The End of "Peaks"?
From Peak Innovation and Peak Electricity to Peak Coal

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This smartphone is more than an amazing gadget. In terms of energy demand, it's the stealth SUV of the IT world. Let me explain.

Just one smartphone used the way I use it, and probably how all of you in the room use yours – and certainly how your children use one -- consumes as much electricity as the refrigerator in your home. I'm not talking about what it takes to charge the battery in your iPhone. That requires about the same amount of electricity as a nightlight. I am referring instead to your *pro rata* use of the massive, but hidden electric-centric infrastructure that gives the smartphone its smarts.

Consider another remarkable and indicative fact relevant the direction of electric demand. The world manufactures more transistors each year than we grow grains of wheat – not tons or bushels of wheat, but ***grains***.

Transistors are used of course to process, store and transport information. And transistors consume electricity, and only electricity; individually not much, but collectively that many transistors move the meter – literally.

In fact, globally, transistors in all their various forms and functions now use more electricity than the generating capacity of Japan and Germany combined.

But the world has baked in the historic rise of digital technology over the past two decades. The central question of our time is: has that revolution peaked? Is it true, as is so commonly claimed, that we are finally at peak innovation in general?

Let's put that proposition in the colorful terms offered by some of the adherents to the theory of peak innovation. The claim is that in the grand sweep of history the invention of the smart phone is far less impactful, has changed fewer lives, than the invention of the flush toilet. This view, espoused by John Gordon, a professor of economics at Northwestern University, is shared by many others including Harvard's estimable Niall Fergusson. They go on to claim that the incremental advances in things like the iPhone – itself the icon of modern innovation -- are just that: incremental and not foundational.

If it is true that innovation has peaked and that the new normal is slow growth, then the implication for future electricity demand is dismal – or deeply satisfying if you are an acolyte of no-growth. The use of kilowatt-hours has from the dawn of the electric age been closely linked to economic growth. In order to gauge whether more robust *electric* growth is likely to return the most important thing we need to know is whether more robust *economic* growth is on the horizon.

If it is true, as JPMorgan's CEO Jamie Dimon said in a recent interview, that "no one can forecast the economy with certainty," then I suggest we follow instead the maxim of Peter Drucker the brilliant management consultant. He used to say that he only predicted what already happened. Drucker meant by this that one should consider trends that have what, in effect, I would term high inertia; the equivalent, to put it simplistically, of knowing that the sun will rise tomorrow or that populations are aging. In that spirit let me predict some things that have already happened with relevance to our economy and the future for electric demand.

Let's start with a core fact. Today in America the share of our economy devoted to moving bits -- ideas and information -- is bigger than the share associated with moving people and stuff. And the former is growing far faster than the latter.

Just over $1.2 trillion of our GDP is associated with information – counting everything from data centers to digital movies, from Intel factories to iPhones.

About $0.5 trillion of our GDP is associated with the transportation sector involved in transporting stuff and people – counting everything from making and using cars and airplanes, and from Norfolk Southern to FedEx.

The stuff-moving industry is all about liquid fuels; almost entirely oil. The bits-moving industry is, of course, all about electricity. The latter is growing far faster than the former.

The bits-moving industries already consumes more electricity than all of the office buildings in America, more than the metals and chemicals industries combined.

But has the digital cycle run its course? To know the answer to that question, we need to look at the recent past.

New products – not new technologies *per se* – and new businesses and new economic growth come from what has ***already*** been invented and perfected in the recent past and is ready to be implemented in new ways. The near future emerges from, to paraphrase Drucker, what has already happened.

So to understand what the future might look like based on what has changed in technology it is useful to wind the clock back a few decades to 1980.

In 1980 the economy was limping along. The real estate and job markets were terrible. College graduates were despondent. The big innovations that changed the world over that past several decades were all history. This should sound like a familiar pattern.

I choose 1980 because it was a pivot in history, not just politically (Ronald Reagan was elected), but also in technology. December 1980 saw Apple's IPO presaging by only a few years the emergence of the Internet. Neither AOL nor Google existed then, much less Twitter and Facebook. For those who might remember the names, the big dogs of innovation at that time were companies like Wang and Digital Equipment that have long since evaporated.

Not a soul imagined in 1980, no one in the media, punditocracy or government then, imagined that technology would soon ignite two decades of torrid growth creating thousands of new companies and millions of jobs. And, collaterally, lead to an overall doubling in U.S. electric demand. Well, to be accurate, one person did imagine what was to come: it was, perhaps unsurprisingly, Steve Jobs in a little-noted speech he gave in Europe in 1985, still available YouTube.

The new products, service and companies that sprung up in the decade immediately following 1980 were all built on technologies that had been developed over the *previous* decade. Apple didn't invent the microprocessors it would use. It took advantage of capabilities that had matured in the previous decades.

The tool kit of technologies available in 1980 emerged from the innovation that started back in 1950 when Reagan was elected president of the Screen Actors Guild, maturing through 1980 when he became President of these United States. The decades from 1950 to 1980 saw America vault from Univac's vacuum-tube computer to ubiquitous IBM 370 mainframes. In 30 years computer speeds rose 1,000-fold while computing costs collapsed 10,000 fold.

No bank, business or university worth its salt was without a central computer. By 1980 we were deep in the Age of Central Computing – and it bears noting, many were worried about Japan seizing the lead in mainframes from us.

Then after 1980, the age of the central computer was superseded by the age of distributed computing and Internet. And the economic benefits began to flow. But early in that transformation the economic benefits were not obvious. Remember the famous quip made by Nobel economist Robert Solow in 1987? "You can see the computer age everywhere but in the productivity statistics." No one today doubts the productivity and economic benefits of, to use the now quaint phrase, “the computer age.”

Now we fast forward to 2013 to consider the character of the tool kit of technologies now available to make our near future different.

Compute-communicate technologies have advanced ***more*** over the past three decades than they did during the 30 years that preceded 1980.

Computing speeds are up 200,000 fold since 1980. They rose only 1,000 fold in the 30 years prior to 1980.

Computing costs have collapsed 1 million-fold since 1980. They decreased only 10,000 fold in the 30 years prior to 1980.

Maybe we may have lost our capacity for amazement. An IBM 370 mainframe introduced in 1970 managed the blazing speed of one million instruction sets per second -- or ***one*** MIPS. Today a single iPad operates at one thousand MIPS and at one-ten-thousandth the cost. And in just one Cloud data-center we pack in the equivalent of tens of thousands of iPads.

The world has thousands of such warehouse scale data-centers now, each of which I should note consume electricity at levels that rival a steel mill.

Not only has digital technology changed in capability and cost, it is now becoming truly ubiquitous with the emergence of wireless broadband networks that will soon connect anyone, anywhere to, any *thing* everywhere. Wireless technology of the past 30 years has seen data speeds increase 1 million-fold along with a 100-fold drop in the cost.

This scale and reach of change is unprecedented. And the power and opportunities enabled by this magnitude of technology advance has *yet to be fully implemented*.

As with the previous tech-driven cycle, we are entering uncharted territory – and it goes beyond the much-discussed emergence of Big Data and the Cloud.

The emergence of the era of 3D printing in manufacturing will in due course become a trillion dollar industry, unleashing as big a change in how we make things as did the agricultural revolution change how we grew things. It is a technology that not only uses computers but is also deeply electric intensive. 3D printing typically replaces combustion-based processes with electric-based-laser-fusing.

But long before we see the energy impact of computational manufacturing, there is already resurgence in conventional manufacturing underway, driven in large measure by the radical increase in U.S. natural gas production from America's vast shale fields.

As an aside – and one that has enormous importance, but a subject for another night - - America is reversing its role on the world energy stage for first time in a half century migrating away from being the primary consumer to becoming the primary producer of hydrocarbons. We are witnessing the literal reversal in the flow direction of pipelines, as huge swaths of the nation go from being import to export-centric. All of this has far-reaching and permanent economic and political implications.

The newfound hydrocarbon abundance also comes in large measure from information technology and not just hydraulic fracturing, or from new discoveries. The US Geological survey mapped the shale fields out a century ago. But now using sensors and super-computer-class computation on desktops drillers we not only know where to drill but how to steer drills horizontally in real time in order to follow hydrocarbon-rich seams. Call this computational drilling.

Computational drilling, or more simply "smart drilling," has unleashed a flood of foreign direct investment in this sector already past $300 billion cumulatively in the past half-dozen years, with more to come. Add to this over $70 billion in investments in 100 new conventional manufacturing operations scheduled to come on line in the U.S. in a few years that will generate a million jobs and add $300 billion to the GDP.   This broad-based manufacturing renaissance is bullish for the economy, and bullish for electric demand.

And then there is the emergence of an era of computational medicine (and by this I am not referring to the ObamaCare Web site). An entirely new character and scale of data is now emerging to be transported and stored, all of it associated with the voluntary and real-time monitoring and storage of personal human physiology.

The specifics of what will emerge and who will dominate from all these changes is as hard to predict today as it was in 1980. But as before, many of tomorrow's big dogs are today's niche players – much as Apple was itself in 1980. And as before, many of today's big dogs will disappear.

We have now begun the next supercycle of tech innovation. And, as with the previous two, this one is led by the United States.

The first modern supercycle that began in 1950 yielded the era of central computing. The second supercycle that began roughly 1980 yielded the era of distributed but wired computing. The third supercycle, now beginning, is one of truly ubiquitous distributed and wireless ***super***computing.

So much for peak innovation. But what about peak electricity?

The power implications of the next digital supercycle are huge. The economic growth accompanying this next cycle will push up electric demand, even as the exa-flood of bits themselves will require industrial-scale quantities of electricity-using hardware.

To reduce the electric implications to a simple example: watching a Major League baseball game on your iPad uses as much energy as driving about 30 miles in your electric car. In the iPad's case, unlike a Tesla, most of the energy is consumed remotely in the Cloud and networks.

This calculus includes, by the way, the energy cost needed to manufacture info-tech products. Digital-centric products require roughly 1,000 times more energy per kilogram to manufacture than the materials that dominated the 19th and 20th centuries, and the energy is dominantly in the form of electricity.

I've itemized and documented the scale of electric appetite of the global information-computing ecosystem in the report I believe you have all seen – *The Cloud Begins With Coal*. The origin of this deliberately provocative title will shortly be clear.

Before turning to how all that electricity is likely to be supplied, we have to deal with the issue of efficiency. Presented with the facts I've outlined, I commonly encounter the claim that things, especially computing-centric things, will get far more efficient in the future and *that* will slow if not stop demand growth. But advocates of efficiency-as-a-way-to-stop-demand-growth have it exactly backwards. Efficiency always increases – and that efficiency is precisely what ***creates*** demand.

Measured from 1950 computations per kWh have improved ten **trillion**-fold. That's exactly *why* so many more data-machines got built. It is exactly why the total amount of electricity used to perform computations has ***increased*** 300-fold since 1950.

If it were not for the astounding improvements in energy-efficiency for data-processing there would be no Google or iPhone. At the efficiency of 1980 computint, one Google data center would consume more electricity than Manhattan. Making computing more efficient has lead to and continues to led to the proliferation of warehouse-scale computers all over the planet.

We should at this point digress briefly to note that the future for billions of people around the world is about much more than watching YouTube on tablets.   Too many people live in energy poverty; billions have little or no electric illumination. Even more have no air conditioning. This is where efficiency gains are vital in order to drive down costs. As those traditional electric technologies get cheaper and a wealth expands, demand will rise.

The potential world demand for residential air conditioning is 45 times greater than the electricity used for home AC units in the U.S.

All this has relevance for American firms that seek to export talent and technology to build hardware and services, and to export fuel from coal to LNG, to supply the world's insatiable appetite for electricity. And if anyone ever invents a practical low-cost way to put electricity in a barrel or supertanker, America will export low-cost electrons our industries are so good at producing from our low-cost gas and coal resources.

So much for peak electric demand.   But how will the demand be met? We turn now to the third trope in the triad of peaks – from peak innovation and peak electricity we turn to the idea of peak coal.

We could dispose of the idea of the end of the age of coal by looking at forecasts from the IEA and EIA – neither of which could be considered pro-coal. And while both incorporate assumptions unfavorable to the use of coal, both forecast that coal will remain the single largest source of electric supply in the world and US for the coming decades.

There are those who argue that the phase-out of coal is coming, in part because, well, coal is old and must have run its course.

Well, coal has been in use for a very long time. But age has nothing to do with the utility of primary resources. The use of concrete reaches back to Roman times with a similar storied history. Yet concrete still anchors the physical infrastructure of the world, and coal will continue to anchor the electric infrastructure of tomorrow. Technology keeps advancing the utility of concrete, as it does for coal.

And no, I am not obtuse to the debates swirling around carbon dioxide emissions. But I would argue that in certain important respects the future will be like the past. Economic and social imperatives will continue to dominate, which is to say that ensuring the reliable and affordable supply of electricity at the scale the world needs requires staggeringly large quantities of low-cost primary energy. Just as modern roads and buildings require concrete, modern grids in most of the world will continue to require coal.

But what about alternatives? In a very real way we've done that experiment. According to the IEA, the world has spent over the past two decades $1 trillion subsidizing non-hydrocarbon and in particular non-coal alternatives. Yet over that period coal still supplied 70 percent of new electricity. The IEA forecasts that another $4 trillion in subsidies will be needed in the coming two decades to achieve an outcome not much different. I doubt the world will spend that. I predict that we're entering a new era, one of intolerance for such massive subsidy spending – call it peak subsidies. The focus instead will turn ever more to the cost and reliability of electricity.

Cost and reliability have already reached criticality levels in the digital parts of our economy – despite the PR from the likes of Apple, Google and Facebook. Over the past decade the cost of electricity has risen to become the top digital infrastructure challenge. A recent global survey found that the cost of power is now the number one concern for data center operators.

And in America, and several other countries, we will soon learn what share of electric supply can come from non-dispatchable wind turbines, the overwhelmingly dominant non-hydrocarbon alternative. Power reliability is the *sine qua non* of the digital age. Every data center that brags about using wind turbines is doing so in coal-dominant grids. The digital economy, and the economy at large cannot operate at the will of the wind.

Using episodic wind requires a large grid with abundant 24x7 power, or a way to store electricity at scale. But there is simply no viable – which is to say both reliable and cost-effective – means to store electricity in quantities that matter in time-frames that matter. The cheapest way to store electricity is as a pile of coal adjacent to a coal plant.

It is widely known that coal's competition in America at least comes mainly from the abundance of natural gas. But in the past couple of years we have seen that the price where natural gas easily beats coal is, on average, below the cost where gas producers can make a profit.

Thus the future, at least in America, looks largely like one where gas and coal trade market dominance, depending on short-term particularities. But the two fuels together will for years supply three-fourths of all electricity. This is extraordinarily bullish for American industry which stands to benefit from what amounts to a permanent advantage in the cost - - and reliability – of electricity.

Finally, there has been in recent months a resurgent claim that the traditional electric utility model is now broken. Pundits propose that the dual assault of photovoltaics and a smart grid portend not just the end of the central coal plant, but the end of the electric grid as we know it – maybe there's another sub-concept here, the idea of peak grid. It's another silly idea.

Setting aside the fact that photovoltaics have the same availability and dispatchability challenge as wind turbines, the bigger question is whether the very idea of a transmission and distribution utility is now a failed model. But some inventions, some concepts, once discovered are essentially permanently useful; they can't be undiscovered.

The wheel comes to mind. And highway networks, which also go back to Roman times. The highway system isn't about to disappear, though we can now make it smarter. The structure of the electric network is similar: it is how electricity is most effectively moved just as highways are the best way to move cars. The grid has always been smart and will get smarter yet – but all the essential smart technologies are arguably only perfected and deployable in a utility network architecture. Big Data and silicon controls will enhance the management and operation of electric networks, as they will for all networks and supply chains in our economy.

But the truly exciting potential of Big Data analytics, of the Internet of Things lies elsewhere.

Since supercomputer-anchored computational tools have application in ***all*** existing businesses and services – and will touch every thing – we are entering an era of more than the emergent Internet of Things. Next is the Internet of Everything.

The specifics of the new digital age will emerge from new products, businesses, and services that are inherently difficult to predict, just as they were in 1980 when the previous supercycle started.

The future may seem dim from the perspective of an economy still bumping along bottom in a tepid recovery from the Great Recession. But when robust growth returns, and return it will, the business of building the electric power infrastructure will become a huge challenge. I have no special insights about the next couple of years. But the realities of the next two decades have already happened. These are truly exciting times with the advent of the next supercycle of innovation.

I'd like to wrap up with yet another indicative fact. Cisco has termed our times the zetabyte era in recognition of our having crossing a Rubicon: data traffic has blown past a zetabyte a year, and it is continuing to grow at a blistering pace. Since all bits are electrons, consider how big a number a "zeta" represents.

For the prefix challenged, a zeta is the last prefix available in the pantheon of big numbers. The next and last named number is the yottabyte. A zeta stack of dollar bills would reach from the earth to the sun, 93 million miles away, and back – one million times. It is simply not conceivable that these scales of information electrons won't impact the business of commodity electricity.

I am bullish about the prospects for the American electric sector, for the American economy, in fact for an American-dominated 21st century. I am realistic about the ways in which overzealous politicians, policymakers and regulators can hold down an economy, much as Gulliver was pinned down by the Lilliputian army. But Gulliver ultimately prevailed, as I think the forces of sanity will on the American political scene as well.

We are in middle of not just a technology revolution but something of a political revolution as well … epitomized by but far from isolated to the debate over ObamaCare in regards to the role and reach of government. Charles Krauthammer would argue that this is ***the*** debate, because if you can't get the politics right nothing else can confer.

Recent polls that show that the majority of citizens perceive that America is in decline *will* have political consequence. Most Americans don't like that idea. The good news is that the forces now in play - - if not the politics and policies quite yet – portend a different America. When the opportunities are so great, the economic and social benefits so enormous – as they are from this next tech supercycle -- they tend to overwhelm political intransigence.

The American system and people are, as Nobel economist Edmund Phelps observed in his important new book, uniquely suited to a mass flourishing. In his book, by that title, he explains why tech innovation that is readily available everywhere from Russia to Riyadh flourishes instead here. A spoiler alert here: he illustrates in detail that it is America that flourishes from what is readily available to all because of the nature of Americans, our culture and our political system.

As a Canadian and immigrant to this great land, I can say that history has shown good reason to be confident that America will in due course get its politics right. The stage is now set once again for a mass flourishing. <><>