Prospects for Energy on Earth

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Introduction

A sustainable world requires resources - materials and energy - that must not be irreversibly depleted. We have made progress in reusing and recycling materials, but are seriously lacking in defining our long term sources of energy.

The following discussion moves quickly through topics and astrophysics and electronics. My approach is not exact science, since the underlying math has been omitted. Nor is it just science fiction or some kind of fantasy, since credible references cited by author & date are provided for each concept.

My hope is that the essay will stimulate thought leadership in the most critical aspect of our need for new technology today: how to provide energy for future generations on earth.

I propose here a path, based on current developments in electronics, optics and relativistic physics, that is capable of capturing overwhelming energy, without combustion or fission of any materials on earth itself. The outline of this discussion is as follows.

- Energy generation roadmap: past, present and future
- Energy in the universe and advances in civilization
- Beyond Ohm's Law: Electrical charge and magnetic flux devices- memristors
- Fundamental electromagnetic properties: permittivity (ε) and permeability (μ)
- Negative ε and μ- double negative or metamaterials- composite structures with both negative ε and μ

- A vision for harnessing the energy all around us

A Roadmap for Energy Generation

Electricity is arguably the most useful form of energy we know today. Electricity (once generated) does not produce pollution, nor does it generate waste, except for some losses in distribution and inefficiencies in the systems powered by it. Here we summarize our progress in conversion of various other resources to electrical energy. In the tables that follow, the types of input and output are listed to show where we are and where we are going.

Historical windmills captured wind as to rotation in their blades, converting their motion to other useful motions like sawing, grinding, or pumping water. No electricity was involved.

Energy used in transportation ranges from the basic coal-fired steam locomotive to internal combustion gasoline and diesel engines used in cars and trucks. Some electricity is generated in most cases by rotating in-vehicle generators (alternators). Hybrid vehicles burn fuel, while more powerful electrical systems like additional batteries, electric drive and regenerative braking improve overall efficiency. Pure electric cars, trains and buses, burn fuel remotely at a main power plant. A modern diesel train locomotive burns fuel locally to generate electricity for its motors, rather than burning fuel to create wheel motion. (Airplanes have not been considered since there are no plans to make them electric). Except for a few experimental solar vehicles, all modes of transportation today burn fuel.

Fuel Burning Generating Motion and/or Electricity	**Input**		**Output**		**Notes**
	Motion	**Fuel**	**Motion**	**Electricity**	
Car or truck (internal combustion, electric, or hybrid)		X	X	x	Also generates some electricity for internal use
Diesel Locomotive		X	X	X	Primarily generates electricity for motion

Steam engines were the backbone of the first Industrial Revolution, powering the motion of factories and early railways. Steam remains the primary means of electrical generation to this day. All electrical power plants use some type of fuel, whether coal, natural gas, or fissionable nuclear fuel, to rotate steam turbines coupled to electromagnetic generators. Fossil fuel combustion generates heat and byproducts carbon dioxide and water, plus unwanted pollutants. Nuclear power only uses a small proportion of the starting material's mass, yielding huge amounts of energy according to $E = mc^2$, but leaving most of the material behind as radioactive byproducts.

Fuel Burning to Produce Steam Motion to Generate Electricity	Input		Output		Notes
	Motion	**Fuel**	**Motion**	**Electricity**	
Coal Electric		X	x	X	Generates steam to produce motion to generate electricity
Natural Gas Electric		X	x	X	Generates steam to produce motion to generate electricity
Nuclear Electric		x	x	X	Generates steam to produce motion to generate electricity

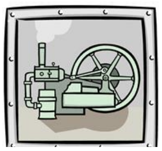
But this only the beginning. In the next category, we note that wind turbines can eliminate the fuel to steam step entirely, generating motion directly for electromagnetic induction to produce electricity. A hydroelectric plant does the same, though adding some concern for how the water is dammed to create a waterfall in the first place. *No burning of fuel is involved*.

Motion Generating Electricity	Input		Output		Notes
	Motion	**Fuel**	**Motion**	**Electricity**	
Wind Turbine	X			X	
Hydroelectric	X			X	

Only one type of electrical generator in use today involves no motion and no earth-based fuel: the photovoltaic solar cell. Photons of light are converted to electrons in the junctions of these devices, with no physical motion of the apparatus required. With today's technology we have harnessed just a fraction of the energy sent to us by the sun. There remains untapped energy all around us. The future will undoubtedly bring us to whole new levels of direct energy generation without the need to burn fuel or generate steam.

Direct Generation of Electricity	Input		Output		Notes
	Motion	**Fuel**	**Motion**	**Electricity**	
Solar Photovoltaic				X	Electricity from photons in the solid state
Electromagnetic Flux from free space (sun, stars, black holes, etc.)				X	To be developed
High Energy Particle Conversion (solar wind, earth's magnetic field)				X	To be developed

We put all these categories together in the following pictorial roadmap of our electrical generating technology. Note the evolution from fuel-generated steam to *direct conversion of free energy to useful electricity*. This is our vision of the future.

Energy Roadmap for Planet Earth				
Fuel to Motion	Fuel to Electricity via Steam	Motion to Electricity	Photons to Electricity in Solid State	*Future*: Electricity from Free Energy
  	  	 		 

Why carry it with you when it is all around you?

Next let us consider one of the “advanced” developments of the last century: the rocket ship. In this technology, the ship carries all its own fuel since the vacuum of space is void of any such material. However, even the rocket’s predecessors, such as the steam engine, internal combustion engine, and of course any animal who utilizes respiration, relies not upon internal fuel, but fuel readily available in the ambient surroundings, namely, oxygen.

What we need to satisfy ongoing requirements for our energy needs requires us to look to our extended surroundings, and beyond our planet, to our sun, or better yet, far beyond to other suns or galaxies as vast sources of energy. Stars run on fusion energy. It is well known that the sun sends to earth something on the order of 1 kW per square meter. This is the basis of current solar (photovoltaic, wind, ocean, etc.) energy work. What if we could harness not only our own sun more efficiently, but the energy of additional suns as well?

As originally proposed by (Kardashev 1964) in a paper discussing radio transmission limitations between distant life forms, civilizations may possess varying degrees of ability to harness the energy around them. (Note that the word "harness" itself comes from utilizing the energy of a horse or other animal…here we open the scope to include any means of capturing energy for an intended use.)

The energy harnessing classifications of Kardashev are as follows:

- Type I civilization– can harness all energy of their own planet
- Type II – able to harness energy of their own sun
- Type III – harness energy of their own galaxy
- Type IV – tap energy of multiple galaxies, universe, etc.

The energies available on earth and within our solar system and galaxy are estimated as follows:

- Earth 10^17 watts
- Sun 10^26 watts
- Milky Way galaxy 10^37 watts

As of the 21st Century, we on the planet earth have achieved only a pre-Type I energy mastery. Based on the above figures we have some 20 orders of magnitude improvement yet to realize.

Nonlinear Resistance, Negative Resistance and Memristors

Conventional energy systems to date are built on linear systems. *We need to move beyond this paradigm to create new solutions.*

One of the basic relationships of electronics is Ohm's law, which says that the ratio of voltage to current in typical (Ohmic) materials is a constant, measured in units of Ohms, which are always positive. A graph of current vs. voltage follows a straight line, as shown here.

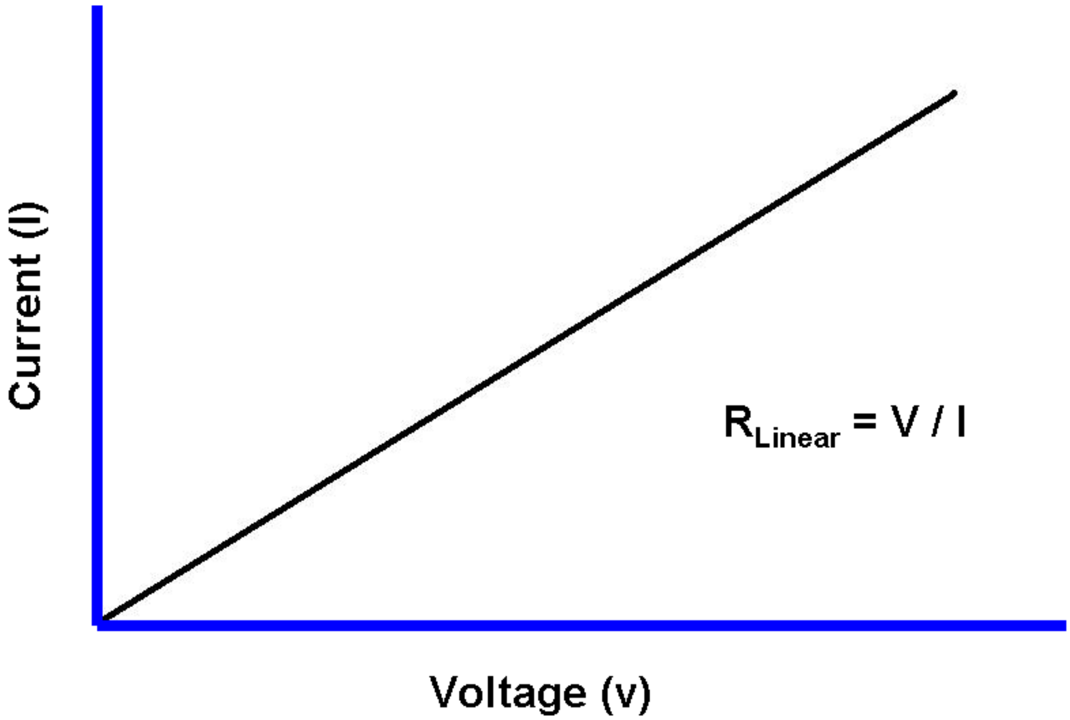


Fig. 1

Many techniques have been developed to create differential *negative* resistance. Negative resistance is only a first step to understand current research in electronics and physics. Beyond the current-voltage relationship of electricity that defines resistance and negative differential resistance properties of devices like tunnel diodes (Franz 2010), there are many examples of negative impedance in the realm of electromagnetics.

The importance of negative electrical parameters will become clear in a moment. For now keep in mind the non-linear current-voltage curve shown below. Within the curve is a region where the slope becomes negative. This property is used to today in many applications like oscillators. In the next sections we show how it can be used to produce the next generation of energy devices.

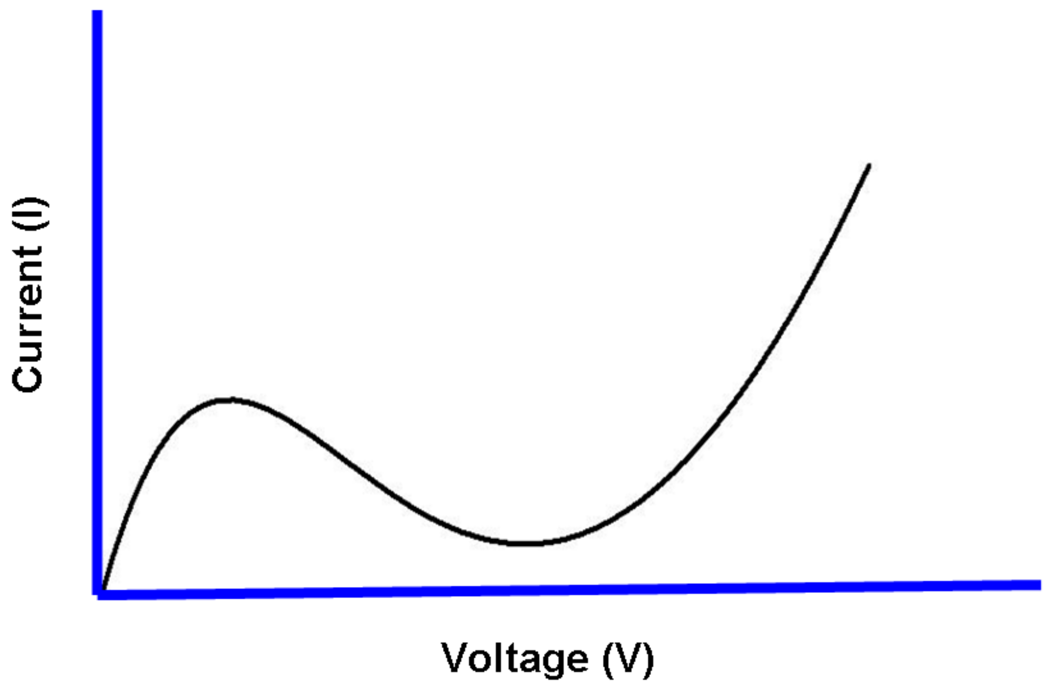


Fig. 2a

Based on Maxwell's equations of electromagnetism, there exists a fourth electrical element in addition to the familiar resistance, capacitance and inductance (Chua 1971). This element has been named memristance. Memristive behavior lies on the relationship of charge and flux, while its present value depends on its past history. If a memristor's voltage or current are known, it behaves like a linear but time-varying resistor.

Until recently, memristance could be simulated only by fairly complex active circuits, but no simple physical circuit element that behaved like a memristor had been reported.

A realization of the memristor at the device level has now been reported in nano-scale devices, based on TiO2 (Strukov 2008). It is expected that developments in this type of new device will enable categories of memories having advantages over CMOS technology that is prevalent today. This work has just begun, as memristance appeared for the first time as an emerging technology in the International Technology Roadmap for Semiconductors in 2009. But it may be the key to the next level of electronic device and product performance. Memristive circuits will be required to be good stewards of future energy inputs by operating with low loss, using their ability to change as time-variant demands dictate.

Existing electronics technology is amazing enough, but lacks this additional fourth element to yield new kinds of performance. Improving the energy efficiency of semiconductor memories and switches, while reducing unwanted leakage losses in the off-state, continue to be major technical challenges. Memristance offers a solution to the time-based problems of standby current loss and time sharing of electronic data processing resources. How exactly this fourth circuit element will be implemented in practice remains to be seen in the coming few years.

The aging power grid is based on very low frequency (50-60 Hz) alternating current. Frequencies of future interest lie above even radio waves and microwaves into the optical region of the spectrum or beyond. These frequencies are sent to us by the sun and are all around us from innumerable sources across the universe. Advances in electronics and optics will soon be able to tap into these boundless energy sources and provide useful electricity to our systems here on earth. This is our energy future: earth's magnetic field, the sun and all the stars and other bodies in space.

Metamaterials

Let us consider the other basic electrical circuit elements that could also be nonlinear. In alternating current circuits, impedance is composed of resistance as well as two other familiar electrical parameters: capacitance and inductance. Capacitance is based on the fundamental property of electrical charge: and inductance, is based on magnetic flux. Like that of negative resistance, there are many materials and composite structures that can produce negative impedance.

Capacitors and inductors as circuit elements operate under the fundamental parameters permittivity (ε) and permeability (μ), respectively. Some particularly interesting and useful properties of ε and μ are realized in the optical region of the electromagnetic spectrum. While light travels fastest in a vacuum, its speed is reduced in other media according to the ratio of velocities that is defined as refractive index n. Refractive index is defined as the square root of the medium's relative ε times relative μ.

The foregoing becomes much more interesting when one considers the possibility of *both* ε and μ being negative. The concept of double negative materials has been demonstrated mathematically (Veselago 1968), and has more recently been demonstrated physically by composite structures called Metamaterials. A negative refractive index material may also be called a left-handed material. Given a negative refractive index, some very interesting things may happen. The potential applications of double-negative metamaterials are truly exciting:

- Antennas with highly selective spatial patterns
- Superlenses
- Acoustic silencers
- Cloaking- in other words, invisibility- requiring the development of double negative materials across the entire visible spectrum
- Warp space drives
- Electromagnetic black holes
- Relativistic worm holes

> **"In fact, it is now conceivable that a material can be constructed whose permittivity and permeability values may designed to vary independently and arbitrarily throughout a material taking positive or negative values as desired."** (Pendry 2006).

Note that the name is misleading, because metamaterials are not really materials; rather, they are unique *structures* fabricated out of rather common materials. A typical metamaterial construction uses copper split-ring resonators and copper wires mounted on interlocking sheets of fiberglass circuit board, made in dimensions much smaller than the wavelength intended to be controlled.

Engineering metamaterial functionality may become as commonplace as selecting inductors and capacitors (Withayachamnankul 2010). Metamaterials may be fabricated in flexible form, suggesting foldable displays or wearable fabrics or flexible energy storage pockets (DiFalco 2010).

These developments are a natural extension of our ability to engineer new functionality based on new paradigms just being recognized in addition to existing electromagnetic theory.

Even more interesting possibilities arise from double-negative materials that are- in addition to their double negative properties - *nonlinear* as well (Shadrivov 2004). Prospects include ability to change material properties from left- to right-handed and back, and propagate backward waves. The possibility of future designs using either memristance and/or metamaterials together, in a kind of multitechnology or hyperintegration, is also in our near future (Eshraghian 2010). These new paradigms will bring significant waves of change to our scientific understanding and engineering capability.

Energy- The Next Generation

With this background, let us return to environmental sustainability and electrical power generation.

For starters we introduce the Black Hole, a supermassive object in space that is so dense that even light cannot escape its gravity. The exception is energy released as nearby objects are consumed by the black hole, called Hawking radiation. Astronomers believe supermassive black holes reside in the center of many galaxies, including our own Milky Way. The title of this paper sets up the possibility: "Black hole as the ultimate energy source," (Semiz 1995). It turns out that a smaller black hole is more powerful and efficient, and when "fed" any kind of matter whatsoever, acts as an energy conversion device.

We may have already creating fleeting black holes experimentally. It is believed that artificial black holes can be created in ‘atom smashing’ experiments, like the Large Hadron Collider (Smolyaninov 2012). A vortex lattice created in the magnetic field of this experimental accelerator may create a ‘hyperbolic metamaterial’ that is an electromagnetic black hole. While one of the main purposes of the LHC was to look the Higgs Boson, responsible for gravity (ref), it also appears that the required spatial distribution “… arises naturally as a result of off-central heavy ion collisions at LHC.” (Smolyaninov 2012)

Let us think more about the use of smaller, artificial black holes locally. Clearly the inescapable gravity would prevent any consideration of a naturally-occurring black hole anywhere near us. This implies a purely electromagnetic, non-gravitational black hole. “Can non-gravitational black holes exist?” (Novello 1997). Yes they can! Such an electromagnetic black hole could be made of metamaterials (Cheng, 2010). The resulting optical black hole could be a broadband light absorber (Narimanov 2009). Recent experiments have in fact used the negative differential resistance circuit we mentioned above to improve the loss of metamaterials (Xu et. al, 2012). In this particular study, off-the-shelf commercial components – transistors, inductors and resistors, were used negative differential resistance.

This leaves us with an engineering problem: how to “… either find small black holes, possibly primordial, or manufacture them by a means as yet unknown.” (Semiz, 1995, p. 154)

What if advancements in relativistic components could in fact allow us to make suitably small black holes?

Metamaterials may be the bridge to the needed black hole manufacturing, as suggested by Leonhardt (2006), in a paper titled, “General Relativity in Electrical Engineering.” In this work, Maxwell’s electromagnetic theory is put to use making artificial black holes. A black hole allows no light that enters to escape. This type of engineered black hole would admittedly not contain the huge mass and gravity of a celestial black hole like those believed to be in the center of galaxies including our own Milky Way.

A black hole captures all light that enters. What if artificial ones could be made and located where we want them? If we could construct black holes on demand where we want to trap light, what would we do with them? Answer: collect energy from the sun and stars.

Enter Black Holes – Exit Worm Holes

A black hole is understood in astrophysics to be a body that, by virtue of its enormous gravitational field, allows no light that enters it to exit.

These recently acquired images of the relativistic jets of a “naturally occurring” black hole in Centaurus A in our own Milky Way Galaxy should stir the imagination. This is a link to a NASA video of black hole jets.

Radio Telescopes Capture Best-Ever Snapshot of Black Hole Jets

http://www.nasa.gov/topics/universe/features/radio-particle-jets.html

Local black holes that are electromagnetic but not gravitational are also speculated to be possible by using metamaterials (Narimanov 2009; Cheng 2010). These electromagnetic black holes could be used to catch sunlight. Talk about efficiency: all energy captured would be retained.

The problem here is that a black hole is not expected to ever let the light, or its energy, escape. To this problem we bring another relativistic entity as a solution: the worm hole. Wormholes are entrances and exits from black holes. A wormhole could also be made of metamaterials (Greenleaf, 2007). It has been confirmed, in theory at least, that a wormhole could be made "traversable" to allow entry and exit (Shatskiy, 2008). It would not make any difference where these structures were located, since they are relativistic and bend the normal rules of time. An energy source (i.e. star) a great distance away could be brought to a local site in current time.

Energy from stars many light years away could be piped to earth.

If wormholes could be built to tap into black holes collecting energy from distant stars, each having the power of our own sun or greater, earth could easily achieve total energy sustainability. Schematically:

Stars -> electromagnetic black hole -> wormhole -> earth

Stars do all the work with their fusion, at a safe distance. We simply connect more directly than ever thought possible. Yes, this is overly simplified. But it is a dream based on possibility.

Conclusions

We have discussed negative resistances and impedances, emerging time-varying memristance, and double-negative metamaterials. Future electrical and optical engineering will no doubt incorporate these elements as reliably as off the shelf components are used in the products we take for granted today.

The vision is to create metastructures that capture the enormous energy available from our own sun and other the stars within, and even beyond, our own galaxy.

Further ponder the consequences on a cosmic scale. What if we could achieve a Type I energy civilization? What about Type II or III or beyond? What will the human race accomplish as a result? Will we evolve into a more intelligent species that uses energy independence as a force for good across the universe? Or will we just deplete the vast energy of an endless number of stars doing what we have done in the history of mankind: pursuing trivialities, selfishness, greed, and war? I hope not.

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