Fusion Energy: Visions of the Future
Dec. 10-11, 2013

FOCUS

FUSION

Cheap, Clean, Safe & Unlimited Energy
What Is Focus Fusion?

Controlled Nuclear Fusion With a Dense Plasma Focus Device Running on Aneutronic Fuel
What Is Aneutronic Fusion?

It’s a fusion using aneutronic fuel, ideally made of hydrogen and boron, pB11, which produces no neutrons and thus no radioactive waste.

Aneutronic → No neutrons → No Radioactive waste
Why Is Aneutronic Fusion Cheap?

Aneutronic → No neutrons
No neutrons → No Radioactive waste
Aneutronic → Direct energy conversion
Direct energy conversion → No $$$ turbines
Dense Plasma Focus:
small inexpensive device
Inside of FF-1’s Generator

Dense Plasma
REPRODUCING NATURAL INSTABILITIES

- Solar Flares
- Beam From Star Formation
- Quasars
- Spiral Galaxy
Energy (X-rays, Ion Beams) Capture Device
Where Are We?

- Ion temperature—goal achieved—over 1.8 billion degrees, enough to ignite pB11
- Confinement time—goal achieved 20 ns—more than 8 ns goal
- Energy transfer to plasmoid—over 50% of goal
- Density—must increase by 10,000
Aneutronic Fusion Comparison

Log Temperature (eV)

Log (Density x Confinement Time) (sec/cc)
Our Scientific Peers are Excited

What your peers have been reading...

A Listing of the Most Read Articles in 2012 Published in Physics of Plasmas

Fusion reactions from >150 keV ions in a dense plasma focus plasmoid
Eric J. Lerner, S. Krupakar Murali, Derek Shannon, Aaron M. Blake, and Fred Van Roessel

Development of the indirect-drive approach to inertial confinement fusion and the target physics basis for ignition and gain
John Lindl
Steps To Increase Density

- 50x-- Achieve theoretical density—tungsten electrodes to eliminate impurity
- 10x-- Increase current to 2.8 MA
- 20x-- Better compression with heavier pB11
From NJ to your neighborhood

FF-1, 2014

FF-X, 2018

1 Year – conclude scientific feasibility
4 Years – for commercial generator
COSTS

For 5 MW generator, mass production
$0.08-$0.20/W

Electric cost
Less than 0.3 cents/kwH
Vs best today of 6 cents/kwH
Finances

- $3.2M raised from Abell Foundation, 50 investors
- Raising $1 M more for scientific feasibility, transition to eng. phase
- $50M for development, engineering
What Our Peers Say:

- “…the committee feels that the promise of the LPP DPF approach to fusion power has considerable merit and that a much higher level of investment is warranted, based on their considerable progress to date. “
- Review by Robert L. Hirsch, Steven O. Dean, Gerald L. Kulcinski, and Dennis Papadopoulos
Our Intellectual Property:

• US patent 7,482,607
• Chinese Patent No. 200780007065.7
• Australian Patent 2007314648

• Patent applications, same priority date: Europe, Canada, India
Why Is Focus Fusion Cheap?

- Aneutronic fusion
- D-T fusion
- Fission

B&W mPower, NuScale, Terrapower, Areva

Nat’l Ignition Facility, Iter, General Fusion

TriAlpha, Polywell, LPP
Deuterium & Tritium vs. Hydrogen & Boron

Deuterium – Tritium
Low Ignition at 400 Million K vs. 1.6 Billion K

But LPP has already achieved 1.8 billion K
Tokamak
DIFFERENCE #2:

Use Instabilities, don’t fight them!
Pinch Effects!
WHAT IS DPF?

- Dense Plasma Focus is a DEVICE!
Garage Use 5 MW – Generator

Clean
Inexpensive
Safe
Compact
LPP’s Advances On Other DPF Work

• Theory—leads to small size

• Axial Field coil controls spin

• Quantum magnetic field effect suppresses x-ray cooling
Innovation On The Shoulders Of Giants

- Rich body of DPF scientific literature since invention in ‘60’s
- Dozens of research groups worldwide
  - X-ray/neutron applications
  - US teams at KSU, NSTec
- 2009: LPP Focus Fusion-1 lab begins experiments
- Testing our key innovations to demonstrate scientific feasibility of focus fusion
  - Accurate DPF model
  - Optimal angular momentum
  - QMF to reduce X-rays
  - Efficient beam capture
  - Efficient X-ray capture
Ions go one way, electrons the other
THE CHALLENGES: Two Down, One To Go

1. Enough heat achieved; 1.8B K
2. Enough confinement time achieved; 20 ns
3. Density: give-number-here; Not enough!

Fusion reactions from >150 keV ions in a dense plasma focus plasmoid

Eric J. Lerner, S. Krupakar Murail, Derek Shannon, Aaron M. Blake, and Fred Van Roessel
Lawrenceville Plasma Physics, 128 Lincoln Blvd., Middlesex, New Jersey 08846-1022, USA

(Received 23 December 2011; accepted 25 February 2012; published online 23 March 2012)

Using a dense plasma focus device with a 50 kJ capacitor charge, we have observed fusion reactions from deuterium ions with record energies of >150 keV, which are confined for durations of 7–30 ns in the cores of plasmoids with typical radii of 300–500 μm and densities ~3 × 10^{19} cm^{-3}. We have for the first time simultaneously imaged the plasmoid at high (30 μm) resolution and measured trapped ion energy and neutron anisotropy. The isotropy of the neutron emission as well as other observations confirms that the observed neutrons per pulse of up to 1.5 × 10^{11} are produced mainly by confined ions, not an unconfined beam. The conditions achieved are of interest for aneutronic fusion, such as with pB11 fuel. © 2012 American Institute of Physics. [http://dx.doi.org/10.1063/1.3694746]

I. INTRODUCTION

The dense plasma focus (DPF) device has long been known to be an efficient source of neutrons from fusion reactions and of MeV-energy ion and electron beams,1–3 it and higher if the high-energy ions are not yet thermalized, integrated charge-coupled device (ICCD) images, low anisotropy in neutron production, energy considerations, and the strong correlation of ion energy with fusion power all combine to
Getting Net Power
Engineering Challenges:

• Removing waste heat (helium cooling)
• X-ray capture device
• Ion beam conversion (MW magnetron designs already get 87% efficiency)
What Our Colleagues Say:

- “I think that the “Focus Fusion” approach of Lawrenceville Plasma Physics, Inc. should be funded as the science behind it is very interesting.” - Bruno Coppi, Professor of Physics and Senior Fusion Researcher, MIT

- “According to the results of this paper, it could be said that p11B fuelled plasma focus device is a clean and efficient source of energy.” S. Abolhasani, M. Habibi and R. Amrollahi, Amirkabir University of Technology, Tehran, Iran in Journal of Fusion Energy

- “The experimental program that LPP plans to carry out has great potential to show how the plasma focus can be used to generate fusion energy and to demonstrate the feasibility of hydrogen-boron fusion.” - Dr. Julio Herrera, Professor of Physics, National Autonomous University of Mexico
Accelerating Feasibility Through International Collaboration

- Agreement signed with Plasma Physics Research Center in Tehran to cooperatively publish papers
- 150 graduate students, including 50 PhD students
- 90 plasma physics PhD students in the entire US
- PCAST briefed May 25th in DC
- Working to expand cooperation to Japan, elsewhere
PROOF OF 160 KEV—1.8 BILLION DEGREES K
Improvement in Yield/Current Scaling

\[ y = 1E-08 \times 6.7542 \]

Neutron Yield vs. Current I (kA)

- Buenos Aires (PFI)
- FF-1
- Frascati (1MJ)
- Limeil
- NTSC
- Swierk
- U of Illinois LPP
- Stuttgart (HV)
- Darmstadt
- Stuttgart (Poseidon)
- TAVADIL (PAEO)
- Power (FF-1)
Timeline for Total Energy Transformation

Example: Tesla Model S, 1st year (2012) production 5-7k vehicles
Example: 2M total EV’s in 2014

SIMILAR POTENTIAL FOR FOCUS FUSION GENERATORS ENABLES HUGE POSITIVE GLOBAL IMPACT

2012-2013: Scientific demo
2015-2016: Commercial prototype
2016: Mass manufacture with worldwide JV partners and licensees

They’ll stack!
Air Breathing and Rocket Propelled Vehicle-with MHD and Fusion Power

- A neutronic fusion power and rocket propulsion from Mach 14 to orbit
- Air-breathing propulsion and MHD power from Mach 7 to Mach 14

- 2025 time period • LOX and LH2 propellants
- Chemical rocket and air-breathing propulsion from 0 to Mach 7
Fusion in Space

Advanced Fusion Reactors for Space Propulsion and Power Systems
J. J. Chapman (2011), Engineering Division, NASA, Hampton, VA, United States

*not ‘would’ or ‘must’!
Fusion for Peace

"make uranium enrichment obsolete, block proliferation everywhere, liberate the world from oil, and open up a new source of cheap, clean unlimited energy."

- Iranian, Japanese, & US physicists propose working together on clean energy to defuse conflict
- Iran has 6 DPF research groups
  - Also IEC and tokamak
- Open to more countries
- FusionForPeace.org