The Three Engines of Civilization

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Purpose: The civilization we have today is not accidental; it was built on the work of generations of creative people. This paper will introduce three technologies and economics of the past and show their paths into the future (that's *your* path, young reader).

1. Why technological development is nonlinear

Figure 1 shows a generic diagram of the advance of a new technology over time.

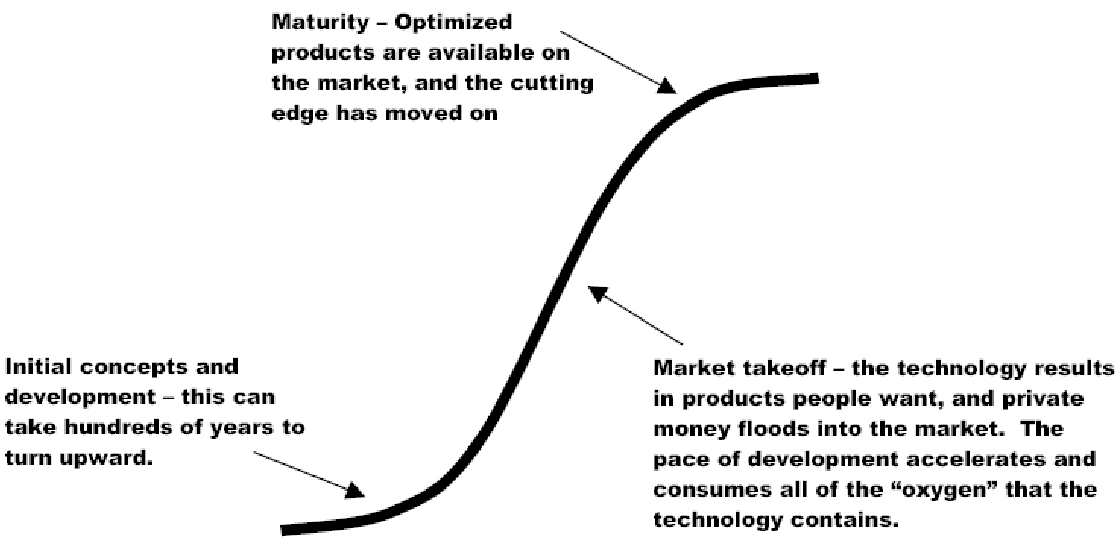

Figure 1 – Fulfillment of a technological field

The original idea could have begun as a passage in the Bible or an ancient Chinese gewgaw or a sketch by Leonardo da Vinci, and then crawled through generations of people who couldn't figure out how to bring it to realization. The pace of development is very slow in this stage, and conventional wisdom is that the job simply can't be done and will likely never be done, and isn't desirable in any case.

The initial pace is slow, but not zero. Eventually, enough barriers have fallen that one determined genius can push through the rest to a working product. Then the existence of one tangible solution excites others to add improvements, and soon commercial products emerge. Competition between suppliers sharpens the design into one that has the maximum benefits for its users, and the market for the products grows as the economies of scale drive down per-unit costs, and customer money floods into the successful companies. This is a period of great expansion of the product line, which can grow from laboratory curiosity to a dominant sector of an economy in one generation.

Every technology is limited by its basic physics, however, and one day all that is left for a technology is incremental improvements in its mature products. It has become a fixture in the society, everyone knows that its existence is their birthright, and the coolest people have moved on to fresher fields.

We will illustrate the life cycle of a technology with three examples taken from the glory days of the United States – the Heat Engine, the Computer, and the Biological Cell.

2. The Heat Engine

If you heat a gas in a confined space, its pressure increases. If you allow that pressure to push something like a piston or a turbine, it will do mechanical work. A heat engine, then, is something that converts gas temperature into mechanical work. Figure 2 shows the development of various forms of the heat engine and the products they have driven.

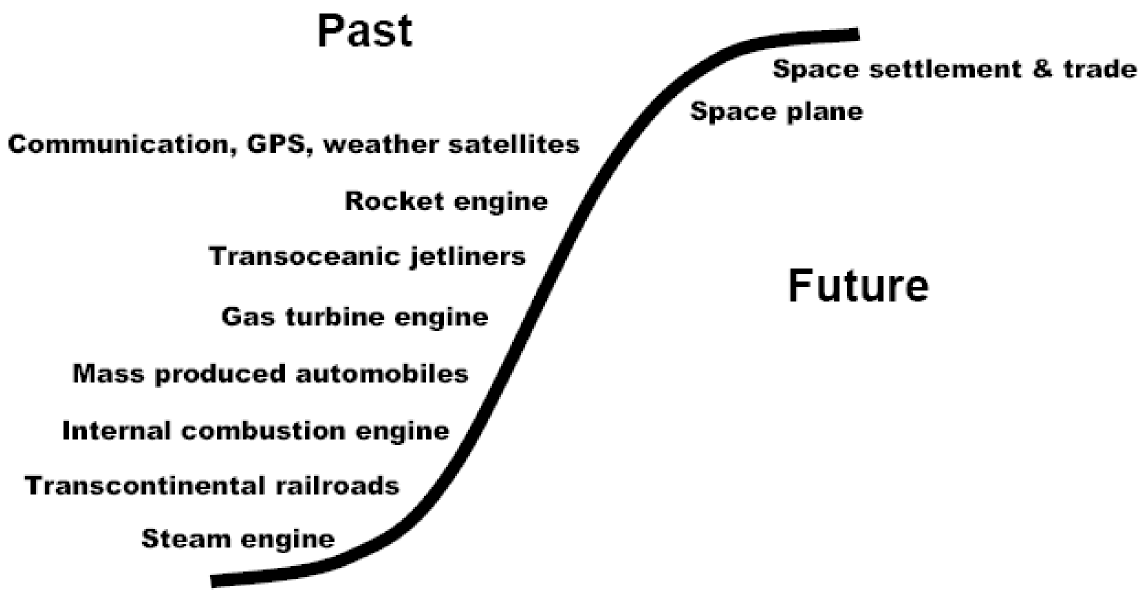

Figure 2 – Development of the heat engine, 1850-2050

Steam engine. Let's go through the engines one-by-one, to see how one basic idea can find implementation in different forms. In an old-fashioned steam engine, water is boiled externally, and a valve is opened to allow high pressure steam to enter a cylinder and force a piston to drive a pushrod that turns a wheel by use of an offset crank. When the piston reaches the other end of the cylinder, a valve is opened to admit high pressure steam on that side to force it back. By sequencing the two valves, the piston can be driven back and forth to create the familiar sight of the steam locomotive pooff-pooff-pooff-pooff pulling out of the station. This is a crude, heavy engine, but it drew far-flung lands into cohesive nations in the 19th century.

Internal combustion engine. The gases are heated *inside* the cylinder in an internal combustion engine by the explosive burning of a fuel and oxygen from the atmosphere. This makes a smaller, lighter engine, using a liquid fuel with high energy density. These innovations made the power plant small enough to put into a personal transportation vehicle, and the automobile was born to transform the society and create one of the greatest practical freedoms we enjoy today.

Gas turbine engine. The piston engine contains a lot of metal to support its reciprocating masses, and it's difficult to balance these masses and to accommodate the finite burn time of the fuel so that the high speed operation needed to get high power density can be achieved. The axial flow turbine was a leap forward in compressor technology that permitted a continuous flow engine made of lightweight rotating masses with no reciprocating motion. Gas turbine engines have achieved the power density to push hundred-ton aircraft thousands of miles at near supersonic speeds, and have tied the continents together in a global economy that has spread the benefits of the capitalist system to the feudal countries of Asia, Africa, and South America.

Rocket engine. Even higher power density can be achieved in a rocket engine, where both fuel and oxidizer are carried as liquid components that are pumped into a combustion chamber and ignited. The heart of the engine is the de Laval nozzle, whose function is to turn the temperature of the combustion chamber products into velocity of the exhaust gases with little power loss and no moving parts. This is an expensive engine, but its ability to operate in vacuum and to build very high vehicle speeds allows us to reach Earth orbit. We have used the plateau of orbit to position satellites for worldwide communications, navigation, weather forecasting, and scientific observation.

Space plane. The space plane will be powered by an engine that breathes air while inside the atmosphere, and transitions to its on-board oxidizer as the vehicle crosses into space. Note that the liquid oxygen carried in a rocket has about 5 times the mass of the liquid hydrogen, so a lot of takeoff weight can be saved if the engine can burn atmospheric oxygen for a portion of the trip to orbit. At the higher air-breathing speeds, burning will take place while supersonic air is moving through the combustion chamber, a feat that pushes the limits of combustion physics. When fully realized, the space plane will be a 100% reusable vehicle that operates for the price of fuel, as an airliner does. Low cost access to space will open an era of colonization and trade in rare materials, low gee manufactured goods, energy, scientific observations, and tourism, and will transform how people see themselves and the future of humanity.

3. The Computer

Development of the digital computer has trailed the heat engine by about 50 years, but it follows a path of similar shape.

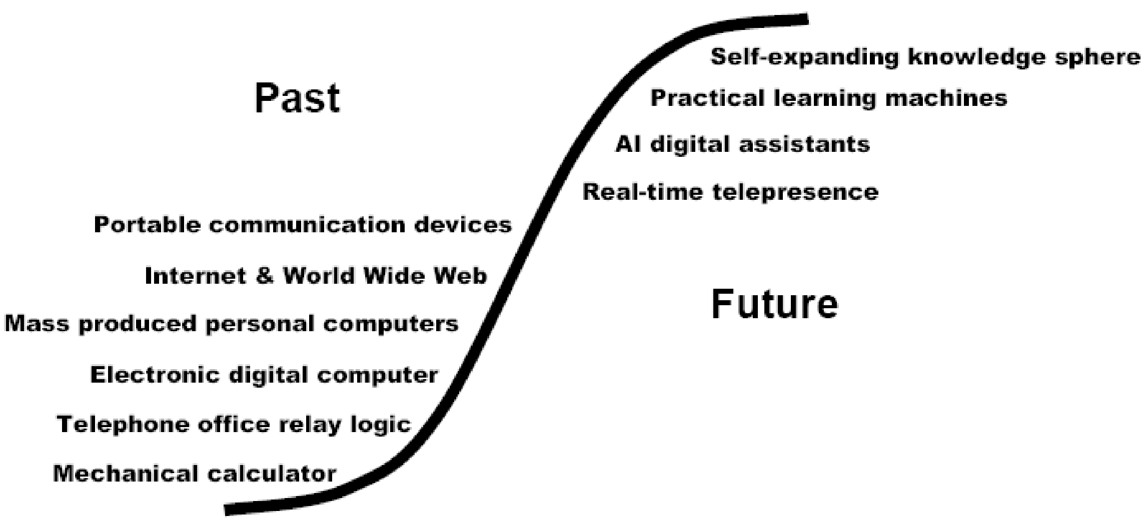

Figure 3 – Development of the digital computer 1900-2100

Mechanical calculator to personal computer. The first rungs on the ladder were built of differing fundamental technologies – first mechanical gears and cams, then electromagnetic relays, and , finally, semiconductor electronic devices. By 1970, the integrated circuit had arisen as the technology of the computer age, and year-by-year Moore's Law allowed more function to be packed into a central processor.

Internet and portable communications. When hardware became a given, software rose in prominence to get the most out of the computer. The internet was a logical progression in hindsight, but it hit with the force of a revolution at the time and shrank the world once more, as the jet airliner and television has previously done. Most recently, hardware development has again come to the fore in the quest for the electronic Swiss army knife – internet node, game console, personalized computer, video and still camera & audio recorder, GPS receiver, personal digital assistant, radio and TV receiver, sensors for the owner's body or other specialized measurements, personal security functions, electronic keys for locks and smart money and ID, cellular telephone – all in one portable, pocket-sized package.

Real-time presence. Wide-bandwidth internet has resulted in the first steps of telepresence – web meeting, computer desktop sharing, virtual lives, steerable webcams. This technology will accelerate in the near future and add sensors and actuators so that collaborative action may take place between scattered participants and expertise will not have geographical bounds.

AI digital assistants. As more of the world's reference works become available online, the job of sifting through them to extract increasingly specialized information will grow without bound and intelligent software agents will be necessary to perform internet research in all languages. These will perform well beyond the software robots of today and include a workable artificial intelligence that can be tuned by the user.

Practical learning machines. A leap beyond the standard AI will be the learning machine that simulates a neural network or similar nonlinear cognitive structure to continuously improve its capabilities. Since these machines will at the heart still be digital computers, their configuration memories can be read out and replicated in other machines, so any skills a machine acquires can be shared among similar machines worldwide. By this means, knowledge (instead of just information) will be distributed worldwide.

Self-expanding knowledge sphere. Advanced learning machines will at some point be set loose on all the unanswered questions of the universe in teams with humans (because a human plus an intelligent machine is better than an intelligent machine alone), and the growth in knowledge will accelerate. This might be diagrammed as the end state in the development of digital computer technology, but it will be just the beginning of a new chapter in human existence.

4. The Biological Cell

About 50 years after the digital computer started upward, the discovery of DNA marked the rise of the science and engineering of the biological cell in the higher life forms.

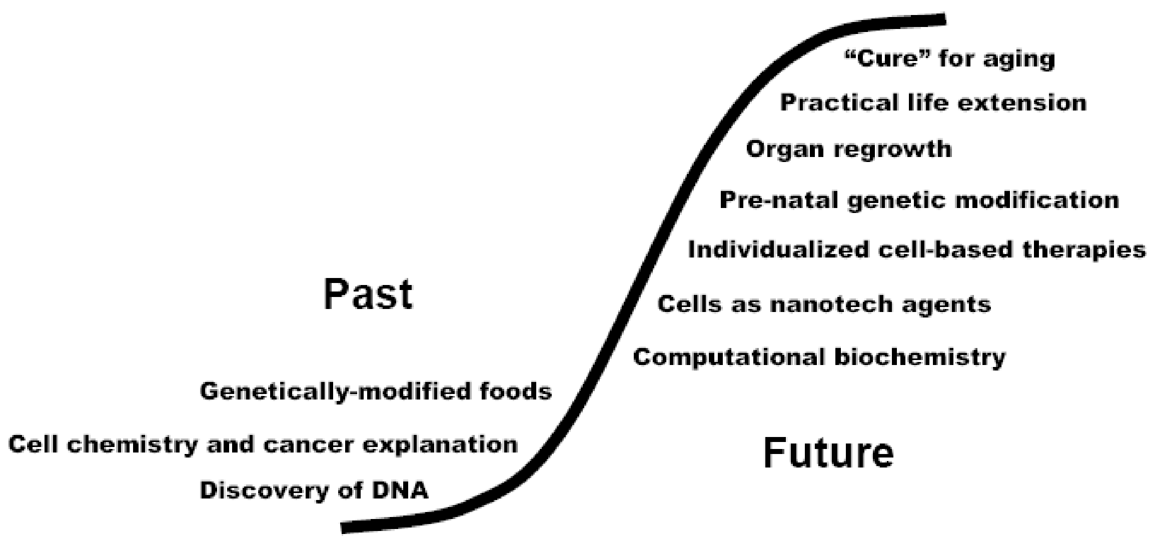

Figure 4 – Development of cell-based technologies 1950-2150

The next generation of scientists found the pawprint of DNA in cancer tumors and inherited diseases, and began commercial engineering of plant cells for food crops.

Computational biochemistry. To this point, experimentation has been the biggest tool for molecular biology, but lab work is costly and time-consuming to run for more than a few simple cases. Bio-proteins are long chains that snarl up into different shapes, according to the sequence of their atoms. Reactions are governed by the physical structure of the molecule, as in a lock and key, and by the electrical forces and bond energies between facing atoms. A bookkeeping problem of this magnitude requires a computer to keep track of all the elements, so, as in other fields, computer modeling will become the complement to experimentation. Current research projects will grow into reliable atomic-level models of complex reactions with the power to show the effects of environment and subtle atomic changes in the reacting molecules. As this technology matures into full cell models, the age of bioengineering will open in earnest.

Cells as nanotech agents. An important set of early applications will be those outside a large plant or animal, where a large number of small, self-replicating agents are needed to perform a job whose components are diffuse. Single-celled plants or animals can be designed to remove pollutants from water, extract dissolved minerals from water, convert carbohydrates or sunlight into food or energy products, assemble structures in water. Critical to the development of custom single-celled bugs will be technologies that can assemble DNA chains from a library of constituents, using standard chemical means and exotic tools like laser "tweezers."

Individualized cell-based therapies. Much of modern medicine is system-based – circulatory, nervous, endocrine, digestive, immune, musculoskeletal – and treatment is aimed at alleviating system-level symptoms. At the heart of a system-level problem, however, is a cell type that's not doing its job properly. If that cell type (it might be multiple cell types for a given symptom) can be corrected or replaced, the system will function like that of a healthy person. Whereas system-level medicines are generic, cell-based therapies are more individualized, because they involve the DNA of the patient's target cells. Technologies to be developed will be cell replacement using stem cells or engineered cells and in situ cell repair using broad –based chemicals or DNA transfection from carrier viruses.

Pre-natal genetic modification. In the hands of government, baby design evokes the image of the "master race," totalitarianism, and concentration camps for the inferior peoples. In the hands of individual parents, however, children will become smarter, healthier, stronger, more civilized, and more individual, all to the benefit of a free society.

Organ regrowth. Not only do organs wear out, but they can be damaged by accident, contaminant, infection, and tumor. Growth of new organs in vitro from starter cells extracted from the patient will lead to "auto repair" medicine, where worn out components are unbolted and new ones installed, and the patient drives off down the road for another 50,000 miles. Growing organs requires feeding them all the chemicals and the electrical stimuli that the human body does. This will be a complicated job, but there are no fundamental barriers. Methods of accelerated growth will be developed to speed the process.

Practical life extension. All of the technologies developed will be employed to lengthen the lives of people. As greater understanding of the chemical workings of the body is obtained, diagnostic tests will improve so that conditions can be detected and corrected in their earliest stages, when the fix is simpler. Computer models will grow to encompass the whole body, and, as we gain complete understanding of the tinkertoys that make us up, medical technologies will be optimized to increase capability and reduce cost. 120 years is the maximum lifespan of a natural human, but this century will see our limits being incrementally pushed forward. With complete diagnostic and manipulative technologies, there are no theoretical limits to how far a human life can be extended.

"Cure" for aging. All human beings grow old in the same way – metabolism falls off, tissues lose strength and elasticity, organ function declines, hair loses pigment. Aging can accurately be viewed as a genetic disease, and it is likely that individual cells have a reproduction limit as a means of cancer prevention or to limit the effects of accumulated mutations. With sufficient insight into the workings of the body, this cell reproduction limit can be removed from our DNA, and the sensitivities that are introduced will be handled by existing medical technology. Our bodies can be maintained in a permanent condition of peak performance, about the level of a 25-year-old.

Can medical technology *really* advance as far and as fast as this section describes? Yes it can, and the key is the nonlinear growth spurt that occurs when a technology takes off. Both heat engines and computers achieved wonders that were hardly imagined a generation or two before they took off. The heat engine gave us mobility, the computer gave us unlimited information, and cell technology will give us life itself. There is a lot of money available for investment in life itself. When confidence in the path of cell technology development becomes widespread, that money will flood the market and ignite near-vertical growth and accelerated technology development.

5. How can this be my path to the future? I don't know *anything* about these technologies!

Modern society has a magical land called "college." It's in the same physical location, but is not the same place as the sports organization with the carousing fraternities, sororities, and alumni, or the church of the save-the-world people. It can transport someone like you on a path from complete ignorance of a field at the age of 17 to a near-complete understanding at the age of 22 or 24 or 26 to advancing into the frontiers of knowledge by the age of 30. It's a big investment of time and money, and work that gets harder and harder, but it's worth it. One of your jobs is to figure out how to go to a college that has the course of study that will take you to where you want to go in the universe. All of the jobs worth doing are done by people who were once like you.

6. Don't we reach a fundamental limit at some point? Isn't there an end to all the technologies and scientific fields that there are to be developed?

No.

Note for parents or other persons who have accepted the responsibility of a teacher: As kids mature, their ability to understand complex ideas matures. It might take your kids a while to wrap their minds around the ideas in this topic, and you will have to be their guide. The younger a kid is, the more he or she learns through the ears rather than the eyes. Don't be shy about inventing different ways to pour these concepts into your kids' ears. And make up as many sample problems as you need – it might take tens of problems spread over a number of weeks to transfer this material from abstract concept to trusty implement in your student's toolbox. Remember that learning in the brain is biological, not electrical, and it takes time for the brain to grow the structures that can crank out a new skill. Print these sheets, let kids write all over them, and date them and keep them in a notebook, so the young'uns can one day look back over the journey they've taken.