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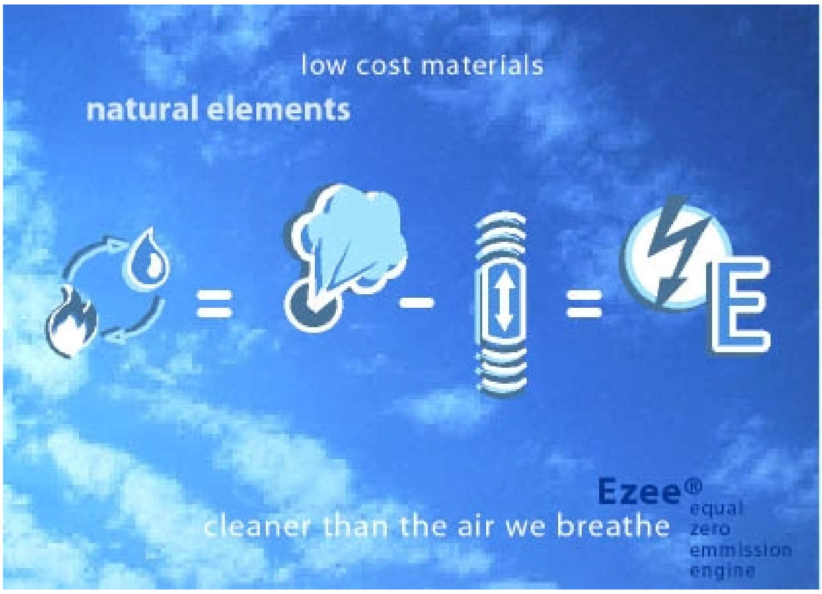
Technical Description

Ezee™

Equal Zero Emission Engine Technology



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Preface

The purpose of this description is to provide information about enginion's Equal Zero Emission Engine (*Ezee*™) Technology. It illustrates complex physical processes in an easy to understand format.

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1. Introduction

The development of the *Ezee*™ micro drive technology represents one of the largest research projects ever undertaken for an external combustion engine technology. It took more than one million engineering hours over six years to develop its basic fundamentals. At the beginning we had set a very ambitious goal to create an all-new propulsion system able to accomplish a long list of unique characteristics by neither sacrificing low production costs or other traditionally desired engine criteria.

It soon became obvious that instead of just one major obstacle there would be several significant barriers which, if unsolved, could immediately bring the entire effort to a standstill. On many of them numerous teams had already worked before at some point, but eventually failed. The hope was to overcome those obstacles by employing latest known technologies and approaches.

While explaining the *Ezee's* basic functionality this description will try to reference a few of those problems, which could finally be solved at the right time with novel techniques, new ways of thinking and certainly fortune.

What came out is a technology that appears to have a serious economic potential in nearly all modern application areas that require heat energy, mechanical energy or electrical energy.

2. Summary

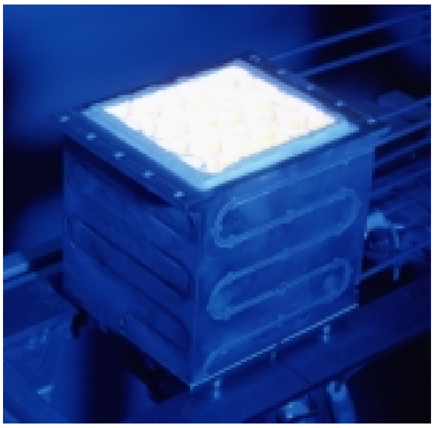
The *Ezee*™ Technology provides a highly innovative external combustion engine, which achieves an emissions profile that is among the lowest of any fossil and renewable fuel combustion technology. It is based on a patented “Caloric Porous Structure Cell” (CPS Cell), employing a recently developed thermo-chemical combustion process, and an electronically controlled, oil free thermal drive (ThermaDrive™).

The *Ezee* Technology incorporates the following benefits:

+ Lowest pollutant emissions (“Cleaner than the air we breathe”)
+ No catalysts

- Very high torque (5 times higher than regular Otto-cycle engines); power to size ratio is equivalent to diesel engines
- Fuel flexibility (gasoline, diesel, natural gas, non-fossil biofuels, hydrogen etc.)
- Independent heat and mechanical power output (both variable)
- Power turnout adapts within thousands of a second
- Near zero noise
- Vibration free
- Compact and robust design
- Oil free
- Lower cost than comparable propulsion technologies (including fuel cells and gas turbines)

3. Caloric Porous Structure Cell (CPS Cell)

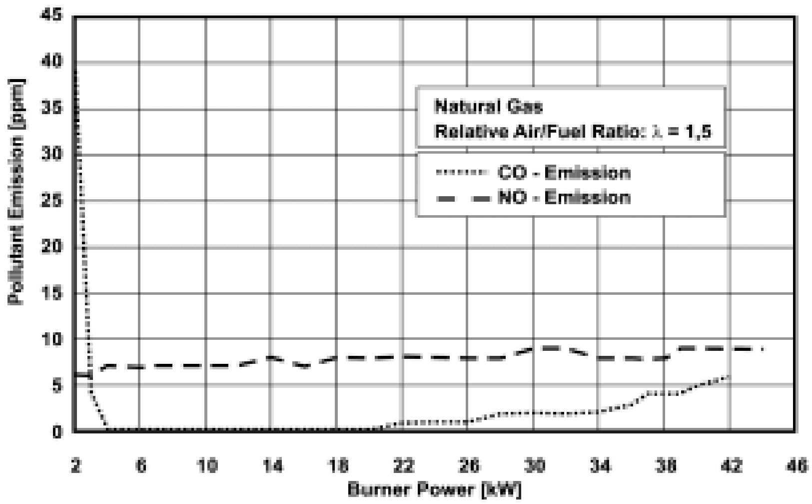


A CPS Cell at full load. Pure thermal energy, no open flame.

An integral part of the Ezee drive technology is a patented “Caloric Porous Structure Cell (CPS Cell)”, occasionally also referred to as “heat cell” or “combustion matrix”. It is a newly developed device capable of oxidizing a fuel with extremely low pollutant emissions. The CPS Cell can theoretically process any fuel that can be vaporized and pre-mixed with air - liquid or gaseous, fossil or renewable. The result is a clean stream of hot exhaust gas that we use to power our innovative ThermaDrive™ system.

The CPS Cell is made of a highly developed ceramic foam. While an air/fuel mixture flows through its sponge like structure, the fuel does not burn up like in a conventional burner. In the

CPS Cell it oxidizes from pore to pore without open flame - similar to a thermal reactor. The pores have a precisely defined structure and size that prevents the fuel from flaming up and therefore developing thermal pollutant emissions. A simple yet sophisticated heat control system keeps the cell's temperature at a moderate temperature of around 1200 Degrees Celsius. This translates into no or ultra low levels of harmful gases such as NOx, CO and HC. The cell's output power can be accurately controlled and varied within 5% to 100% of its rated power. Its response time to changing load demands is only a few Milliseconds (thousands of a second), allowing for highly dynamic applications. With their incredible power capacity of up to 30 MW/m³ CPS Cells can turn out thermal energy so high that a cell of only one cubic metre in size could theoretically generate sufficient heat to supply about 1,000 houses. As a result only a very small cell is required for ThermaDrive™ applications. An effortless ignition system gets the CPS started, afterwards it keeps itself going until the fuel supply is shut off. All used materials and components are inexpensive, fully recyclable and easy to manufacture.



Emissions characteristics of a CPS Cell: Pollutant levels are at the limit of measurability. Hydrocarbons (HC) can not be detected at all. Latest Cell generations achieve another 50% cutback.

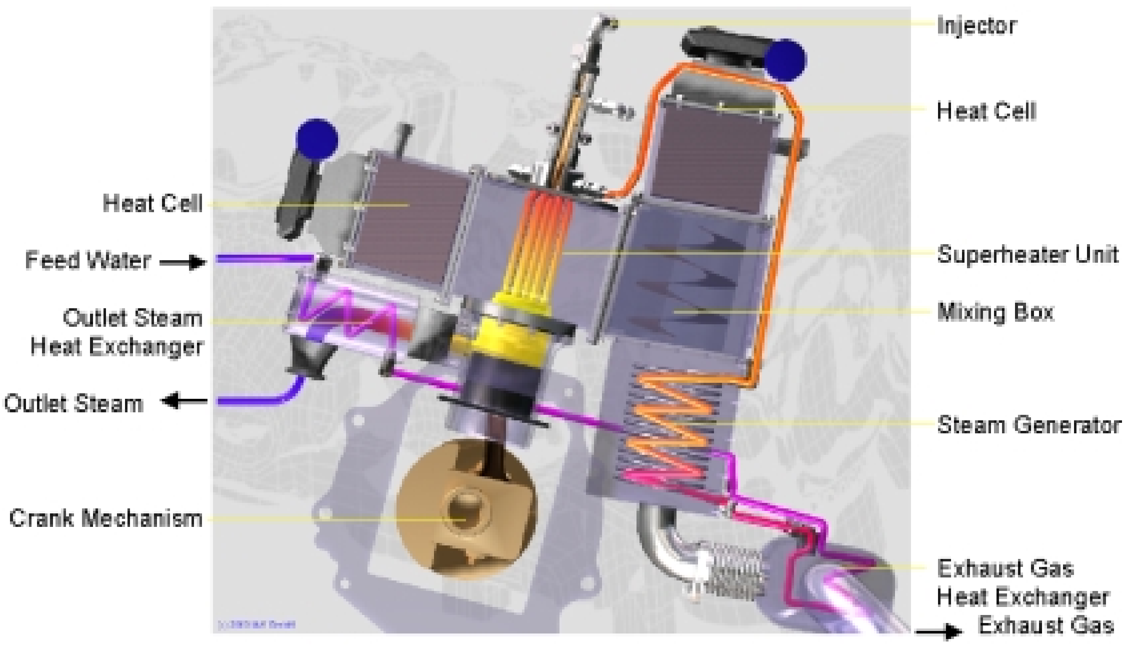
4. ThermaDrive™

The heart of the Ezee Technology is its unique thermal drive, which transforms the CPS Cell's heat energy into mechanical energy in a quiet and efficient process. It was a long way to reach the results that have been listed in paragraph 1. This chapter will describe some of the drive's key elements.

Instead of an exploding air/fuel mixture as used in traditional engines the ThermaDrive internally utilizes ultra vaporized steam as its kinetic work medium. Thus it can certainly be said that the drive's closest cousin would be a steam engine. However, it is not to be confused with traditional steam engines, as the ThermaDrive uses many different approaches such as a closed water system, oil free lubrication and an essentially superior thermodynamic cycle.

Plain, purified water was chosen over other possible work media, as it proved to be the best compromise regarding cost efficiency and compliance with environmental criteria.

Short description of the original research engine.



Cross sectional picture of the original research engine that served as component carrier during the Ezee's basic development. It is a 3 cylinder 2-stroke engine with 1 litre displacement. With its compact dimensions it would easily fit under the hood of a compact car. Nevertheless, this engine reaches an incredible torque of up to 500 NM (400 ft.lbs.) – more than conventional V12 engines.

The feed water for the drive's work cycle enters from a small water tank. On its way through the engine the water picks up as much "waste heat" as possible by being guided through an outlet steam heat exchanger and an exhaust gas heat exchanger. This increases the engine's overall efficiency and additionally guarantees for a safe temperature on its outside body.

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The pre-heated water flows into a steam generator, which is heated by the hot exhaust gas of two CPS Cells. Hence their thermal energy gets transferred into the water, which turns into highly energetic steam with a temperature of 500 Degrees Celsius and a pressure of up to 500 bar.

With an electronically controlled injection system a precisely defined amount of steam is injected into the engine’s expansion chambers. On top of its piston/liner combination resides a super heater unit as part of the cylinder’s headroom. The super heater is directly fired by one of the CPS Cells. When the steam is injected the super heater provides an abrupt temperature boost that can go up to 900 Degrees Celsius. This translates into a powerful expansion plus superb efficiency, as more energy can be “pumped” into the thermodynamic cycle.

The expanding steam’s force pushes down a piston. Higher amounts of injected steam result in a larger force, which directly corresponds to the engine’s torque output. The near “explosive” expansion within the cylinder provides torque that is up to five times higher than regular otto-cyle (gasoline) engines. The whole process works silently, as there is no actual explosion or knocking noise.

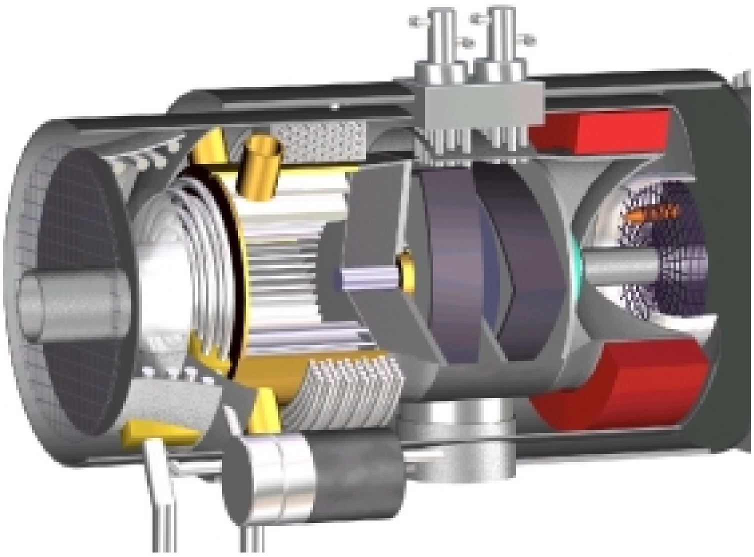
Toward the end of its expansion phase the steam cools down. After leaving the cylinder chamber it additionally gives remnant heat to the incoming feed water. This relatively cold outlet steam finally leaves the engine, flows through a small condenser and is then ready to re-enter the engine as fresh feed water.

The cycle is completely closed and no water needs to be added.

The original research engine fits under the hood of a compact car

This research engine had accumulated several hundred hours of operation for demonstration and measurement purposes without problems, before we went on to the next development phase. We had chosen this small inline reciprocating engine, because it was easy to exchange parts, convenient to compare with conventional reciprocating engine characteristics and indeed much more painless to get used to for someone who hears about it for the first time. The engine has fulfilled the target criteria that we had set. Some measurements can be seen in the last chapters of this document.

However, *Ezee* drives are not limited regarding engine type or size. They can for instance be designed as V-shaped reciprocating engines as well as rotary drives, as shown in the figure below. Their areas of application may range from tiny zero emission lawn mowers up to heavy-duty trucks.



The Ezee Technology allows for large freedom regarding engine layout and design. Shown is an Ezee based drive system with rotary expanders. There is no crankcase necessary.

Current development:

Compared to the initially developed reciprocating engine it can be said that rotary designs of this technology show even greater potential, as they keep the rotaries' specific advantages (no crankcase, no vibration, compact size etc.), but they avoid disadvantages typically known from their internal combustion cousins (lubrication problems, bad emissions etc.).

Accordingly Enginion's latest generation ThermaDrive™ is an innovative rotary design. In an ongoing test the new drive's oil free friction components have so far been tested for more than 35,000 hours, which is a useful indicator for later product durability (comparison: vehicle engines are commonly engineered for a lifetime of 2,000-5,000 operating hours).

Please note: The new rotary design including expansion unit looks different than the one shown in the above picture. Please understand that we need to keep the actual design's details confidential.

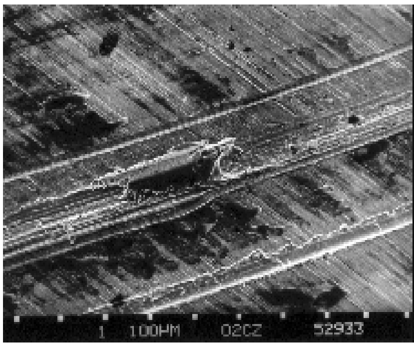
Rather than using CPS cells for powering a ThermaDrive it is also conceivable to employ entirely different heat sources such as environment friendly solar power.

3.1 Oil Free Lubrication

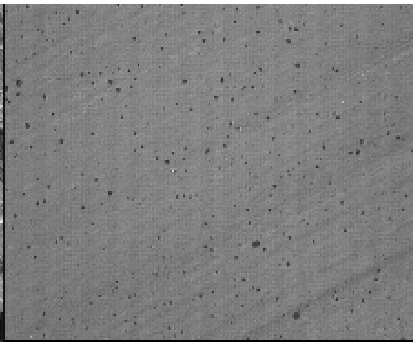
One of the most dramatic developments within the thermal drive is its entirely oil free system. The materials that have evolved after four years of tribologic research are among the lowest solid friction materials ever developed.

The motivation for such enormous research effort was the simple fact that lubrication oils are limited in their capabilities to resist high temperatures, especially those used within an engine based on the Ezee™ Technology. Additionally, oil could possibly get in contact with the steam and therefore contaminate the drive's feed water. This is obviously not desired for ecological and maintenance reasons. Another major obstacle was the necessity to find materials that can withstand the corrosive power of steam media.

After four years of rigorous tribological research, a unique carbon based ceramic material could be synthesized that solved all mentioned friction problems when used in conjunction with another special coating on the opposite friction side. The tribologic system resulting for piston/liner has extremely low friction and wear. It can operate under very hot and dry as well as super heated steam conditions.



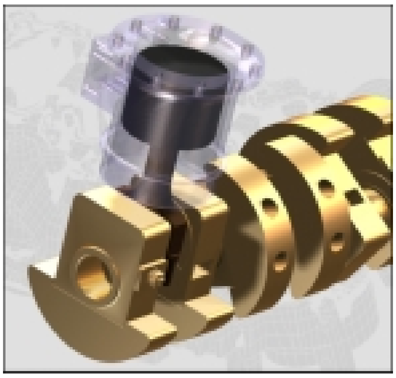
Electron microscope picture of a good commercial dry friction material: Visible scratches.



Electron microscope picture of an Ezee cylinder wall after the same friction test: Almost no wear.

Resulting carbon based piston with carbon based piston rings.

Likewise, for the crankshaft bearings new materials could successfully be designed. The crankcase of the Ezee reciprocating engine is partly flooded with water, which includes a special polyethylene glycol additive. This has various advantages such as additional lubrication to the bearings and frost protection. Blow-by water is allowed to enter the crankcase and mix with the crankcase fluid. Since glycol and water can easily be separated from each other, the excessive water can be fed back into the drive's cycle without problems.

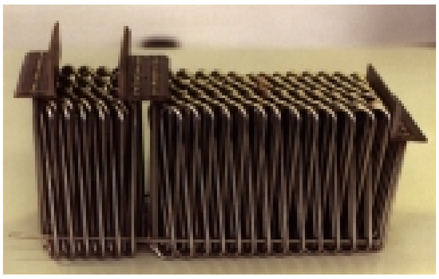


Water lubrication for the research engine's piston, liner and crankshaft bearings.

All used materials are 100% recyclable and non-toxic.

3.2 Steam Generator

The steam generator's task is to transfer as much thermal energy from the CPS Cell to the feed water as possible. This can only be achieved by using highly conductive materials and a large overall transfer surface. The developed steam generator is a very compact bank of austenitic steel tubes. In the original research engine it has for example a total tube length of 200 ft. per cylinder, which results in a heat transfer surface of 10 ft². Feed water flows through its tubes while the CPS Cell's stream of hot exhaust gas drifts along the stack, transferring the thermal energy to the water and steam.



Compact Steam Generator

The resulting steam has a temperature level of up to 500 Degrees Celsius and is more or less dry. Although pressure is lifted up to an incredible 500 bar (=50 MPa or 7250 PSI), its density still reaches only 25% of water. Hence the total mass of molecules moving through the engine is extremely low, and tubes may be built very thin, reducing the engine's overall weight. Because of its low water density people often discuss about whether the work medium can still be called steam. It is also often referred to as "steam gas".

3.3 Superheater Unit

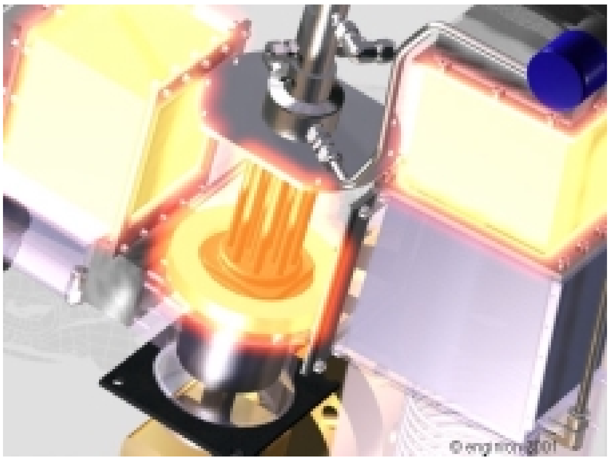
When steam is injected into the engine's expansion chambers, it first has to pass through a glowing stack of steel tubes, named superheater unit. It may look unimportant, but this is one of the most interesting thermodynamic developments within the chain of Ezee Technology inventions.

Large commercial power plants with energy outputs in a gigawatt range (=million kilowatts) can greatly increase their efficiency by "pumping" more heat into the cycle, practically by intersectional heating after several phases of stepwise expansion. The thermodynamic effect that is tried to approach is called "isothermal expansion", meaning that the temperature during expansion should remain nearly constant. So far, there had not been found a solution in terms of how this complex process could be downsized to systems of only a few kilowatts.

The superheater unit was the answer. When the injected steam flows through the device it picks up heat from its glowing walls. During expansion, when the pressure within the engine chamber pushes down the piston, the steam gas would usually be cooling down. But the superheater keeps on introducing more and more heat, as it is supplied by thermal energy from a CPS Cell close by. In some cases it can even increase the injected steam's heat and therefore the engine's efficiency by boosting up to 900 Degrees Celsius during expansion.

Superheater Unit

The employed heat resistant nickel based alloys tend to enlarge when heated up. While developing the superheater unit, this created major issues when designing the tubes' joints. Finding a reliable manufacturing process was a big challenge as well. But finally a technique could be developed that comfortably overcame all obstacles.



The superheater unit is located between injector and piston. It is directly fired by a CPS Cell.

3.5 Injector

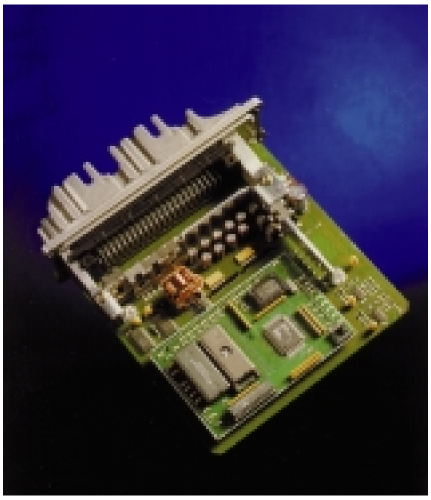
A newly developed electronically controlled injector makes it possible to accurately inject even smallest amounts of steam. This is important because the engine can quickly generate very high torque.

Steam Gas Injector

The injector technology is very similar to top-notch common rail diesel injectors. The employed materials differ though, as they need to be non-corrosive. The injected steam is equally distributed to the superheater unit's tubes.

3.6 Electronic Control

Another dominant effort during the Ezee Technology's research was developing an all-new, sophisticated control system. Since many processes were new and had never been controlled before, it became a challenging joint task for algorithm designers, thermo science experts, simulation engineers and hardware specialists. The resulting system uses the computing powers of modern vehicle control units and incorporates latest technologies including adaptive and neural approaches as well as self-diagnostic capabilities. This translates into a highly exact, dynamic and reliable control over the engine's lifetime. All hardware components are low cost off-the-shelf parts.



Electronic Control Unit

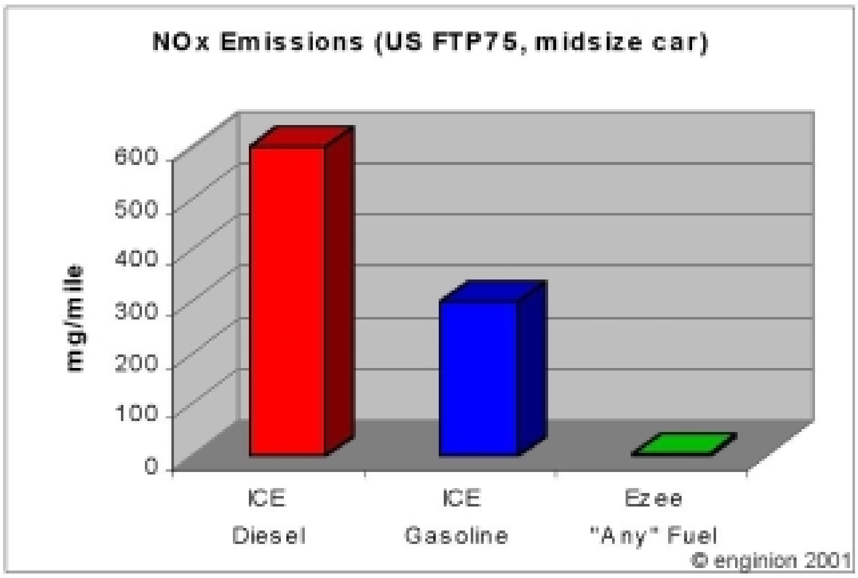
3.7 Cold Start and Anti Freezing

It takes about 2 seconds for a CPS Cell to start up and about 20-40 seconds for a cold ThermaDrive system to deliver mechanical energy. Warm starts are performed within a few seconds. In an optional stand-by mode the engine can power up instantly.

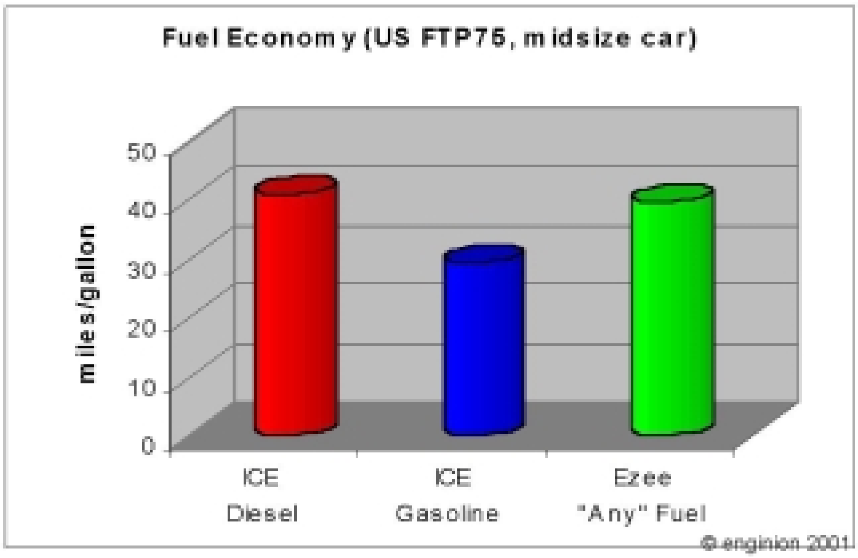
A typical obstacle that usually comes up in conjunction with water based systems is the obvious question how to handle very cold conditions. Water expands when freezing, which can be very destructive.

After turning off an engine based on the Ezee Technology, its own remaining steam pressure can be used to push all water out of the system. It is then collected in a small water tank. The insulation is sufficient to keep the water warm for at least 24 hours. Afterwards a simple heater system with low energy consumption keeps the water temperature above its freezing point. This process only requires so little energy, as the engine uses extremely small amounts of water (passenger car engine: 4 liters). However, for long term shut-off and worst case scenarios the tank is designed for allowing the water also to freeze without causing structural problems. Certainly, startup times will then be increased in order to defrost the water system.

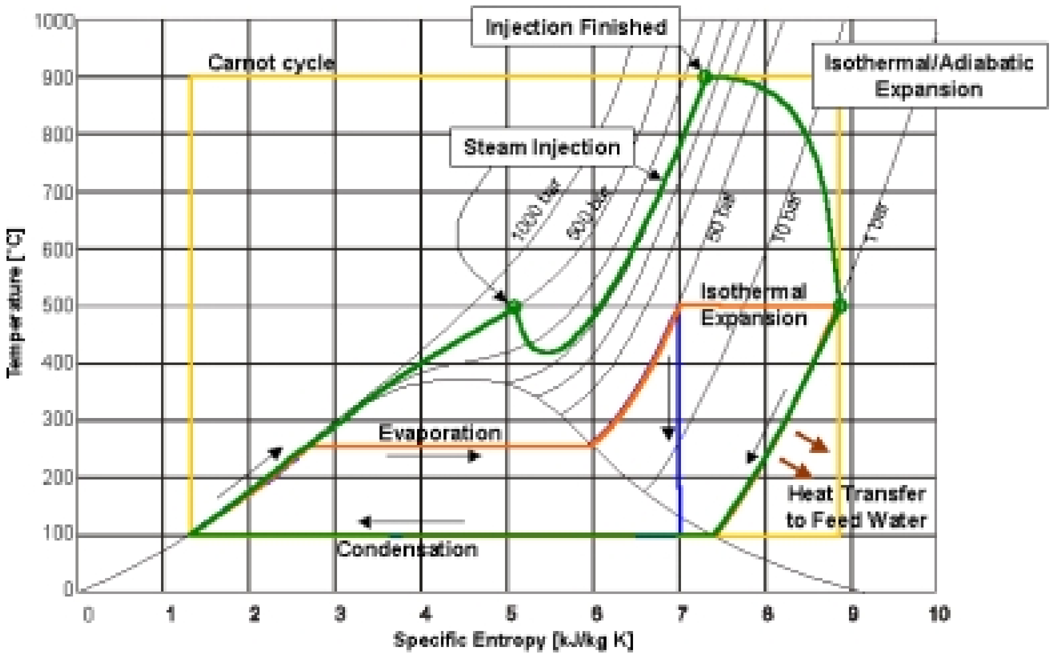
4. Emissions



5. Fuel Economy



6. Thermodynamics



Thermodynamic cycles: A traditional „Rankine cycle steam engine“ passes a wet steam area (evaporation), takes on more heat and finally expands (blue line). The Ezee instead approximates isothermal expansion that is considerably more energetic and efficient (red line). With steam injection system the Ezee‘s efficiency could additionally be improved (green line).

For actual scientific information and measurements please see MTZ Engine Science Magazine, Issue Mai/2001