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Cold Fusion Will Lower the Cost of Both Energy and Equipment

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ABSTRACT

Cold fusion will lower the cost of energy because the fuel costs nothing. It will also greatly reduce the cost of many machines, especially electric generators. The cost of generators is likely to fall by a factor of 200, from $2,000/kW to $10/kW, which is the cost difference between a power company central generator and a portable gasoline generator.

A radical reduction in the cost of one device does not always reduce the cost of others. Since 1900, the cost of illumination has fallen by a factor of 80, but this has not directly reduced the cost of other goods and services by a similar factor. Since 1970, the cost of computer memory has fallen by a factor of 10^8. Microprocessors and cheap memory enhanced many products. They brought us the internet and ubiquitous cheap computing. But so far they have not drastically lowered costs outside of computer applications. Cold fusion is different. All machines use energy, so cold fusion will lower the cost of everything, but it will have the biggest impact replacing large, expensive machines with small mass-produced versions. Other new sources of energy such as solar panels also have zero cost fuel, but they will not reduce the cost of other machines. Only cold fusion can do this.

It follows that the most profitable use of cold fusion in the first decades after it is introduced will be to replace existing technology, rather than to make radical new technology. Microprocessors brought us machines we did not have, such as cell phones and the internet. Cold fusion will — at first — dramatically lower the cost of machines we already have.

Introduction

Winston Churchill wrote about nuclear fusion in 1932, a few years after it was discovered. He understood the two most important things about it: the energy density and abundance are millions of times greater than chemical fuel. He wrote:

> If the hydrogen atoms in a pound of water could be prevailed upon to combine together and form helium, they would suffice to drive a thousand-horsepower engine for a whole year. . . .
>
> The discovery and control of such sources of power would cause changes in human affairs incomparably greater than those produced by the steam-engine four generations ago. Schemes of cosmic magnitude would become feasible. Geography and climate would obey our orders. Fifty thousand tons of water . . . would, if [fused], suffice to shift Ireland to the middle of the Atlantic. [1]

The Irish probably do not want us to move their island, but other megaprojects would benefit humanity. We could build thousands of desalination plants to turn the Sahara desert into farmland. We could afford to do that because <u>the desalination plants themselves would be much cheaper than today's models.</u> That is the key thing, and it is the subject of this paper. Cold fusion does not just lower the cost of energy, it also lowers the cost of machines that use energy.

Large generators compared to automobile engines

I predict the most dramatic cost reductions will be for electric generators. Table 1 shows the capital cost per kilowatt for power company generators, listed from cheapest to most expensive, $1,400 to $6,600 per kilowatt of capacity.

Table 1. Power company generator cost per kilowatt

Type of Generator	Cost per kilowatt
Natural gas, GE LM6000	$1,376 *
Natural gas (advanced)	$2,095
Onshore wind power	$2,213
Coal (cheapest)	$2,934
Hydroelectricity	$2,936
Photovoltaic	$4,183
Nuclear	$5,530
Coal (advanced)	$6,599

* This estimate from Parsons Brinckerhoff New Zealand Ltd.; [2] all others from Energy Information Agency (EIA.gov) [3]

In contrast to the conventional sources of energy in Table 1, cold fusion has characteristics that may make it very inexpensive. It is safe, easy to produce, flexible, scalable and clean. We know it has these qualities because on rare occasions it has produced stable, high power continuously for weeks, at boiling temperatures. In the best experiment on record, the Icarus 9 reactor produced the same power density as a fission reactor core (Table 2). [4] The performance demonstrated in these tests would suffice for nearly all practical applications.

Table 2. Icarus 9 power density versus fission fuel pellet

	Volume	Operating temperature	Power density by volume	Power density by area
Icarus 9 cathode	0.3 cm^3	100°C	300 W/cm^3	16 W/cm^2
Fission reactor fuel pellet	1.0 cm^3	300°C	180 W/cm^3	32 W/cm^2

If this reaction can be controlled and similar performance created at will, cold fusion will swiftly replace most other sources of energy. Even the need for palladium would not prevent this. After a few decades cold fusion heat engines will be cheaper than today's fossil fuel ones, and electric generators will be roughly 200 times cheaper, and eventually thousands of times cheaper. To understand why, let us compare two heat engines.

First, a General Electric aeroderivative gas generator (Fig. 1). This produces 58 MW and it costs $1,376 per kilowatt of capacity.

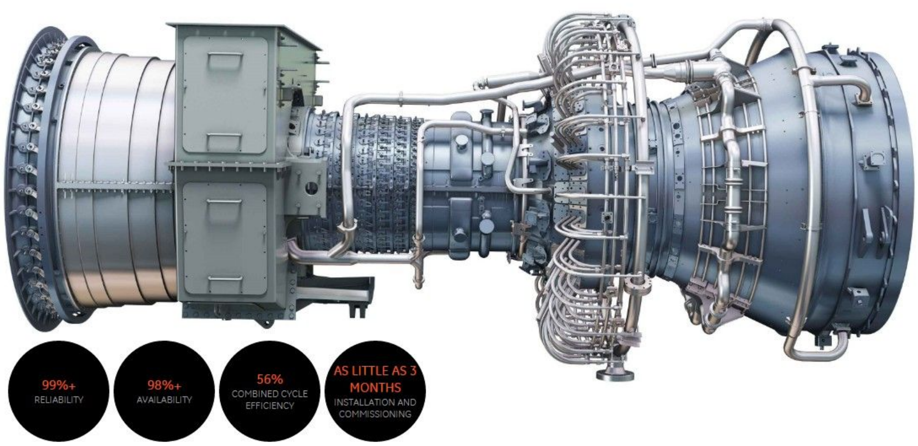

Figure 1. General Electric LM6000-PF gas turbine generator (GE Power Generation)

Second, a Chevrolet engine, Goodwrench 350ci, 145 kW (195 hp), which costs $1,460, retail quantity one, with free shipping (www.jegs.com) (Fig. 2). That is $10 per kilowatt. It is 130 times cheaper than the GE generator, and up to 600 times cheaper than the other power company generators.

Figure 2. Chevrolet Goodwrench 350ci engine (www.jegs.com)

This comparison may seem unfair at first glance, because the Chevrolet engine is not a generator. It needs an alternator to produce electricity. But an alternator is cheaper than the engine itself. The GE generator needs an electric power distribution grid, which is more expensive than the generator. A small, mass produced heat-engine generator does not need the distribution grid. So the ratio is actually better than 130.

Why is a gas turbine generator so expensive? The main reasons are:

1. Efficiency is high. The GE generator shown here is 56% efficient. Combined cycle turbine generators are as much as 78% efficient. They are made this way because over the life of the machine the fuel costs much more than the equipment. Small gasoline powered generator efficiency ranges from 8% for a 1.8 kW unit, to 14% for a 10 kW unit (Generac, Inc. and Kohler, Inc.).
2. Mass production. Gas turbine generators are made in small numbers, whereas 60 million automobile engines are mass produced per year.
3. The turbine is an ultra-modern 21st century machine, sophisticated and complicated. The Chevrolet engine is 19th century technology.
4. Power company generators are designed for a high duty cycle and a long service life. Automobile engines are designed to run a few hours a day, for about twelve years.

The turbine generator is gigantic, complicated, difficult to ship and install. The Chevrolet engine is so small the dealer will ship it to you for free. Small gasoline generators are used everywhere in India today, because they are cheap and light.

So, which heat engine is best for cold fusion? The cheap one. There is no advantage to high efficiency with cold fusion, because the fuel costs nothing. You select a cheap, simple, robust design. You replace large, custom built machines with small mass produced ones.

The small cold fusion generator negates other advantages of power company generators: economy of scale, long duty cycle, service lifetime and reliability. See Table 3 (from Ref. [5], chapter 14).

Economy of scale. As shown in Table 3, there is no economy of scale with cold fusion; there is no economic advantage to central generation or a distribution grid.

Table 3. Advantages of centralized generation and power companies

Advantages of large, central generators	**Cold fusion**
Pollution moved to less populated places, so it hurts fewer people	✘
Remaining pollution reduced	✔
Economies of scale	✘
Efficient use of fuel	✘
Safety enhanced	✔
Cogeneration	✔
Advantages of power companies	
Experts maintain equipment	✘
Experts monitor the network	✘
Quickly repair network after storms and other disasters	✘
Distribute power so that capacity and the cost of equipment is shared	✘
Synchronize alternating current from many different generators	✘

✔ Cold fusion does this better than a large central generator.

✘ Cold fusion makes this function unnecessary.

Duty cycle. The duty cycle of an automobile engine would be a problem. The gas turbine generator is designed to run for many hours a day. Baseline generators at nuclear and coal plants are designed to run twenty-four hours a day. An automobile engine is designed to run a few hours a day. This problem could be reduced by using a battery so the generator turns off when demand is light. Wear and tear on the generator can be reduced with air bearings which have been developed for micro-turbine generators. [6] With these improvements, the generator might run as many hours a day as a refrigerator compressor motor, or a heat pump motor.

Service lifetime. A power company generator is designed to last 30 to 50 years. A consumer appliance with moving parts will probably last about fifteen years. However, natural gas fired thermoelectric generators last 30 years (Fig. 5). [7] They are used for things like remote railroad crossing gates. The cost of today's thermoelectric generators is high, because they are not mass produced, and because they use tellurium or selenium, which are expensive and rare. Research is underway to find less expensive substitutes. [8] The substitutes that have been discovered in recent years are less efficient, but this would not matter with cold fusion.

Reliability. A cold fusion generator as reliable as a conventional automobile or refrigerator would be good enough for most people. It would be more reliable than electric power in cities such as Atlanta, Georgia where trees often fall on the power lines, and the electricity fails several times a year. If a household cold fusion generator failed, it might be repaired or replaced on a 24-hour basis the way furnaces and plumbing are repaired. Facilities where there is a critical need for electric power, such as hospitals and police stations, would have redundant power supplies. They already have them, with standby generators.

Zero cost fuel does not always lower costs

Zero cost fuel does not necessarily make generators inexpensive. It does not always lower the cost of electricity. Wind, photovoltaic and hydroelectricity are powered by the sun. The fuel costs nothing. Yet these energy sources are not cheap, because they are encumbered by fundamental limitations: low power density, intermittency, limited availability, and the need for a distribution grid.

Consider photovoltaic power (PV). Sunlight is weak and spread over a large area, so no matter how efficient PV become they will need large surface area collectors. PV does not work at night or on cloudy days, so it must be augmented. An ideal PV installation in the upper U.S. Midwest covers the whole southern roof of a house and produces 612 kWh/month (Fig. 3). The average U.S. household needs 911 kWh/month. [9] A cold fusion generator will resemble a standby generator such as the one shown in Fig. 4. This is a natural gas-fired 22-kW generator that costs $4,800 (Lowe's Inc.). It is smaller, simpler and cheaper than PV. A cold fusion version will produce up to ~16,000 kWh/month with a fuel cost of zero. A cold fusion heat engine will be about as compact as this because, as noted above, in the best experiments to date it has produced high power density and temperatures, and I assume this would be the norm with mass produced cold fusion heat engines.

Figure 3. Solar panels produce 612 kWh/month in the upper Midwest (cleantechnica.com).

Figure 4. A 22-kW gas-fired standby generator. A 20-kW cold fusion generator will be about this size, and will produce up to 14,600 kWh/month (Lowe's, Inc.)

Cost Savings

Suppose we manufacture 170 million 20-kW generators per year. Suppose they cost $2,000, about half as much as today's standby generator. Mass production will eventually reduce the price more than that, but let us be conservative. This kind of appliance lasts about 15 years. After 15 years we have 2.5 billion units in service, or one for every three people in the world. This would give every person 9 times more than today's per capita generator capacity, and twice as much capacity as Americans enjoy. Since the generators will not cost anything to operate, people will use them all they want, so consumption will probably increase more than 9 times.

Present day total world generator capacity is 5,847 GW or 0.75 kW per capita. [10, 11] The 2.5 billion cold fusion generators would produce 50,000 GW. The electrical energy would far exceed energy from all primary sources today, including gasoline.

We will not actually make all of these generators 20 kW. We will make small ones for houses, big ones for apartments and schools. They will supply electricity, and in cold climates the waste heat will be used for space heating, as a cogenerator.

The cost will be $340 billion per year, which is 22% of what we spend on new cars and trucks worldwide. It is roughly 5% of what we pay for energy. Worldwide revenue made by the 16 top automotive manufacturers is $1.5 trillion. [12]. Worldwide energy costs are estimated at $6.4 trillion. [13]

Wind and PV power have not drastically reduced energy costs because of inherent limitations with these technologies. Other innovations in the last fifty years have lowered costs. The semiconductor revolution dramatically lowered the cost of electronics, computing, and computer memory. This lowered the cost of some machines and it improved many others. It brought about revolutionary new technology such as cell phones and the internet. The cost of semiconductor devices themselves have fallen more dramatically than anything else in history. (See Fig. 6, below.) But semiconductors have not drastically lowered the cost of automobiles, for example, because the electronic controls in an automobile are a small fraction of the total cost. Electronics are incorporated in many machines where they were not used in the past, such as Jacuzzi bathtubs and hotel doors. But they do not lower the cost of a bathtub; they enhance functionality. Cold fusion is different. All machines use energy. With most machines, either the motor or the energy itself are a significant fraction of the cost of the machine.

Energy is "baked into" all goods and services, at every stage. All manufacturers pay energy costs, as do distributors, government agencies, banks, retail stores and so on. Energy costs are included in transportation, data processing, the internet, healthcare, food, water and everything else. Energy costs are at historic lows, but energy still adds an expense at every stage of manufacturing, distribution and disposal of goods.

In the U.S. a 20-kW cogenerator would provide enough power for most houses. The equipment will cost roughly as much as a home heating furnace does today. Since it is a cogenerator, it will replace that furnace. The net additional cost to the homeowner is zero, because you have to have a furnace anyway. (U.S. building codes mandate that houses must have furnaces.) Over the 15-year life of the equipment it will save approximately $30,000 in electricity plus gas used for home heating. People will install these machines gradually, as their furnaces wear out, or when they build new houses. Roughly 15 years after the machines become a commodity, there will be practically no buildings left with gas or electric service, and the electric power and gas companies will be bankrupt.

This estimate of savings is based on data from the US Energy Information Administration, as follows. For electricity, the 2013 Average Monthly Bill – Residential cost was $114.09. [14] U.S. average household winter natural gas expenditures in 2014 were $679 per season. [15] The total over 15 years for electricity and natural gas is $30,720.

In the third world, smaller, simpler generators may be used, similar to the gasoline generators widely used today in India. These are 3 kW and they cost $429 in the U.S. I predict a mass produced cold fusion version will cost about $200, which is about as much as two bicycles. Bicycles are popular in the third world, and most poor families can afford one or two. Per capita income in sub-Saharan Africa is estimated by the World Bank as $137 a month. That includes income per capita for children, so the average family makes more than that.

Drastic cost reductions

This principle — of selecting cheap, simple, rugged, mass produced machines — applies not only to generators but to things like furnaces, kilns, water heaters and thermal refrigerators. (That is, refrigerators driven by heat instead of mechanical compressors.) This will also reduce the cost of energy-intensive industries such as mining, transportation and desalination; and the cost of materials that require a lot of energy to extract, such as aluminum. All of these things will be drastically cheaper.

There are several examples in history of the benefits of transitioning from a small number of large machines to millions of mass-produced small ones, such as the replacement of water wheels and steam engines with electric motors, and the replacement of mainframe computers with personal computers.

I predict that cold fusion will begin with conventional heat engines and generators with moving parts. It will later progress to solid state thermoelectric generators (Fig. 5). These may eventually cost $200, or $10 per kilowatt, which fulfills my starting prediction: electricity 200 to 600 times cheaper then what we have now.

Figure 5. A thermoelectric generator. This has no moving parts so it lasts much longer than the generator shown in Fig. 4 (Gentherm Global Power Technologies).

When a new technology comes along, people use it at first as a one-for-one replacement for existing technology. Later they develop more creative applications that take advantage of the new capabilities. Microprocessors were first used to replace minicomputers, and later for new things such as cell phones and the internet. Cold fusion will, at first, lower the cost of machines we already have. Later it will be used for revolutionary new products.

Drastic cost reductions are not unprecedented. In the first world, food and many other necessities of life are cheaper than they used to be. Intangible goods such as light, energy and computer memory are especially prone to dramatic cost reductions. Since 1800, the real cost of illumination has fallen by a factor of 3,300. It fell by a factor of 80 during the 20^{th} century (Fig. 6). Efficiency increased 700 times, and consumption increased 34,000 times. [16] The real cost of electricity has fallen by a factor of 10 since 1902, from $1.04 per kilowatt hour to $0.10. [14, 17] Since 1960, the cost of computer RAM and disk storage have fallen by 8 orders of magnitude (Fig. 7). [18]

The lower cost of lighting has reduced the cost of other goods and services, for example, by reducing overhead costs in a factory, and allowing longer production hours at night. However, this did not have as much of a dramatic impact on costs as lowering the cost of electricity by a factor of 200 would. At most factories, the cost of illumination is a small part of overhead costs, whereas energy costs are large for many goods and services.

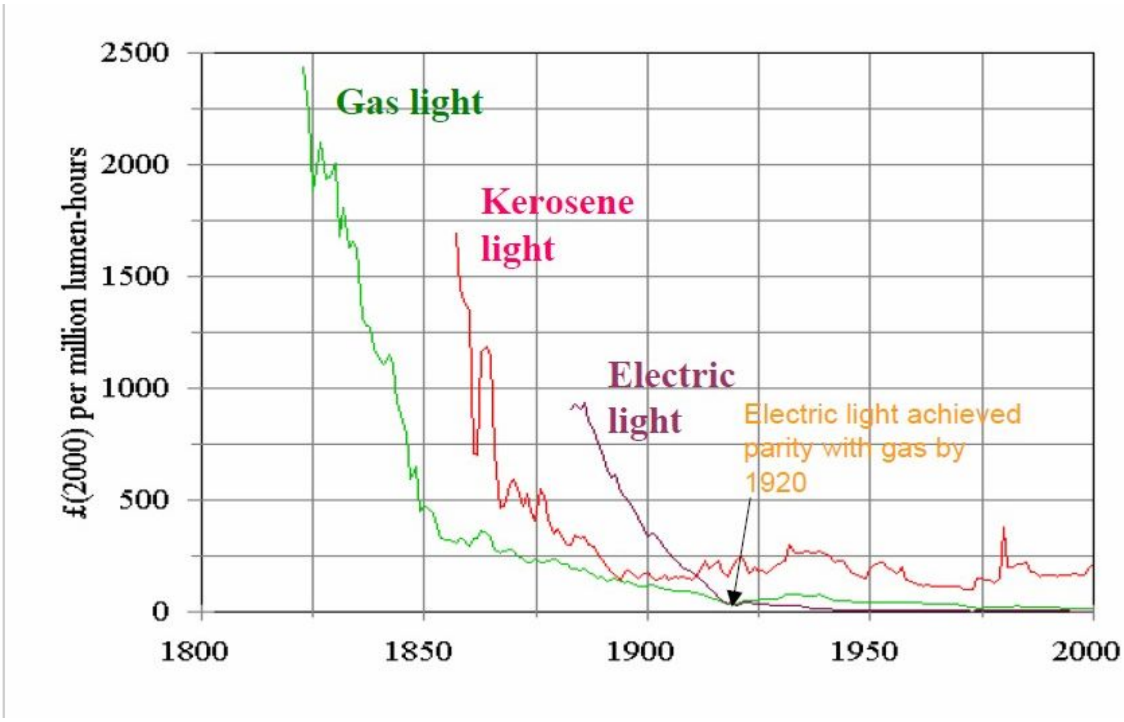

Figure 6. UK Price of gas, kerosene and electric light (£ per million lumen-hour), 1800 - 2000.

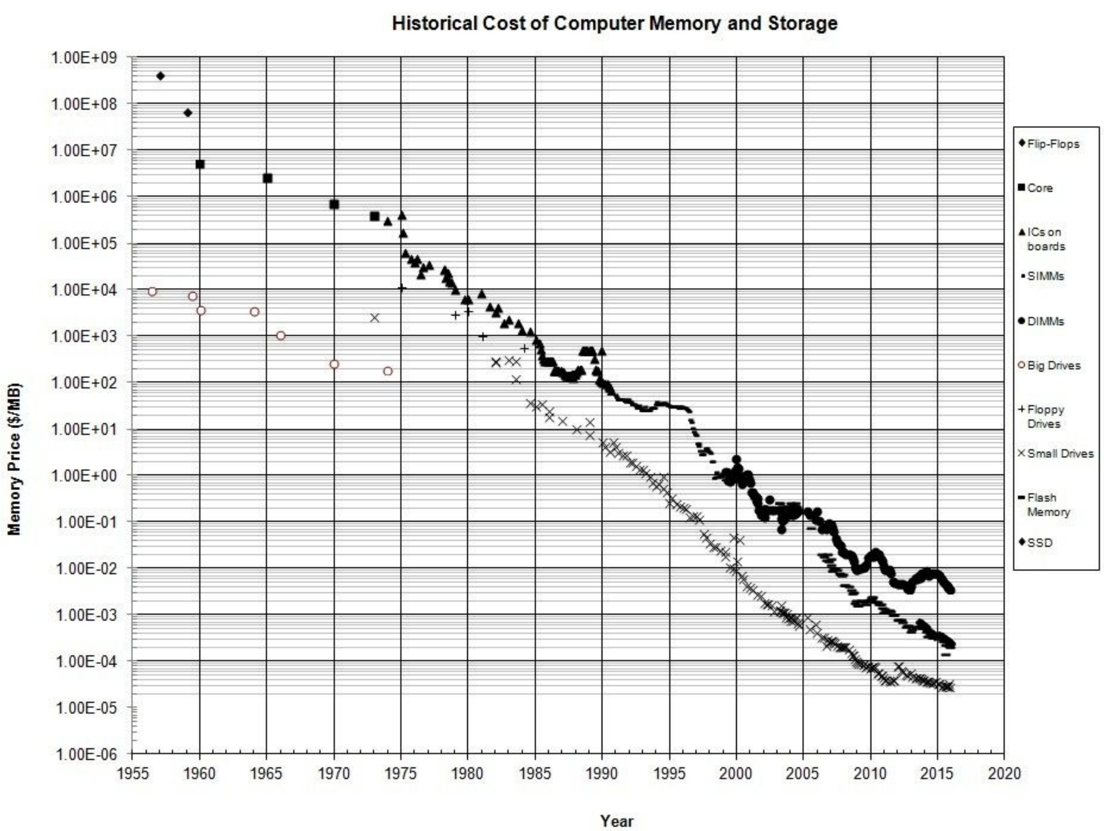

Figure 7. J. C. McCallum, National University of Singapore, Graph of Memory Prices Decreasing with time (1957 – 2015).

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