Endurance Bioenergy Reactor ™

Strategic Deployment & Distribution WG-16

Military Operations Research Society Symposium

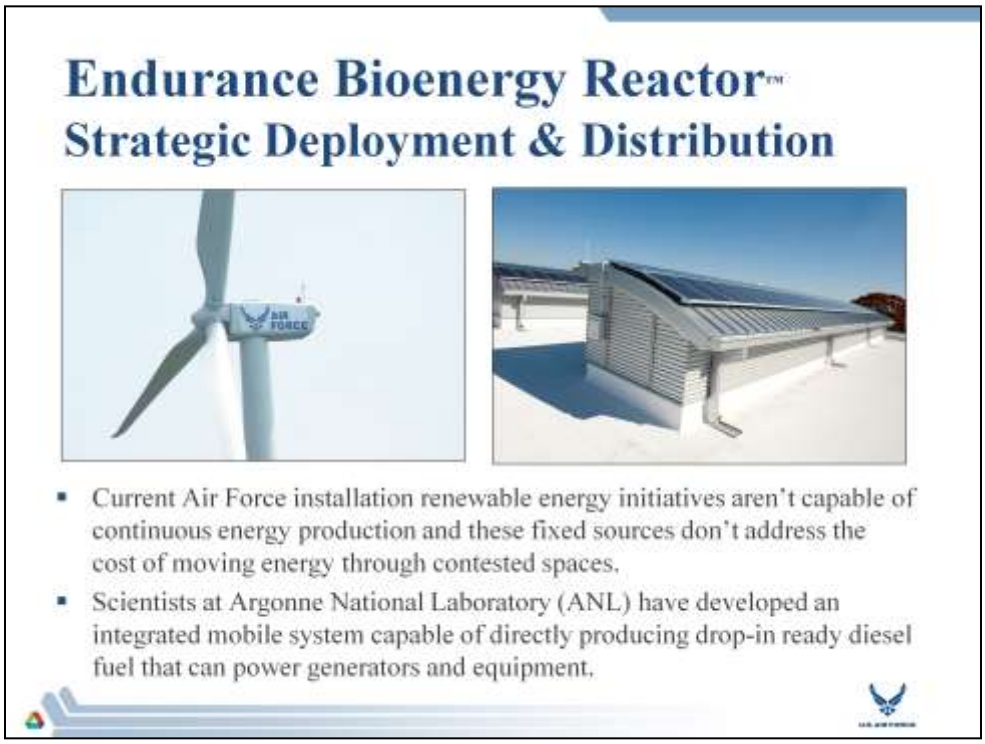
Argonne National Laboratory
Air Force Fellows

Endurance Bioenergy Reactor™

Strategic Deployment & Distribution

- If maintaining the cadence of operations while lowering fuel demand is difficult, then the approach to supply has to change.
- Directly producing renewable fuel on-site lowers logistic demands and increases the efficiency of forward operations.

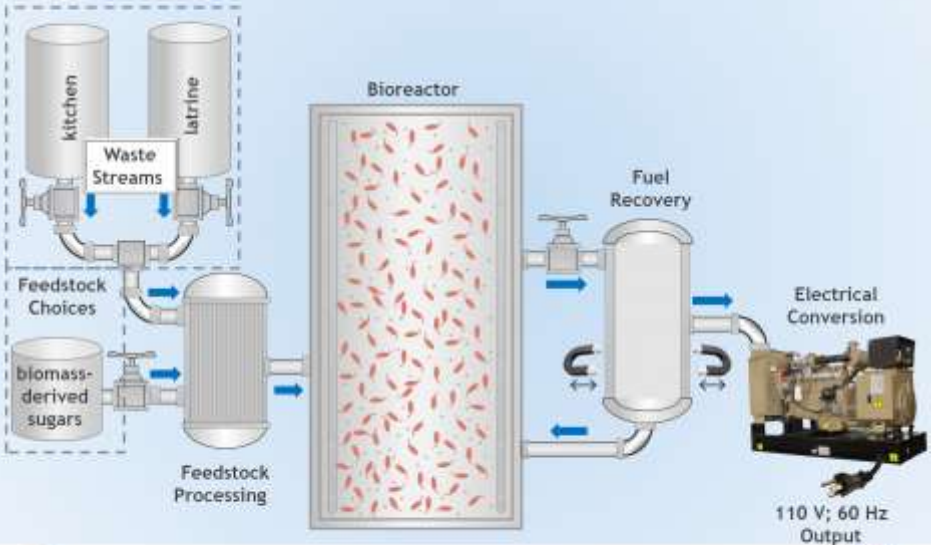
A 2009 Army Environmental Policy Institute report, Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys, stated there were more than 1000 Army casualties in 2004 because of resupply convoy operations. Three years later that number had dropped to over 300, but this number didn't include other services' losses. These are alarming statistics and ten years of fuel convoys in Iraq and Afghanistan suggest that an increase in a forward operating base's fuel endurance would dramatically lower America's losses and likely its operating cost.



Scientists at Argonne National Laboratory (ANL) have developed an organism that is capable of directly producing a drop-in ready fuel. Endurance Bioenergy Reactor™ is a simple-to-use system that is portable and produces fuel for direct consumption by engines and generators without refining, eliminating complicated logistics. This system can increase the endurance of any operation by decreasing their reliance on supply chains.

Beyond the tactical advantages, Endurance Bioenergy Reactor™ the system is rapidly deployable to humanitarian activities around the world, producing fuel where and when it's needed.

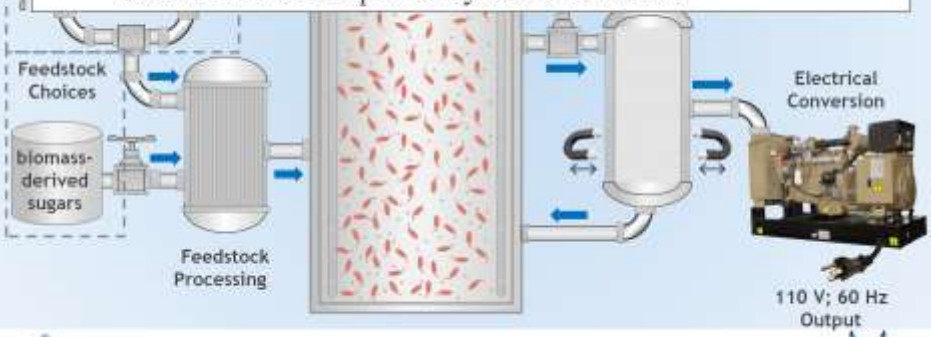
Endurance Bioenergy Reactor™



Endurance Bioenergy Reactor™

The 2012 Air Force study, Energy Horizons states,

> "To date over 3000 American soldiers and contractors have been killed or wounded protecting supply convoys in Iraq and Afghanistan (approximately one life per 30 convoys), 80% of which are primarily fuel and water."

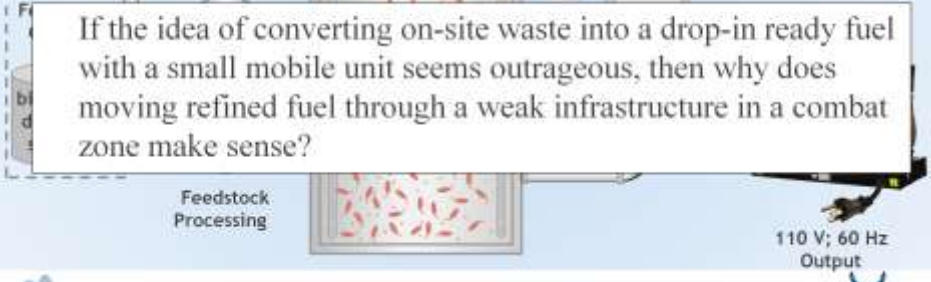


Endurance Bioenergy Reactor™

The 2012 Air Force study, Energy Horizons states,

> "To date over 3000 American soldiers and contractors have been killed or wounded protecting supply convoys in Iraq and Afghanistan (approximately one life per 30 convoys), 80% of which are primarily fuel and water."

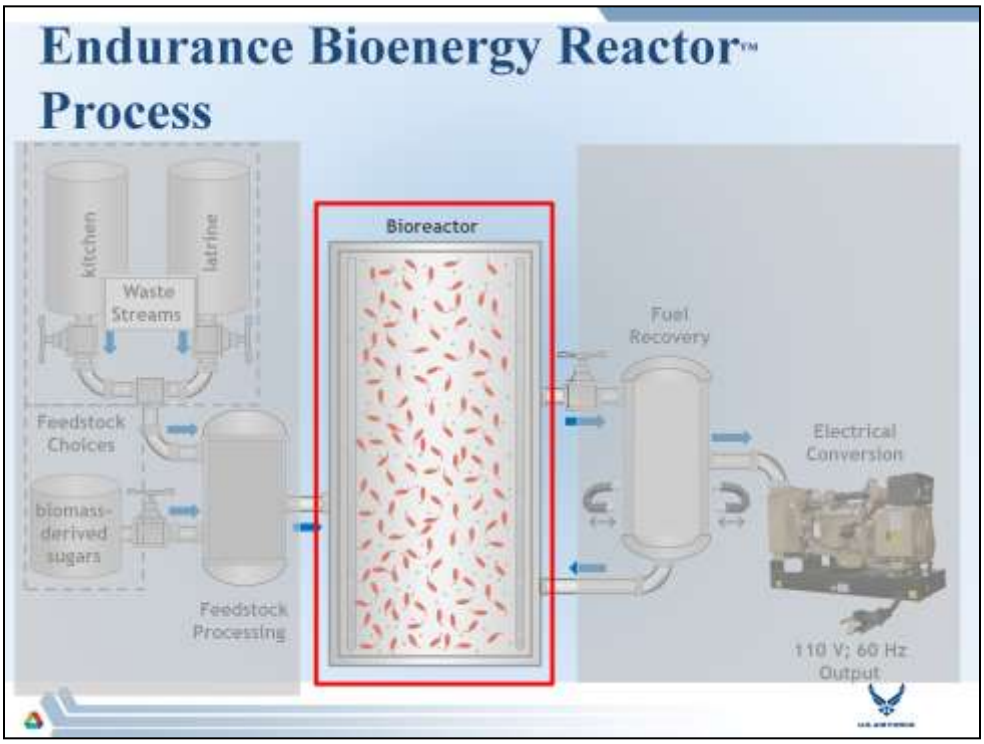
If the idea of converting on-site waste into a drop-in ready fuel with a small mobile unit seems outrageous, then why does moving refined fuel through a weak infrastructure in a combat zone make sense?



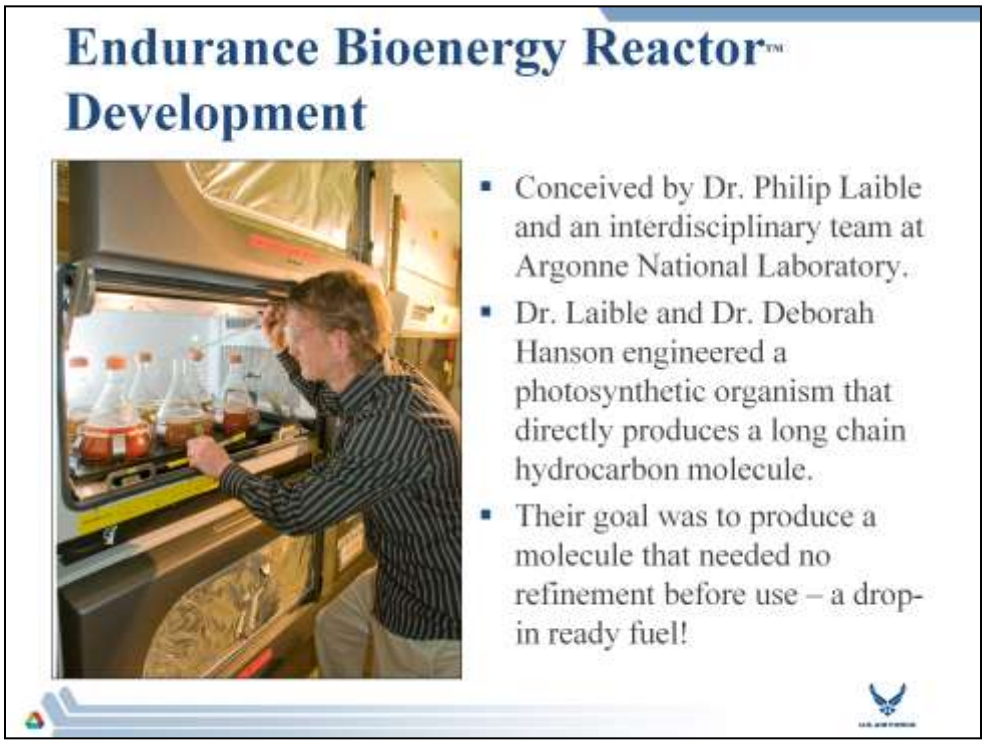
Endurance Bioenergy Reactor™

- Self-contained, mobile, on-site system that directly produces a drop-in ready fuel.
- Can produce 25 to 50 gal* of diesel fuel per day using on-site resources to sustain any operation in any location.
- If conditions dictate, EBR could remain behind to fulfill humanitarian and strategic needs.
- EBR changes the dynamics of energy requirements and logistics anywhere in the world, in any type of operation.

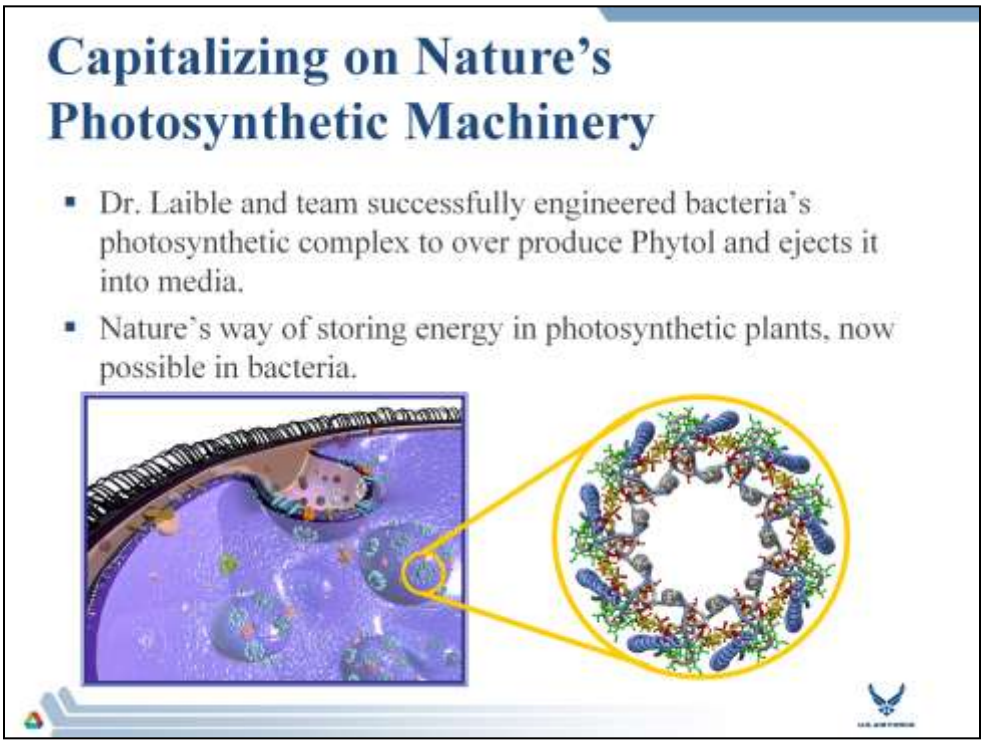
* Estimated from laboratory tests



Now we'll focus on the heart of EBR, the engineered bacteria.

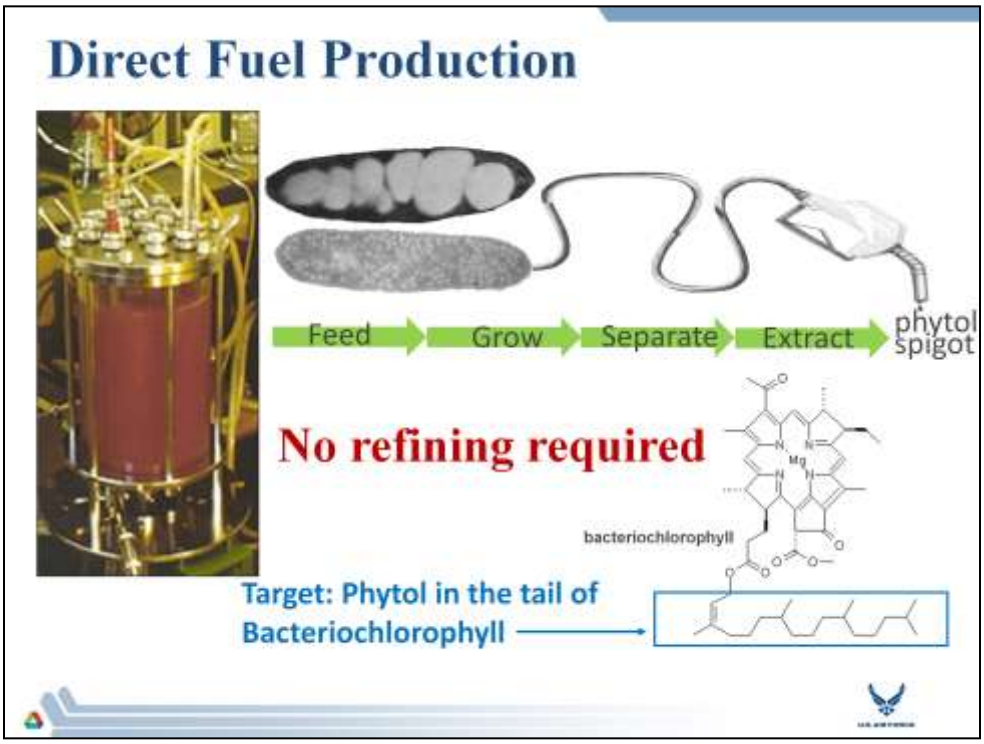


The genesis of EBR began nearly three years ago (2009) when a group of scientist gathered to form a Fuel and Engine Energy working group. The formation of an interdisciplinary group of Biochemists, Mechanical Engineers, and Biophysicists came from Dr. Philip Laible's personal desire to affect a change in energy production and its consumption in modern energy systems. The group's charge was simple, look for innovative ways to produce renewable energy that doesn't compete with feed stocks, is energy neutral and is compatible with existing infrastructure.



Up until this point in the developmental story, the ANL interdisciplinary team had only identified what others had known, even the DOD. Within nature, photosynthetic organisms and plants produce a porphyin ring and tail, and within that structure lay a desired molecular chain that works well as a bioenergy source. The DOD had identified these molecules with these attributes as being a good source of renewable energy in its 2010 study, Opportunities for DOD use of Alternative and Renewable Fuels, "The key advantage of renewable and cellulosic fuel (over FAM biodiesel) is that these drop in diesel fuels are chemically similar to petroleum diesel and fungible within the current petroleum supply system."

As many groups identified these types of fuels as being advantageous, Dr. Laible and his team needed to obtain this molecule without the use of traditional refining. This would be the key discriminator of their technology and tremendous energy savings.

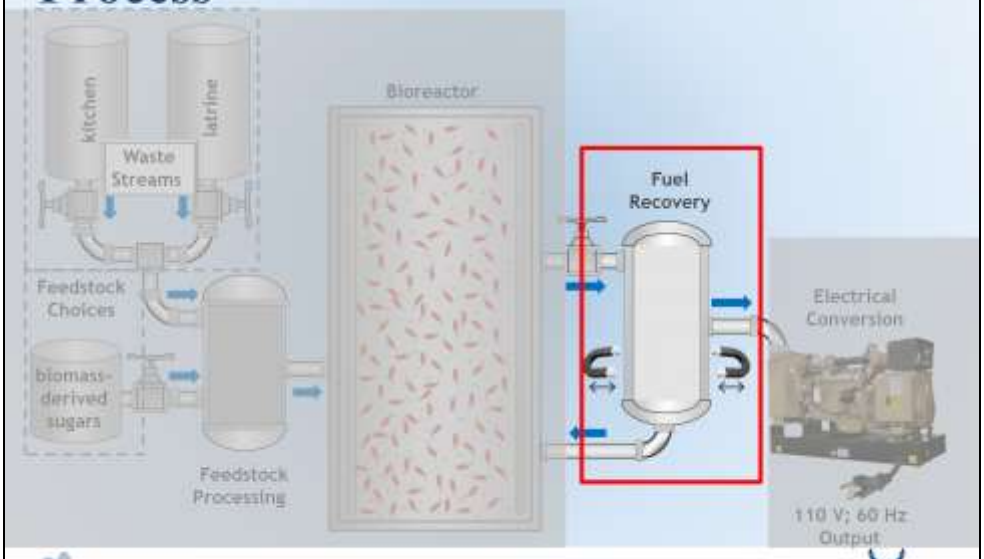


The ANL team was able cleave a C20 alcohol from the bacteriochlorophyll.

Additionally, the metabolically diverse bacterium can produce the molecule autotrophically (using sunlight and fixing CO2 from air) or heterotrophically (using energy and carbon from sugar in feedstocks).

All of these accomplishments mean that the ANL team has produced very versatile bacteria capable of producing a drop-in ready fuel from a number of different energy sources and under diverse conditions. The system can use a number of waste products like filtered grey and black water from any facility to feed the organism in an environment that can be with or without air and/or sunlight. All of this is possible at the rapid growth rates of bacteria with the simplicity of the desired molecule being exerted into the growth media or sequestered in compartments of the organism that are easily isolated.

Endurance Bioenergy Reactor™ Process

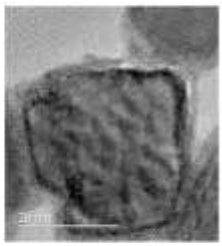


Endurance Bioenergy Reactor™

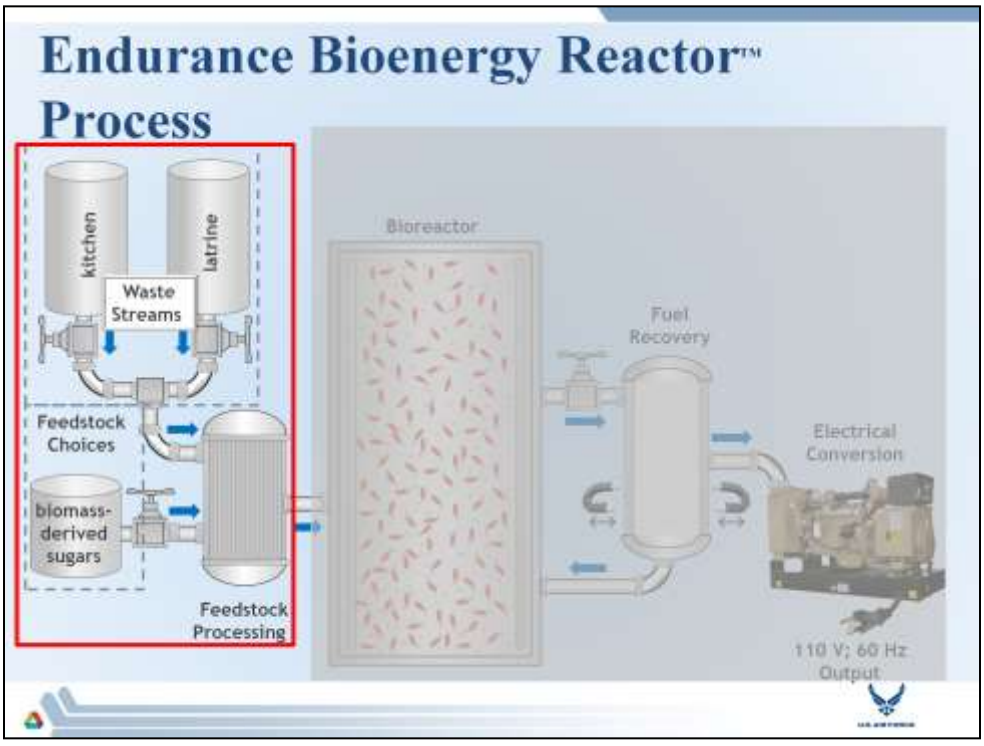
Separation

Superparamagnetic nano-particles

- Start with Fe nano cubes that are chemically treated to form a loop structure.
- These structures combine to form a microscopic net that has been tailored to trap the desired molecule and are magnetic only in the presence of a magnetic field.
- This allows the fuel to be separated form the growth media with minimal energy requirements.



This separation method consumes very little energy and adds to the overall efficiency of Endurance Bioenergy Reactor™.



At the current phase of development, there doesn't seem to be any special handling or building requirements for the system. It would be entirely up to the user where to place the system, allowing for maximum flexibility when integrating it within existing facilities.

Specifically, the design of EBR is comprised of a large bioreactor that will have an intake port connected to a supply of waste energy. The exact type of waste energy can be determined by the user, the bacteria is very versatile and feed on a number of different sources.

Once the main tank of the reactor is full of filtered energy source, inoculation with the engineered organism can occur. The current design calls for the organism to be freeze-dried and shipped within the EBR hardware, making this a simple step. Just open the package of bacteria and drop them into the main tank.

Endurance Bioenergy Reactor™ Advantages

- The energy and feedstock materials used don't compete with resources for food or farmland.
- Elimination of refinery step maximizes efficiency, minimizes the need for land and water, and reduces the carbon footprint.
- Fuel produced is compatible with existing engines and delivery infrastructures.
- Fuel production at the point of use reduces the need for costly (monetary and human) logistical convoys.
- The EBR's small scale, mobility, efficiency, and low maintenance make it a logical choice for many situations:
  - Military FOBs
  - Humanitarian situations
  - Remote construction locations
  - Existing installations

Endurance Bioenergy Reactor™ Objectives

- Administrative
  - Must be portable, similar in size and shape of standard shipping containers.
  - Must be able to be transported by truck, rail, ship and air (e.g.1-2 C-17s) to a Forward Operating Base (FOB).
  - Must be operated by 1 to 2 people* with minimal education and training.
- Tactical
  - Should produce 25 to 50 gal* of fuel per day within 48 hrs of set-up.
  - Provide selectable production rate for times of low demand.

* Estimated from laboratory tests

Endurance Bioenergy Reactor™ Objectives

- Survivable
  - Ability to produce long chain hydrocarbons in the temperature range of -10 to + 40°C.*
  - Simple recovery from inadvertent contamination with on-site resources.
  - Versatility of inputs allows use of local renewable resources – energy for organism.
  - Totally self contained, from molecule production to distribution.

* Projected range

In the End…

- EBR fulfills many requirements, here are some examples:
  - There are 120,000+ electrical generators in theater, each consumes between 40 to 90 gal of fuel per day; many are at the end of a costly logistic system.
  - 50 Gals a day equate to over 60% increase in stamina for a 60 kVA gen.
  - A single EBR at an FOB could fill up equipment or fuel a generator that could charge up to 60 light- to medium-duty electric vehicles (EVs) in a 24-hr period.* Each of these EVs would have an estimated 50 mile range.

A single EBR enables a fleet of EV to operate 3,000 miles per day –

That's efficiency, that's security, that's Endurance!

* Estimated by ANL energy systems division

Contact Information

- **Dr. Philip Laible**
  Biophysicist
  Membrane Protein Engineering Group
  Argonne National Laboratory
  630.252.4875
  laible@anl.gov

- **Major Matt "Hammer" Michaud**
  US Air Force Fellow
  Argonne National Laboratory
  630.252.7861
  matthew.michaud@us.af.mil

Endurance Bioenergy Reactor ™

Strategic Deployment & Distribution
WG-16

Military Operations Research Society Symposium

Argonne National Laboratory
Air Force Fellows

Disclaimer

- Although the Endurance Bioenergy Reactor is a proven technology, aspects of it are still in development.
- The figures herein represent best conservative estimates of performance and desired expectations by the EBR development team.
- As laboratory testing continues and EBR development progresses, true performance numbers will be established.

Two Main Types of Transportation Fuel

Table of fuel oils

Name	Alias	Alias	Type	Chain Length
No. 1 fuel oil	No. 1 distillate	No. 1 diesel fuel	Distillate	9-16
No. 2 fuel oil	No. 2 distillate	No. 2 diesel fuel	Distillate	10-20
No. 3 fuel oil	No. 3 distillate	No. 3 diesel fuel	Distillate	
No. 4 fuel oil	No. 4 distillate	No. 4 residual fuel oil	Distillate/Residual	12-70
No. 5 fuel oil	No. 5 distillate	Heavy fuel oil	Residual	12-70
No. 6 fuel oil	No. 6 distillate	Heavy fuel oil	Residual	20-70

1. **Gasoline**
   A. Cars, light trucks and small engines.
   B. Spark ignition.
   C. Specific density ranges from 0.71–0.77 kg/l, higher densities having a greater volume of aromatics.
   D. Complex mixture of over 500 hydrocarbons that may have between 5 to 12 carbons.
   E. Market: BIG

2. **Diesel**
   A. Semis, boats and jets.
   B. Compression ignited in cylinder.
   C. The density of petroleum diesel is about 0.85 kg/l about 18% more than petrol (gasoline).
   D. Diesel fuel has a much longer carbon chain length compared to gasoline.
   E. Market: **BIGGER**