Columbia, June 10-13, 2008.
5. Compact Readily Deployable Reactor Systems for Secure Power for Civilian and Defense Applications, International Congress on Advances in Nuclear Power Plants (ICAPP'08) in Anaheim, CA, June 8-12, 2008.
6. Compact Rapidly Deployable Multi-Megawatt Nuclear Power Systems for Generation of Electricity Hydrocarbon Fuels and Water at Remote Locations, Alternative Energy Now Conference, Lake Buena Vista, FL, February 20-21, 2008.
7. Compact Transportable Nuclear Power for Remote Locations and Humanitarian Applications, ANS/ENS International Meeting, Washington, DC, November 11-15, 2007.
8. Autonomous Military Power, U.S. Marine Corps Alternative Energy Sources Meeting, MKI/Dumfries, VA, October 30, 2007.
9. Easing Logistic Supply Requirements for Army Field Bases by Generating Vehicle Fuels and Electrical Power Using Compact Light Transportable Nuclear Energy Systems, Military Fuels Conference, Washington, DC, November 6-7, 2006.
10. On-Site Generation of Power and Fuel for Critical Operations at Military Bases, Defense Science Board Conference, Arlington, VA, November 30, 2006.

Recent Related Publications

1. James R. Powell, J. Paul Farrell and George Merkel, "Compact, Transportable Nuclear Power Systems for Rapid Deployment to Remote Locations for Industry, Oil Recovery, Municipalities and Disaster Relief," Proceedings of the 30th Annual Canadian Nuclear Society 2009 Conference (June 2009).
2. James R. Powell and J. Paul Farrell, "Compact, Deployable Ultra Lightweight Multi-Megawatt Nuclear Power Systems for Very Long Range Electromagnetic Launchers," IEEE Conference Proceedings of the 2008 14th Symposium on Electromagnetic Launch Technology (June 2008).

3. James R. Powell, George Maise and J. Paul Farrell, "MACE: A Compact Deployable, Lightweight Electric Energy Storage System with Multi-Megamp and Gigajoule Delivery Capability," IEEE Conference Proceedings of the 2008 14th Symposium on Electromagnetic Launch Technology (June 2008).
4. James R. Powell and J. Paul Farrell, "Compact, Readily Deployable Reactor Systems for Secure Power for Civilian and Defense Applications," 2008 ICAPP Conference Proceedings (June 2008).
5. James R. Powell and J. Paul Farrell, "Deployable Nuclear Power Systems for EML and Other Tactical Applications, Proceedings of the Classified Seminar on Applications of Electromagnetic Launch Technology (May 2007).

Meyer Steinberg

Dr. Steinberg will serve as Chief Chemist on this project.

Education

Polytechnic Institute of Brooklyn, NY	1947 – 1949	M.Ch.E.
The Cooper Union, School of Engineering, NY	1941 – 1944	B.Ch.E.
Professional Engineer License 025373, NY	1953	

Biography

Meyer Steinberg began consulting with Brookhaven Technology Group (BTG) as a Senior Chemical Engineer in 2005. Previously, he was on the staff of Brookhaven National Laboratory (BNL) since 1957 where he began as a Chemical Engineer, Nuclear Engineering Department and later became Senior Chemical Engineer, Department of Energy Sciences & Technology. Steinberg retired from BNL in 1997. Currently, in addition to consulting with BTG, he is the Vice President and Chief Engineer of HCE, LLC in Melville, NY. Steinberg has authored over 500 papers and reports and holds 40 patents. He has received many awards, including: The Federal Laboratory Consortium (FLC) 1990 Special Award for Excellence in Technology Transfer; 21st Century Earth Award (1991) in Biomass and HYDROCARB Technology for removal of Atmospheric CO2; and The Greenman Award (1996) presented by the Third International Conference on Carbon Dioxide Removal for contribution towards harnessing technology for the betterment of the environment.

Steinberg's research and development expertise lay in the following areas: nuclear waste, management and safety, coal conversion, liquefaction and gasification, fluidized-bed combustion and regeneration of sulfated limestone, CO_2 control technologies applied to global greenhouse problem, flash hydropyrolysis of coal, inventor of concrete-polymer materials development for

geothermal energy applications and fur highway construction, conservation programs in recycling waste glass for sewer pipe, synthesis and utilization of low cost copolymers of ethylene with CO and with SO_2 (polyketones and polysulfones), use of fission and fusion reactors for synthesis and production of chemicals and fuels, linear accelerators for nuclear fuel production and transmutation of fission product waste. Performed extensive research on radiation processes and chemonuclear reactors for the fixation of nitrogen, decomposition of CO_2, and production of ozone; inventor of Hydrocarb process for clean coal conversion. Inventor of process for producing synfuel from nuclear power, air and water.

Professional Affiliations

Fellow, American Institute of Chemical Engineers (AIChE)
Member, American Chemical Society (ACS)
Member, American Association for the Advancement of Science (AAAS),
Member, Sigma Xi
Fellow, American Nuclear Society (ANS)
Fellow, American Concrete Institute (ACI)
Fellow, American Institute of Chemists (AIC)
Fellow, American Technion Society (ATS)
Fellow, New York Academy of Science

Related Presentations

1. Electric Power to Fuel and Water, U.S. Army Deployable Nuclear Power Workshop, Adelphi, MD, October 17, 2008
2. Hydrogen Production from JP-8 Fuel for Quiet Energy, U.S. Army Deployable Nuclear Power Workshop, Adelphi, MD, October 17, 2008

Related Publications and Submitted Papers.

1. M. Halmann and M. Steinberg, “Greenhouse Gas Carbon Dioxide Mitigation,” Book Publisher: Lewis, N.Y. (1999) 568 pp.
2. M. Steinberg, "Biomass and Hydrocarb Technology for Removal of Atmospheric CO2," Brookhaven National Laboratory, Upton, NY. BNL Report No. 44410R (February 1991).
3. M. Steinberg and H. C. Cheng, "Modern and Prospective Technologies for Hydrogen Production from Fossil Fuels,” Int. J. Hydrogen Energy 14, No. 211, pp 797-820 (1989).
4. H.C. Cheng and M. Steinberg, "Effects of Energy Technology on Global CO2 Emissions." U.S. Department of Energy, Carbon Dioxide Research Division, Office of Basic Energy Science, Washington. DC, TRO-30 (December 1985).
5. M. Steinberg and Y. Dong, "Process and Apparatus for the Production of Methanol from Condensed Carbonaceous Material", U.S. Pat. 5,344,848, Sept. 6, 1994.
6. M. Steinberg, "Production of a Clean Carbon Fuel Derived from Coal for Use in Stationary and Mobile Heat Engines.” Presented at the 8th International Symposium on

Coal Slurry Fuels Preparation and Utilization, Lake Buena Vista, FL, May 1986. BNL Report No.38086 {April 1986).

J. Paul Farrell

Dr. Farrell will serve as Physicist on this project.

Education

University of Chicago	1958 – 1961	B. Sc. Physics
University of Pittsburgh	1966 – 1975	Ph.D. Physics

Service

United States Marine Corps 1959 – 1963

Biography

Dr. Farrell received his Ph.D. in Theoretical Nuclear Physics from the University of Pittsburgh and his B.Sc. in Physics and Mathematics from The University of Chicago. Dr. Farrell's professional experience has been principally with the design and applications of electron and ion accelerators for research and industry. He worked for 12 years with Radiation Dynamics Inc. (RDI), where he was responsible for beam line design, systems design, installation and demonstration of the first high power (150 kW) electron accelerator system for radiation sterilization of medical products. He worked closely with Food and Drug Administration and Association for Advancement of Medical Instrumentation (AAMI) to establish the first guidelines for use of electron radiation for medical device sterilization. While at RDI, he obtained patents for a method to improve the lifetime of tritium targets used for neutron cancer therapy and for a method of regulating the energy of a dc electron accelerator during high current pulsed operation. He joined General Ionex Corp. as Head of Physics in 1982 where he participated in the development of the Tandetron accelerator and he played a leading role in the development of a high energy ion implanter based on a tandem accelerator design.

In 1987, Dr. Farrell founded Brookhaven Technology Group, Inc., a research and development company that designs, tests and integrates industrial accelerator systems and components. In the ten years since the company began performing innovative research, the company has participated in more than 11 SBIR and other government research projects and has sold more than $300,000 of products based on the research. Dr. Farrell is a member of the Association for Advancement of Medical Instrumentation (AAMI), American Nuclear Society, American Physical Society, SPIE, and the New York Academy of Sciences.

At Brookhaven Technology Group, Inc, Dr. Farrell was a lead investigator in the design and testing of a 5 MeV laser triggered, photo excited pulsed electron gun that produces sub-nanosecond voltage pulses and currents up to 600 A for 100 ps at a pulse repetition rate of $1/10^{th}$ Hz..

Dr. Farrell served as Chairman of the Industrial Applications and Materials Effects Subcommittee of the Council on Ionization Radiation Standards and Measurements (CIRMS), an organization that works with the U.S. National Institute of Standards and Measurements (NIST) to define National Needs in the Ionizing Radiation Program at NIST. He also served as co-chair of the Working Group on Electron Beam Sterilization of Medical Devices from 1985 to 1989 that wrote the first industry wide Guideline on Electron Beam Sterilization of Medical Products. Later he served on the ISO committee on Radiation Sterilization of Medical Products.

Related Presentations

1. A Compact Transportable Nuclear Power Reactor, Western Focus of the 30th Annual Canadian Nuclear Society (CNS) Conference in Calgary, Alberta, Canada, 31 May – 3 June 2009.
2. Compact Deployable Nuclear Power Systems for DOD/Army Applications, U.S. Army Deployable Nuclear Power Workshop, Adelphi, MD, October 17, 2008.
3. Compact Deployable Ultra Lightweight Multi-Megawatt Nuclear Power Systems for Very Long Range Electromagnetic Launchers, 14th Electromagnetic Launch Technology Symposium, Victoria, British Columbia, June 10-13, 2008.
4. MACE-A Compact Deployable Lightweight Electric Energy Storage System with Multi Megamp and Multi-Gigajoule Delivery Capacity, 14th Electromagnetic Launch Technology Symposium, Victoria, British Columbia, June 10-13, 2008.
5. Compact Readily Deployable Reactor Systems for Secure Power for Civilian and Defense Applications, International Congress on Advances in Nuclear Power Plants (ICAPP'08) in Anaheim, CA, June 8-12, 2008.
6. Compact Rapidly Deployable Multi-Megawatt Nuclear Power Systems for Generation of Electricity Hydrocarbon Fuels and Water at Remote Locations, Alternative Energy Now Conference, Lake Buena Vista, FL, February 20-21, 2008.
7. Compact Transportable Nuclear Power for Remote Locations and Humanitarian Applications, ANS/ENS International Meeting, Washington, DC, November 11-15, 2007.
8. Autonomous Military Power, U.S. Marine Corps Alternative Energy Sources Meeting, MKI/Dumfries, VA, October 30, 2007.
9. Easing Logistic Supply Requirements for Army Field Bases by Generating Vehicle Fuels and Electrical Power Using Compact Light Transportable Nuclear Energy Systems, Military Fuels Conference, Washington, DC, November 6-7, 2006.
10. On-Site Generation of Power and Fuel for Critical Operations at Military Bases, Defense Science Board Conference, Arlington, VA, November 30, 2006.

Recent Related Publications

1. James R. Powell, J. Paul Farrell and George Merkel, "Compact, Transportable Nuclear Power Systems for Rapid Deployment to Remote Locations for Industry, Oil

Recovery, Municipalities and Disaster Relief," Proceedings of the 30th Annual Canadian Nuclear Society 2009 Conference (June 2009).
2. James R. Powell and J. Paul Farrell, "Compact, Deployable Ultra Lightweight Multi-Megawatt Nuclear Power Systems for Very Long Range Electromagnetic Launchers," IEEE Conference Proceedings of the 2008 14th Symposium on Electromagnetic Launch Technology (June 2008).
3. James R. Powell, George Maise and J. Paul Farrell, "MACE: A Compact Deployable, Lightweight Electric Energy Storage System with Multi-Megamp and Gigajoule Delivery Capability," IEEE Conference Proceedings of the 2008 14th Symposium on Electromagnetic Launch Technology (June 2008).
4. James R. Powell and J. Paul Farrell, "Compact, Readily Deployable Reactor Systems for Secure Power for Civilian and Defense Applications," 2008 ICAPP Conference Proceedings (June 2008).
5. James R. Powell and J. Paul Farrell, "Deployable Nuclear Power Systems for EML and Other Tactical Applications, Proceedings of the Classified Seminar on Applications of Electromagnetic Launch Technology (May 2007).

Facilities/Equipment

The company occupies more than 2000 square feet of office and laboratory space in Long Island, New York. Currently, there are three administrative employees and four scientists working for the company, each with over 25 years of professional experience. The Phase I research requires analysis of thermodynamic and chemical systems, which will be carried out using both in-house and outside computer facilities. The company owns two 3 GHz dual core Xeon computer workstations and it owns licenses for Wolfram Mathmatica, Mathworks Matlab, SolidWorks, and Fortran and C++ compilers. In addition, the company has access to the full chemical, petrochemical, refining and other process industry computer modeling and simulation software through our affiliation with the Institute for Advanced Technology at the University of Texas in Austin, TX and State University of New York at Stony Brook, Stony Brook, NY. Using these tools and expert scientific staff, the company takes full advantage of the recent advances in modeling capabilities, combined with scalable low-cost, high-performance hardware to develop new reliable ways for design, manufacturing, operation and optimization of process equipment including reactor design, pollution control, thermal and energy management, safety and structural viability, as well as product quality and process efficiency.

Subcontractors/Consultants.

There is no direct involvement of a university or other subcontractor or consultant in the Phase I research. In the Phase II construction and demonstration phase of the project, BTG will collaborate directly with a private company, university, or both to optimize the process and build and demonstrate the concept. Memorandums of Understanding will be negotiated with the appropriate entities in the Phase I research.

Prior, Current, or Pending Support of Similar Proposals or Awards.

There are no prior, current, or pending support of similar proposals or awards.

Cost Proposal.

Offerer	**Brookhaven Technology Group, Inc** **19 Bridge Road, Setauket, NY 11733**					
Title	**Transportable system for production of liquid transportation fuel using atmospheric CO2 and water**					
TIN	**04-2998642**					
CAGE	**1MK14**					
Topic Number	**OSD09-EP6 (OSD/OSD)**					
Topic Title	**Extraction of Atmospheric CO2 and Conversion to Liquid Hydrocarbon Fuel**					
TOTAL Amount of Proposal		**$100,000.00**				
Personell			Rate	hours	Fringe	
	James Powell	PI	$68.00	270	25.00%	$22,950.00
	Meyer Steinberg	Chemist	$60.00	205	25.00%	$15,375.00
	Paul Farrell	Physicist	$68.00	230	25.00%	$19,550.00
				TOTAL Direct Labor		**$57,875.00**
Consultants						
	Programmer		$50.00	100	0	**$5,000.00**
Other Direct Costs						
Travel		People	Trips			
	Ohio to meet vendor	2	1	$1,000.00		
	New Jersey meet collaborator	3	1	$100.00		
	Maryland meet with PM	3	2	$600.00		
				TOTAL ODC		**$1,700.00**
General and Administrative						
		45%	(Direct + Fringe + ODC)			$29,058.75
				TOTAL Cost		**$93,633.75**
Profit		6.80%				$6,366.25
				TOTAL Charge		**$100,000.00**