Cavitation-Induced Fusion: A Path to Clean, Affordable Alternative Energy

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1. Cavitation-Induced Fusion Technology: The Big Idea

Nuclear fusion (which powers the sun) is the energy of the future: 10 microgram of deuterium is equivalent to a barrel of oil. Deuterium is cheap, plentiful and easily extracted from water. Unlike uranium fission that powers modern nuclear power plants deuterium fusion does not produce radioactive waste.

So where are the fusion power plants? U.S. government has spent more than 20 billion dollars over 40 years on fusion-related research (Chu, 2008) and achieved only limited success: National Ignition Facility (NIF) pursues inertial confinement fusion (ICF) where deuterium target is forced to implode through the action of multiple precisely timed laser beams; Princeton Plasma Physics Laboratory (PPPL) is a home of magnetic confinement fusion (MCF) projects where billion-degree plasma is held together by a magnetic field. Enormous R&D costs and numerous unresolved technical challenges contribute to the failure of the conventional approaches to fusion. Fusion's current hopes are with ITER – International Thermonuclear Experimental Reactor, a joint venture of China, India, Japan, Korea, U.S., and European Union (scheduled to be completed by 2018).

What makes fusion so difficult? High temperatures (millions degrees) and high pressures (millions of atmospheres) are hard to achieve. ICF mega-lasers and MCF super-coils require more energy to operate than the energy they produce through fusion and technological limitations preclude sustained operation of these systems.

So is fusion hopeless? Definitely not! While conventional ICF/MCF may be fruitless, there are *alternative* fusion approaches such as Cavitation-Induced Fusion (CIF) that have not yet been fully explored.

The idea behind CIF (also known as bubble fusion) stems from the phenomenon of sonoluminescence: when a liquid is excited with powerful acoustic waves, bubbles are formed (acoustic cavitation); under the influence of the alternating acoustic pressure the bubbles periodically expand and collapse; the collapsing bubbles get so hot that hey give-off a bright flash of light – Fig. 1.

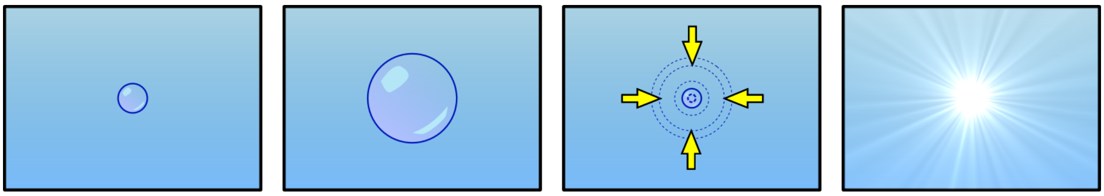

Fig. 1. Bubble growth and collapse during cavitation resulting in sonoluminescence (from Wikipedia).

Scientists studying sonoluminescence discovered that bubble core conditions resemble those found in stars: pressures in the range of thousands of atmospheres and temperatures in excess of 35,000K have already been measured. Theoretical modeling of bubble collapse predicts temperatures and densities sufficient for deuterium fusion when certain conditions are met (Moss, Clarke, White, & Young, 1996), (Bass, Ruuth, Camara, Merriman, & Putterman, 2008).

Then why is nobody pursuing CIF? They are! Oak Ridge National Laboratory (ORNL) and Purdue University were involved in bubble fusion research in the U.S. until "bubblegate" scandal made further inquiry in the field impossible. It all started when Taleyarkhan and co-authors (Taleyarkhan R. , West, Cho, Lahey, Nigmatulin, & Block, 2002) published what was believed (albeit incorrectly) to be the first successful "bubble fusion" experiment. Their report (which appeared in Science) with follow-up papers published in Physical Review (Taleyarkhan, Cho, West, Lahey, Nigmatulin, & Block, 2004), stirred a hornet's nest provoking all sorts of nasty developments ranging from academic rivalry, to conflict of interests in research funds appropriation (ICF researchers felt threatened), to tenure and promotion issues and culminated with charges of academic misconduct (Krivit, 2011). As a result of the ensuing "bubblegate" scandal Taleyarkhan's career was destroyed (Reich, 2009) and CIF research became a taboo.

With no government funding available and deliberate avoidance of the topic by academia there is a **unique opportunity for a private enterprise** to capitalize on the scientific breakthrough and bring the CIF technology to the market. The primary goal of the initial effort must be a convincing demonstration of a neutron flux (a telltale sign of nuclear fusion) and a roadmap towards commercial power generation (Section 2.1).

How does cavitation-induced fusion work? The process is very simple: a cloud of fuel-filled bubbles is injected in a suitable carrier liquid and the bubbles are made to oscillate via a variable pressure drive. Properties of the liquid, dimensions and gas content of the bubbles as well as the characteristics of the pressure drive are engineered such that each bubble collapse results in mini-thermonuclear explosion with minuscule yield of just a few fusion reactions per collapse. However, due to large density of the bubbles and high frequency of the pressure drive a large amount of energy is released into the carrier liquid in a form of heat. The heat is removed by a heat exchanger and is used to produce steam driving a turbine that spins an electric A/C power generator. Alternatively, the heat can be used directly for heating, boiling, melting, etc. Overall design of a fusion power plant is little different from that of a conventional nuclear power plant and is shown on Fig. 2.

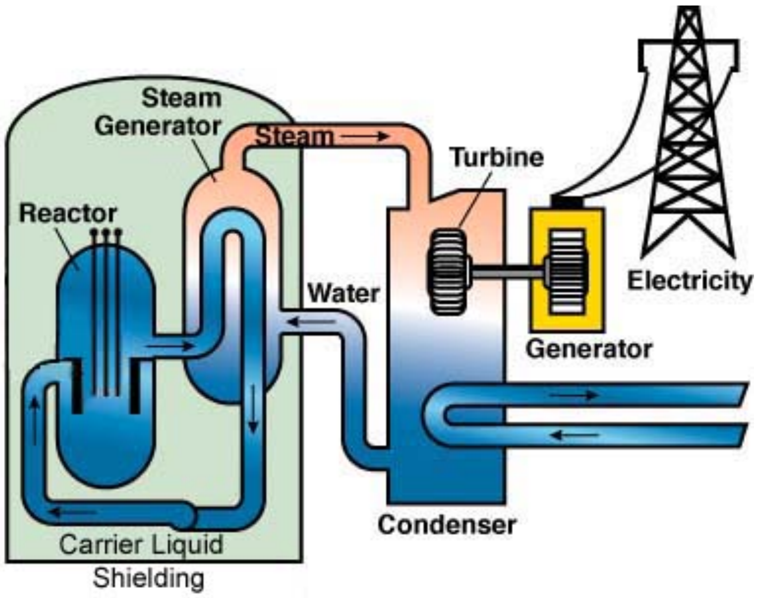

Fig. 2. CIF power plant; rods in the reactor are used to inject fusion fuel bubbles that collapse violently under the influence of a variable pressure drive and produce fusion reactions that warm up the carrier liquid.

2. Commercialization Plan

2.1 Potential Applications

Cavitation-induced fusion has a number of immediate practical applications that can be broadly classified into three categories:

- **Low-grade heat production**,
- **Water desalination/water treatment**, and
- **Power generation**.

The **low-grade heat** application is the simplest one to achieve, as it requires the least amount of engineering. Just like a conventional nuclear-fission reactor, CIF reactor produces heat, which can be used for:

- Residential and commercial space heating;
- Industrial heating for steel/metal industry (e.g. melting) and petro-chemical industry (e.g. for endothermal chemical synthesis, hydrocarbon cracking or heavy oil upgrading).

Thus, the first product of CIF technology is essentially a cheap heat source with zero carbon emission. This cheap heat can be successfully used for **desalination** and **wastewater recycling** by evaporation of large quantities of non-drinkable water with the resulting vapor condensing due to atmospheric cooling into pure, drinkable liquid.

As CIF technology is going to be developed further and the CIF process going to be optimized towards higher power yield, an application in electric power generation will become possible. Once sufficiently high fusion efficiencies are reached, CIF reactors will produce enough heat to drive a steam turbine thus enabling:

- Residential power generation (kW range);
- Industrial power generation (MW-GW range);
- Mobile power generation (kW-MW range) to power electric motors in trucks, locomotives, and ships;
- Lightweight mobile power generation (kW-MW range) to power electric turbofan engines on aircraft.

The application of CIF technology in air transportation will enable economic supersonic cargo and passenger flight thus drastically reducing the costs and time associated with air travel, and, perhaps, ultimately resulting in a development of flying cars, which have been technologically possible for a long time yet economically unfeasible due to high costs and huge consumption of jet fuel.

Additionally, the CIF technology will revolutionize space travel by dramatically reducing the costs of orbital payload delivery. CIF technology will enable satellite lunch at a fraction of the current cost because a payload can now be delivered to a high altitude by a CIF-powered aircraft and then boosted to orbit via conventional rocket propulsion requiring only fraction of fuel when compared to earth-surface lunch due to high altitude and high velocity of the lift-off.

By scope and impact CIF technology can be compared to the invention of A/C power. Adoption of fusion technology will trigger a new era of industrial and technological development resulting in rapid increase in living standards for all of humanity.

2.1 Development Stages

Development of any new technology can be subdivided into three phases:

1) Theory and feasibility study (complete),
2) Proof of concept demonstration (partially complete, ongoing),
3) Reduction to practice (planned).

The theory of cavitation-induced fusion relies on mainstream, well accepted and uncontroversial physics that has been developed and advanced by leading scientists in the U.S. (Moss, Clarke, White, & Young, 1996), (Taleyarkhan R. , West, Cho, Lahey, Nigmatulin, & Block, 2002), and Russia (Nigmatulin, et al., 2005). Commercial reactor feasibility was evaluated by (Krakowski, 1995).

Proof of concept and feasibility of CIF was demonstrated in many experiments in Russia (Lipson, et al., 1990), (Bityurin, Bykov, Velikodny, Dyrenkov, & Tolkunov, 2008), (Smorodov, Galiakhmetov, & Il'gamov, 2008), and in the U.S. (Taleyarkhan R. , West, Cho, Lahey, Nigmatulin, & Block, 2002), (Taleyarkhan R. , West, Lahey, Nigmatulin, Block, & Xu, 2006), (Xu & Butt, 2005), (Forringer, Robbins, & Martin, 2006), and (Bugg, 2006).

Reduction to practice, unfortunately, did not follow due to academic infighting (Krivit, 2011) and conflict of interests with well-funded ICF group (Lahey, 2011, private communication). Therefore, the first step in the development process must be a new incontrovertible experiment demonstrating feasibility of CIF and publication of the results in scientific peer-reviewed literature in order to reestablish the field as a legitimate area of research and attract collaboration of leading scientists, government agencies and academic institutions to advance the technology towards a commercial product.

By collaborating with researchers from Pennsylvania State University and Russian Academy of Sciences Quantum Potential Corporation is uniquely positioned to achieve such a goal.

2.2 Project Timeline

2012	Proof of concept demonstration, scientific publication
	Capital requirements: $1M, Employees: 5
2013	Demonstration of process control towards the increased fusion yield
	Capital requirements: $2M, Employees: 10
2014	Commercial 100kW generator design
	Capital requirements: $5M, Employees: 20

2.3 Engineering Roadmap

The engineering roadmap steps are as follows:

1) Demonstration of nuclear emission from a single cavitation bubble (new feasibility experiment);
2) Demonstration of nuclear fusion in a bubble cluster, which results in the increases fusion yield.
3) Demonstration of control over the fusion process by scaling up the fusion yield via adjustment of the process variables;
4) Demonstration of net power production;
5) Demonstration of the process scalability by going to larger volumes of carrier liquid;
6) Development of process modeling software to assist CIF engineering;
7) Commercial reactor design and licensing of CIF technology.

CIF modeling software and necessary theoretical work will be carried out throughout the entire lifetime of the project.

2.4 Fusion Process Optimization

Exponential dependence of fusion yield on temperature and cubic dependence of total power on maximum bubble radius makes CIF process easy to optimize: e.g. an increase in temperature of just few percent will double the power (a 10-fold bubble core temperature increase results in astonishing 500,000 power boost). **Hence even minor process improvements (such as bubble gas pressure reduction or driving pressure increase) will result in exponential increase in power and efficiency.**

In this regard CIF process is unique because it does not abide by the law of diminishing returns that plague typical engineering problems where massive effort is required in order to achieve just a few percent of efficiency increase. On the contrary, CIF is an engineer's dream because minor process improvements results in huge efficiency boosts. This unique quality sets CIF technology apart from other engineering projects.

2.5 Fusion Reactor Safety

Reputation of nuclear power was seriously tarnished due to recent Fukushima disaster forcing nations (e.g. Germany) to abandon their nuclear plans. We wish to emphasize that *nuclear fusion* unlike conventional *nuclear fission* is clean and green technology that does not produce radioactive waste. Therefore nuclear fusion power generation is as clean and as safe as solar power. Granted, D/D and D/T fusion produces neutron radiation that is harmful to humans. However, this radiation is easily screened by hydrogen-rich shielding such as polyethylene or water. Moreover neutron emission stops as soon as reactor is shut down and it the future it should be possible to design reactors operating on neutron-free (e.g. proton-boron) cycle.

Another important aspect of CIF reactors is inherent safety against runaway "chain reactions". If for whatever reason reactor temperature increases and the excess energy is not transported away from the reactor the reaction yield will plummet due to excessive vapor formation in the cavitation bubbles. All discussion in this proposal assumed very low (nearly-zero) vapor pressure, which is possible to achieve with heavy organic liquids and liquid metals for a certain rather narrow range of temperatures (vapor pressure grows exponentially with temperature). Therefore if a reactor operation mode is skewed towards higher power output the bubble gas temperature will rise producing more vapor, which will rapidly quench fusion by increasing the mass of the gas subjected to compression work. In other words, should a reactor fail (e.g. due to heat exchanger damage in a natural disaster) the reactor will automatically and quickly shutdown without catastrophic explosion. This is yet another advantage of CIF over nuclear fission: while fission reactors require constant maintenance to remain cool (hence Fukushima disaster that resulted in reactor core meltdown when backup cooling generators failed), CIF reactors *will not operate* unless heat is constantly removed from the system and will automatically shutdown when the power production exceeds engineered parameters.

2.6 Fusion Fuel Considerations and Tritium Safety

From the standpoint of power output and efficiency 50/50 deuterium/tritium mixture is the most desirable nuclear fuel. Tritium is a radioactive isotope of hydrogen with half-life of 12.3 years. Tritium is only mildly radioactive and beta-decays into helium-3. Beta radiation does not persist and easily screened and mitigated by common materials (a sheet of paper will stop beta radiation, which is nothing more than a flux of high-energy electrons). In fact despite its radioactive nature tritium is routinely used for illumination (tritium vials) and is harmful only when inhaled or ingested directly in *substantial* quantities.

At the moment of writing tritium costs $30k per gram (Willms, 2003). Despite its high costs tritium is universally touted as fusion fuel for conventional ICF/MCF megaprojects with the expectation that the tritium costs will come down when mass production of the substance begins to supply the fusion industry. Right now tritium is produced as a byproduct of nuclear reactions at research facilities and available quantities are therefore minuscule. At the current price power generation via D/T fusion will cost $0.30/kwh, or 4.5 times higher than the current cost of electric power generation and transmission of $0.07/kwh. Still, even at this higher-than-electric cost D/T fusion is commercially attractive for trucking and air transportation where the price of diesel fuel and gasoline is a major cost factor.

Fortunately, CIF process can operate on pure deuterium fuel, which is much cheaper, abundant, and non-radioactive. When compared to D/T, D/D fusion is harder to achieve due to ~100 times lower reaction cross-section and the power output is 4.5 times. Still, D/D fusion has been already demonstrated in a number of CIF experiments and therefore is in principle feasible. While D/D fusion is likely to be feasible in practice this question cannot be answered with certainty until easier D/T cavitation-induced fusion is studied in depth and appropriate bubble collapse and fusion models are constructed. This is one of the immediate tasks of CIF research. However, even if D/D fusion ends up being commercially unfeasible the D/D fusion can still be used for tritium production as tritium is one of the byproducts of D/D fusion. Therefore it may be possible to have commercial net-power producing reactors operating on D/T mixture while fuel-sourcing power-consuming reactors operating on D/D fuel will be used to produce tritium.

Alternatively, neutrons originating from D/D or D/T reactions can be used to bread tritium from lithium, which can be injected in the carrier liquid or in the reactor shielding. Thus the reactor in principle can be self-breeding tritium (the lithium reaction is a standard solution for fusion reactors).

2.7 Business Model and Potential Market

The main focus of our activities will be research & development of CIF technology and pilot manufacturing. We plan to derive the lion share of our revenue from licensing of the technology to 3rd party engineering and manufacturing companies such as General Electric, Westinghouse, Mitsubishi Siemens, etc.

Wide spectrum of CIF technology applications points to a multi-trillion dollar market. Given the success of CIF it is reasonable to assume that Quantum Potential Corporation will be the world's first trillion-dollar company by valuation.

3. Team – Key People

3.1 Max Fomitchev-Zamilov, Ph.D., Chief Scientist, CEO

Dr. Fomitchev-Zamilov is a leading force behind Quantum Potential Corporation. Primary mission of the company is design, development and sales of cavitation equipment and high-risk/high-payoff research in science and technology. Physicist and computer engineer by training, Dr. Fomitchev-Zamilov's designs the equipment produced by Quantum Potential Corporation. Dr. Fomitchev-Zamilov's relevant experience includes theoretical and experimental physics, molecular dynamics, high-performance computing, ultrasonic pulse shaping and piezoelectric transducer frequency control. Dr. Fomitchev-Zamilov holds an Assistant Professor of Computer Science & Engineering appointment at Pennsylvania State University.

3.2 Sergei Godin, Chief Engineer

Mr. Godin is a talented experimentalist, electrical engineer and a cavitation technology expert. His encyclopedic knowledge of alternative energy and the ability to build and run experiments is critical to the project.

3.3 Stewart Kurtz, Ph.D., Consultant

Stewart Kurtz is a Professor Emeritus of Electrical Engineering at Penn State University and President of Septor, Inc. a materials science and engineering consulting firm. He is a former Director of the Penn State Materials Research Laboratory and founder and Vice Chair of the Penn State Materials Research Laboratory. He is an expert in optical spectroscopy and nonlinear optics who has spent the past 7 years advising students and participating in spectroscopic research on resonant Raman scattering in benzene and aromatic hydrocarbons, inductive RF plasmas for miniature electro-propulsion space devices, and high energy UV/VUV resonant energy transfer processes in atomic hydrogen mixed gas plasmas. He has also contributed in his consulting business to due-diligence and research for several start-up companies working on high voltage-power diamond microelectronic devices, nanoscale materials such as polymer nanofibers, and clean alternative energy (including LENR, hydrino theory, and hadronic mechanics). Dr. Kurtz was involved in validation of BlackLight Power process as well as in evaluation of syngases produced by MegneGas Corporation.

3.4 Andrew Belmonte, Ph.D., Mathematical Modeling

Andrew Belmonte is an Associate Professor of Mathematics at Penn State and a researcher at Pritchard Fluid Mechanics Laboratory. Dr. Belmonte's background in physics and mathematics coupled to his experience, ability and genuine interest in fluid dynamics experimentation is ideally suited for mathematical modeling and theoretical advancement of CIF necessary for success of the project.

3.5 Gary Catchen, Ph.D., Nuclear Engineer

Gary Catchen is a Professor of Nuclear Engineering at Penn State and an expert in radiation detection in general and neutron detection in particular. He has agreed to supervise neutron detection effort for the project to confirm nuclear emission due to CIF.

3.6 Robert Nigmatunil*, Ph.D., Multiphase Flow Theory

Dr. Nigmatulin is a member of Russian Academy of Science (RAS) and a director of the institute of Oceanology. Dr. Nigmatulin is a world's leading theorist and expert in multiphase flow and cavitation bubble dynamics. Dr. Nigmatulin and his colleagues were co-authors of Taleyarkhan's seminal bubble fusion work (Taleyarkhan R. , West, Cho, Lahey, Nigmatulin, & Block, 2002) and developed a theory of CIF in deuterated acetone environment (Nigmatulin, et al., 2005).

* Participation proposed

3.6 Richard Lahey, Ph.D., Bubble Fusion Pioneer, Consultant

Along with Nigmatulin Richard Lahey was intimately involved in groundbreaking bubble fusion experiments conducted by Taleyarkhan's group. Dr. Lahey has authored a 160-page chapter on the subject published in Advanced in Heat Transfer (Lahey, Taleyarkhan, Nigmatulin, & Akhatov, 2006) and has agreed to help us reproduce Taleyarkhan's neutron-assisted bubble fusion experiment.

4. Current Status

Quantum Fusion, Inc. (www.quantum-fusion.com) is a whole owned subsidiary of Quantum Potential Corporation. The company maintains a fully equipped laboratory at Penn State Innovation Park (State College, Pennsylvania, USA) where we research and develop hydrodynamic/acoustic cavitation equipment with a wide spectrum of technological applications – Fig. 3. We possess a full range of analytical equipment including high-speed pressure transducers (PCB, Kistler, etc.), digital memory oscilloscopes, variety of pressure gauges, power amplifiers and piezo drivers (Branson Sonifier 450, Metrlologix PiezoAmp, etc.), and BF_3 neutron detector Eberline ASP-1, 50-Pa fore-vacuum pump, 10^{-7} Torr turbo vacuum system, Hadland Ultra-8 100,000,000 frames-per-second camera, as well as necessary chemical supplies such as deuterium and xenon gas.

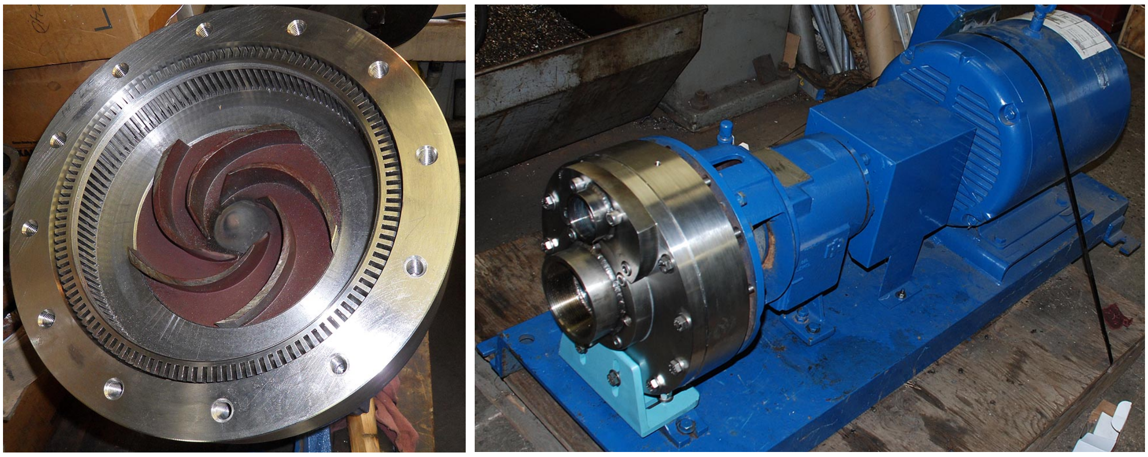

Fig. 3. Left: rotor-stator cavitation unit built by Quantum Potential Corporation; Right: Assembled cavitation unit driven by 50HP three-phase electric motor built by Quantum Potential Corporation.

At the moment of writing our company has achieved the following preliminary results:

1. We have developed a numerical solution (Mathematica 8) for supersonic bubble collapse governed by Rayleigh-Plesset-Keller (RPK) equation that accounts for acoustic losses due to shockwave compression and liquid compressibility. We can solve the RPK equation together with the deuterium equation of state and estimate fusion reaction yield to obtain a lower bound of fusion reaction rate since our

calculations assume adiabatic collapse (uniform temperature and pressure) and ignore shockwave-related effects. Using this tool we were able to identify a range of parameters (such as maximum bubble radius, driving acoustic pressure, ambient bubble radius, liquid choice, etc.) that we will result in highest fusion probabilities in a laboratory setting.

2. We have modified molecular dynamics software originally developed at UCLA by Bass (Bass, Ruuth, Camara, Merriman, & Putterman, 2008) so we are able to simulate shockwave formation in the collapsing bubble and calculate fusion reaction rate thus further increasing the accuracy of predictions obtained with the Mathematica model and discovering a new range of parameters that has to do with shockwave formation, which is an extremely powerful mechanism for fusion initiation.
3. We have performed an initial series of cavitation-induced fusion experiments using the micro-reactor depicted on Fig. 4 and detected weak neutron emission (using ASP-1 BF_3 detector) coinciding with cavitation. The initial reactor design proved inadequate due to excessive power requirements and poor reaction yield stemming from inadequate resonator cavity design. Because fine-tuning the resonator is a laborious and costly process requiring precise numerical simulation that is sensitive to many design parameters (Lahey, Taleyarkhan, Nigmatulin, & Akhatov, 2006) we hade designed a new experiment – Fig. 5.
4. We have conducted 8 tests with the single-bubble fusion experiment shown on Fig. 5. In this experiment a 200 lb weight impacts piston that is in contact with glycerin to generate a 1,000 bar shock. A 5-mm deuterium bubble is injected into glycerin prior to impact. The shockwave collapses the bubble lunching a spherical converging shock within the bubble's gas, which leads to fusion. The first two tests registered neutron yield coincident with the shock. During the second experiment the reading on our neutron detector went off the chart. Subsequent 8 tests produced no signal, which we believe was due to pressure reduction due to crack in the Plexiglas enclosure. After the last test the Plexiglas separated completely and the system became dysfunctional. We have measured the shock pressure and it was in excess of 200 bar and saturated our pressure transducer. The pressure rise was 1 ms, which was too slow for supersonic bubble collapse required for best result. Consequently we are rebuilding the system to stiffen the enclosure and minimize pressure rise time as well as outfit the system with 75,000 psi rated pressure transducer. New batch of experiments to be conducted soon.

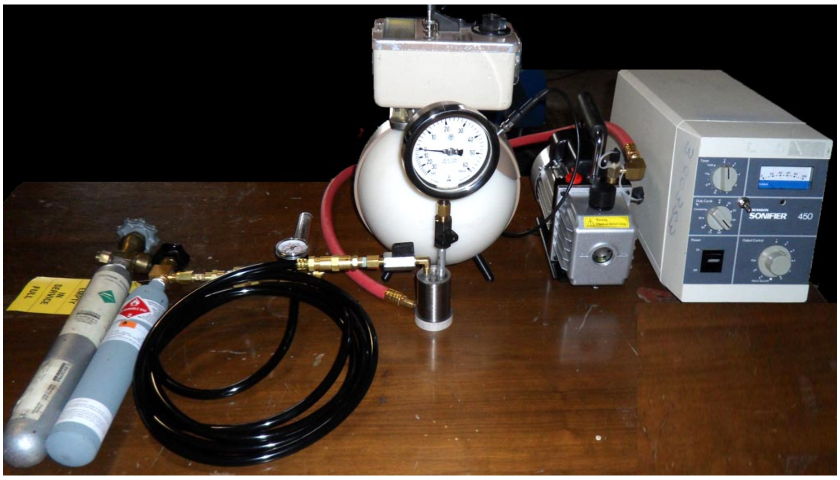

Fig. 4. Micro-reactor developed by our company for CIF experimentation: small cylindrical stainless steel reactor (middle) is fitted with a piezoelectric-ring (bottom of cylinder) driven by a power amplifier (right); pressure gauge is mounted on top of the chamber and connected to a vacuum pump; gas bottles (left) are connected to the chamber via a supply system; the reactor chamber is set in front BF_3 neutron detector enclosed in polyethylene moderator sphere.

Fig. 5. Single-bubble shockwave fusion system according to Smorodov. In this design 200 lb weight impacts piston that is in contact with glycerin to generate a 1,000 bar shock. A 5-mm deuterium bubble is injected into glycerin prior to impact. The shockwave collapses the bubble lunching a spherical converging shock within the bubble's gas, which leads to fusion.

5. Competition

CIF technology directly competes with government-sponsored fusion megaprojects, such as:

- Joint European Torus (JET)
- International Thermonuclear Experimental Reactor (ITER)
- United States National Ignition Facility
- European Union High Power Laser Energy Research (HiPER)

Additional competition comes from the private sector:

- General Fusion (Canada), www.generalfusion.com
- Impulse Devices, Inc. (USA), www.impulsedevices.com
- Lawrencevill Plasma Physics (USA), www.lawrencevilleplasmaphysics.com
- Blacklight Power, Inc. (USA), www.blacklightpower.com
- MagneGas Corporation (USA), www.magnegas.com
- Proton-21 (Ukraine), www.proton21.com.ua
- Defkalion (Greece), www.defkalion-energy.com

Despite 40 years of research and over $20B in federal funding (Chu, 2008) government-sponsored megaprojects are not close to commercial product. The longest fusion experiment can last for 0.5 seconds and is plagued by huge technological and financial challenges. Also, government-sponsored fusion projects are a reason behind cold reception of CIF technology by academia since success of CIF will mean shutting down of the failed ICF/MCF projects. That is why no government funding is available in the U.S. for CIF research.

In the private sector **General Fusion** pursues ICF approach to fusion, which is very promising and feasible. General Fusion resurrected an old LINUS concept, which involves creating a bubble-like cavity in liquid led. A magnetically confined plasma is then injected into the cavity and the cavity is compressed via the action of 192 pistons lunching a shock wave into the molten led. The D+T plasma in the bubble will be inertially confined and compressed to fusion temperature with the onrush of the shockwave from the pistons. General Fusion has raised more than $33-million to implement the idea and estimate that they may need $500M for a grid-friendly demo plant rated at 100 MW (Quick, 2009). We believe General Fusion is a strong with viable technology, which given the funding is posed to succeed within 5-10 year time frame.

Impulse Devices is another close competitor technology-wise as they pursue research & development of Extreme Acoustic Cavitation™ with the objective to commercialize CIF technology. The company was founded by Dr. Felipe Gaitan who is credited with the invention of single-bubble sonoluminescence. Impulse Devices was a recipient of a $35-million dollar Advanced Cavitation Power Technology (ACPT) contract by DoD. Because it was a military contract no details or publications are available on the results of that work. The company would not comment on how close they are to achieving their goal therefore we conclude that their results up to this date were negative. In our view, unlike General

Fusion, they are on the wrong path because they rely on high vapor pressure liquids such as heavy water. We believe that this approach is non-viable.

Blacklight Power develops a new power source based on Randy Mills' controversial hydrino theory (Mills, 2000). The company has secured in excess of $60M of venture funding (Kimes, 2008) and some aspects of the Mills' theory have been independently verified by 3rd party scientific consulting firms (GEN3 Partners, 2009). At the moment of writing Blacklight Power does not yet have a commercial product.

MagneGas Corporation is the only "new physics" based alternative-energy company on the market with a commercial product and a growing customer based. The company was founded by Nobel-nominated physicist Ruggero Santilli. Dr. Santilli publishes his own scientific journals (e.g. Hadronic Journal) and his theories are gaining recognition among researchers in Europe, Japan, and Former Soviet Union. Recently MagneGas Corporation announced a successful fusion proof-of-concept experiment (Brenna, Kuliczkowski, & Leong, 2011), which in our view has a high chance of commercial success.

Ukrainian company **Proton-21** is the only fusion-oriented alternative energy company in the former Soviet Union. Funded at $50M level by Ukrainian steel moguls Proton-21 has achieved a major breakthrough in controlled nucleosynthesis (Adamenko, Seleri, & van der Merwe, 2007). Essentially, Proton-21 possesses a technology for electron-beam induced nuclear fusion and nuclear transmutation of macroscopic quantities of matter (milligrams to grams) requiring only modest amounts of power (MJ). Proton-21 technology is very advanced and truly revolutionary and can be brought to the market quickly given sufficient resources. The company has made plans to commercialize their technology in the U.S. and has invited our company to be a stakeholder and a major participant in this process. There is no doubt that Proton-21 technology will succeed commercially, although the first applications are likely to be related to radioactive waste decontamination. The controlled nucleosynthesis is a viable "new physics" technology with revolutionary potential. We estimate that it will take in excess of $100M and 3-5 years to fully adapt their technology for commercial nuclear waste decontamination and power generation.

Defkalion is another premising alternative energy company with potentially viable technology rooted in cold fusion. For over a hear Rossi and Foccardi have been circulating reports about MW-rated cold fusion low-grade heat power plant dubbed e-Cat. Defkalion has similar technology and arguably better engineering. We are familiar with the investors performing due diligence on Defkalion's cold fusion reactor and according to them the technology looks extremely promising and commercializable within the 2012 time frame.

5.1 Our Advantage

All players in the fusion energy market are many millions of dollars and many years away from a commercial product because they have chosen to pursue very difficult, expensive and unwieldy technologies.

Our advantage is that we have been able to come up with a genuinely simple approach to nuclear fusion that does not require high capital costs to develop. We anticipate a commercial product within 3 years of development and thus aspire to be the first company to deliver fusion power to the market.

6. References

Adamenko, S., Seleri, F., & van der Merwe, A. (2007). *Controlled Nucleosynthesis: Breakthroughs in Experiment and Theory.* Springer.

Bass, A., Ruuth, S., Camara, C., Merriman, B., & Putterman, S. (2008). Molecular Dynamics of Extreme Mass Segregation in a Rapidly Collapsing Bubble. *Physical Review Letters , 101*, 234301.

Bityurin, V., Bykov, A., Velikodny, V., Dyrenkov, A., & Tolkunov, B. (2008). Theoretical and experimental investigation of the effect of shockwave on porous deuterated liquid. *Fiziko-Khimicheskaja Kinetika v Gazovoy Dinamike , 6*.

Brenna, R., Kuliczkowski, T., & Leong, Y. (2011). Verification of Intermediate Nuclear Fusions without Harmful Radiation and the Production of Magnecular Clusters. *New Advances in Physics , 5* (1), 9-17.

Bugg, W. (2006). *Report on Activities on June 2006 Visit.* Purdue University.

Chu, S. (2008). *Have we spent too much on fusion?* Retrieved from Focus Fusion: http://focusfusion.org/index.php/site/reframe/wasteful

Forringer, E., Robbins, D., & Martin, J. (2006). Confirmation of Neutron Production During Self-Nucleated Acoustic Cavitation. *Transactions of the American Nuclear Society , 95*, 736-737.

GEN3 Partners. (2009). *Water Flow Calorimetry, Experimental Runs and Validation Testing for BlackLight Power Inc.*

Kimes, M. (2008). *BlackLight's physics-defying promise: Cheap power from water*. Retrieved from CNNMoney: http://money.cnn.com/2008/07/01/smallbusiness/blacklight.fsb/index.htm

Krakowski, R. (1995). *Bubble fusion: Preliminary estimates.* Los Alamos National Laboratory, New Mexico.

Krivit, S. (2011). *Bubblegate Investigation Portal*. Retrieved from New Energy Times: http://newenergytimes.com/v2/bubblegate/BubblegatePortal.shtml

Lahey, R., Taleyarkhan, R., Nigmatulin, R., & Akhatov, I. (2006). Sonoluminescence and the Search for Sonofusion. In G. Green (Ed.), *ADVANCES IN HEAT TRANSFER* (Vol. 39, p. 1). Academic Press.

Lipson, A., Klhyuev, V., Deryagin, B., Toporov, Y., Sirotyuk, M., Khavroshkin, O., et al. (1990). Observation of neutrons accompanying cavitation in detuterium-containing media. *Pis'ma v Zhurnal Tekhnicheskoj Fiziki , 16*, 89-93.

Mills, R. (2000). *The Grand Unified Theory of Classical Physics.* BlackLight Power, Inc.

Moss, W., Clarke, D., White, J., & Young, D. (1996). Sonoluminescence and the prospects for table-top micro-thermonuclear fusion. *Physics Letters A , 211*, 69-74.

Nigmatulin, R., Akhatov, I., Topolnikov, A., Bolotnova, R., Vakhitova, N., Lahey, R., et al. (2005). Theory of supercompression of vapor bubbles and nanoscale thermonuclear fusion. *Physics of Fluids , 17*, 107106.

Nigmnatulin, R. (1991). *Dynamics of Multiphase Media.* New York: Hemisphere.

Reich, E. (2009, November). Bubble-fusion scientist debarred from federal funding. *Nature news* , p. 1103.

Smorodov, E., Galiakhmetov, R., & Il'gamov, M. (2008). *Physics and Chemistry of Cavitation.* Moscow: Nauka.

Taleyarkhan, R., Cho, J., West, J., Lahey, R., Nigmatulin, R., & Block, R. (2004). Additional evidence of nuclear emissions during acoustic cavitation. *Physical Review E , 69* (3), 036109.

Taleyarkhan, R., West, C., Cho, J., Lahey, R., Nigmatulin, R., & Block, R. (2002). Evidence for Nuclear Emissions During Acoustic Cavitation. *Science , 295* (5561), 1868-1873.

Taleyarkhan, R., West, C., Lahey, R., Nigmatulin, R., Block, R., & Xu, Y. (2006). Nuclear Emissions During Self-Nucleated Acoustic Cavitation. *Physical Review Letters , 96*, 034301.

Willms, S. (2003). *Tritium Supply Considerations.* Los Alamos National Laboratory, Fusion Development Paths Workshop.

Xu, Y., & Butt, A. (2005). Confirmatory Experiments for Nuclear Emissions During Acoustic Cavitation. *Nuclear Engineering and Design , 235*, 1317-1324.