FROM OIL SANDS TO INTERNET SERVER FARMS: THE SEVEN REALITIES OF OUR ENERGY FUTURE

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Thank you for the honor of joining you. Thanks in particular to sponsor AREVA, and our host CNA's Murray Elston. Judging by the record number of people attending this year's Annual Meeting of the CNA, it is obvious there is an exciting future for nuclear energy. I have the assignment today to address the overall energy context in which to consider that future for nuclear power.

Discussions about energy necessarily start though with the present, not the future, and specifically not with physical principles, but with a commodity - oil. There is much angst today about the availability, and the price of oil. But the most important question, largely unaddressed and certainly largely unanalyzed: how is it that, with today's very high costs per barrel, our economies have not only survived, without recession, but have grown rather dramatically?

The world has discovered that economies not only survive, but can thrive with crude prices staying not only north of $40/bbl, but north of $50. The last time oil rose, and only briefly, in to this price territory was in the 1979 to 1981 period. Then, the world's economies were hammered in to a terrible recession. But not today. In fact, by all measures economic growth has been remarkable, continuing nearly oblivious to high and rising oil prices. What happened?

In a word, technology happened. By this I do not mean oil exploration and production technology; though that is important too. I am referring to a deep technology transition underway in our economy. In simple terms -- it is a "new" economy. Our gross domestic product is increasingly tech- and information-dominated. The effect is to make us economically ever more distant from the cost of oil, and in fact of all raw fuels.

Obviously; high-priced oil does matter. The price of everything matters at some level. High-priced oil takes money out of peoples' pockets, which is of course particularly painful for those with lower incomes. And high commodity prices do ripple through an economy – but it is a *ripple*, not a tsunami. This was not always so. Consider a much earlier, analogous trend.

In bygone eras, and today in undeveloped countries, the price of food and the health of the agriculture sector utterly dominated national economies. In an industrial economy, while self-evidently food still matters – no one stopped eating after the industrial revolution – fluctuating food prices and agriculture vicissitudes can't undermine an industrial economy. And now in a post-industrial increasingly tech-based economy, rising oil prices are similarly eclipsed by larger forces. We still eat, and we still use lots of oil-dependent vehicles. But we have crossed over, largely unnoticed, a pivotal economic Rubicon – one where electricity has become our primary energy commodity. In other words, electrons trump barrels -- which is the first of the 7 Principles of Energy Reality.

Principle #1: Electrons trump barrels

Look at where energy is used, rather than the point of raw resource supply. Consider what directly powers the machineries of businesses that constitute our economy where the GDP is generated. Our economic machinery uses only two forms of energy; either electricity, or oil and its hydrocarbon cousin, natural gas. Now observe how much of our GDP is produced on the backs of each of these two forms of energy.

When the first oil-shocks hit in 1973 and 1979, 60 percent of the industries and economic activity that comprise North America's GDP directly used barrels of oil (or the equivalent) – the remaining 40 percent were electric-consuming industries and activities. Today, the ratio has completed reversed; 60 percent of today's GDPproducing activities depend on electricity. We are dramatically more electrified.

This single fact explains the unanticipated resilience of Western economies to oil hovering beyond $50 per barrel. The oil-based, engine, and boiler parts of our energy economy are receding in the economic distance. Adjusted for both inflation, and for the declined oil share of the GDP, oil would need to hit $120/bbl to have the same economic impact as the recession-inducing $81/bbl price spike of 26 years ago.

The electrification trend will continue, and for decades, which leads to the second Principle.

Principle #2: Silicon – a digital economy - increases energy demand

The once and future rise in electric consumption cannot be attributed to the use of lots more lights, air conditioners, motors and pool pumps, as it was during the post WW-II industrial boom. In fact, engineers have made that class of mid-20th century appliances astoundingly more efficient; so much so that growth in electric demand should have stayed flat or, more likely, declined over the past couple of decades. Somewhere along the way to a North American economy that is twice as big today, compared to 1979, new electricity-consuming devices emerged.

There is today a vast new constellation of electricity-consuming silicon-based technologies that didn't exist two decades ago. There are hundreds of millions of digital devices from desktop to palmtop, used in homes and offices, on factory floors and shipping docks, and there are thousands of mega-watt-scale digital technology enterprises from microprocessor manufacturing plants to server farms. All plugged in to the electric gird. All part of the silicon revolution.

Count every aspect of the digital economy's infrastructure – from manufacturing to communications to desktops and server farms – and you find well above 10 percent of total North American electric demand.

You can find acres of electric-consuming silicon concentrated in the belly of the beast -- massive data centers, especially Google's. Recently a Google engineer slipped – "slipped" given Google's penchant for a stratospherically high firewall around any of their core strategic thinking – noting in a blog that data centers were about to cross their own Rubicon: the cost of electricity to run a server rack will shortly exceed their capital cost. I can also tell you, from the perspective of a Board member of a leading company that designs power systems for data centers – there are today more new massive data centers planned and under construction than at any time during the tech bubble. And this time, it's not a bubble.

Given that data centers are the epicenter of the new digital-industrial economy, and that a single data center can require steel-mill-class electric demand measured in tens of megawatts, it is no surprise that this issue has bubbled up as an "energy concern." The U.S. EPA is undertaking a major study of this issue leading to calls for new energy-efficiency standards for data centers, and doubtless some will incorrectly forecast (once more) a future diminution in net demand.

Which brings us to the third principle; one that I readily admit is utter heresy to an entire sub-industry long devoted to the proposition that efficiency can reduce energy demand.

Principle #3: Improving efficiency <u>increases</u> energy demand

Energy efficiency policies have a remarkable feature: they are deeply favored by politicians of all stripes, and on all continents. But, unfortunately for the disciples of energy-efficiency-as-savior, it is demonstrably fallacious that the national energy demand will decrease as overall efficiency rises.

At the highest level of abstraction, the North American economy is twice as energy efficient today compared to 50 years ago, and we use three times more energy. Fifty years from now, likely we'll be three times more efficient and double energy use.

It is apparently seductive, but both obvious and uninformative to note that replacing a specific device or appliance with a more efficient one will decrease that specific object's energy use in that one specific application. The problem is the real world finds not only many more new uses for that same or similar device, but many new devices and technologies appear with the passage of time, as if by magic, and they too consume energy. This has been an enduring trend not just for decades, but for centuries.

From the perspective of basic economics, improving efficiency is synonymous with reducing the cost to operate something. And, absent punitive regulations and sumptuary laws, the overall effect of reducing costs increases consumption. Put another way; if you want to decrease demand, you increase costs which is achieved by decreased efficiency – or of course, simply taxation. (The latter often requires rather aggressive - read punitive - approaches because of the economy's understandably insatiable appetite to grow and stay fueled.)

The statistical scoundrel's fallback is to calculate how improving efficiency reduces the <u>rate</u> of growth. Energy use went up, the argument goes, but it would have gone up even <u>more</u> if we didn't promote energy efficiency. Simplistic, and backwards. Demand grows, in large measure, because efficiency improves.

The steel mills of Dickens' London were horribly inefficient – one tenth the efficiency of those today. The industrial revolution followed because that technology got better, more efficient, cheaper. So too the automobiles at the dawn of the 20th century; today's SUV gets 50 percent better mileage than a 1952 Buick of the same weight and horsepower. Post WWII aircraft inhaled aviation fuel at double the rate of today's Boeing.

And more to the point of our digital economy – compared to the dawn of the digital age, today's computers are one million times more energy efficient in electrons per logic operation. ENIAC was a frightening 170 kW beastly array of vacuum tubes -- the first and planet's sole data center. Because today we have astronomically more efficient logic processors we now have tens of thousands of data centers, and not just one, many clocking in at well above 100 times the power per building of an ENIAC. Total electricity fueling data centers three decades ago was irrelevant; it is now one of the largest single industrial-classes of demand.

In fact, the recent emergence of even more efficient and faster processors is leading to a new hot class of petaflop supercomputers. For the prefix-challenged, a petaflop is one million gigaflops. Supercomputers are the mainframes-on-steroids of the 21st century. Mainframes are far from dead as fatuously declared in the oft-repeated mantra; PCs-killed-the-mainframe. In fact today's mainframes have moved from exotic laboratory curiosity to increasingly vital part of every industrial pursuit from oil exploration and medical research to weather and economic forecasting. Make logic processors more energy efficient yet – and count on that – we'll soon be talking exaflops and zetabytes. For prefix cognoscenti, that's another thousand and million-fold north of "peta."

Power is the biggest engineering challenge for today's super-mainframes. Super-computing, and data centers still untapped capabilities will continue to drive demand for more. And not only will we continue to experience rising digital electric demand, but we are also witnessing the more rapid rise in a unique sub-class of ultra-high-reliability high-quality electric power to keep data-centric systems lit.

Which brings us to the 4th Principle. This is one that engages the strangest and least understood aspect of the physics of energy.

Principle #4: All BTUs are not equal

Much about energy policy is distorted by the metrics we use to count energy supply and consumption. The unit of choice is the (archaic) BTU, the British Thermal Unit.

One source, or use, of BTUs looks like another when toted up in a government's national energy accounts. And all governments and international agencies count all sources and uses of energy using just one metric (or its equivalent). So we trot off looking for ways to find or save BTUs here and there – essentially driven by the intellectually bankrupt logic that all BTUs are equal. This is roughly as useful as comparing tons of gold to tons of wheat; obviously a ton is a ton but is a near meaningless measure of value. So too with BTUs.

The BTUs in photons from sunlight basking a field can appear as BTUs of carbohydrates in wood burned in a fireplace, or transmuted into BTUs of alcohol. Similarly the BTUs of heat released by coal piles, or drums of uranium oxide, can appear as BTUs of electrons to power microprocessors, or BTUs of photons from a laser. They can, and are, all counted exactly the same way. And, simplistically, a BTU is a BTU, just like a ton is a ton. It's a measure. But of what?

There are only two energy metrics that really matter. One is easy to measure. The other, essentially, impossible. The easy one is the money.

Since BTU as easy to convert numerically from one form to another – consider what we pay, on average, for a barrel-of-oil-equivalent of BTUs in various forms. We pay $2 for a barrel's worth of the BTUs from wood burning in a fireplace; $60 for a barrel's worth of BTUs as heat from wood alcohol. We pay $10 for a barrel's worth of coal BTUs in a boiler, and $200 for a barrel's worth of kilowatt-hours spinning a motor. We pay $10,000 for a barrel's worth of electrons consumed by Pentiums, and $200,000 for a barrel's worth of photons from a laser. The market, needless to say, recognizes and willingly pays for – indeed prefers -- the most expensive BTUs. But what is the market paying a premium for? BTUs that are somehow higher in quality, that can do more, and more valuable things. But other than what we pay, what is the metric for this?

The phenomenon we pay for is entropy, or more properly, getting rid of entropy. This is the essential, central core characteristic of energy, and for it there is no unit of measure. The idea of entropy has puzzled physicists and inspired philosophers, poets and pundits since the Victorian era. Defining entropy is actually easier than understanding it, or measuring it. Entropy is, basically, the desire of everything to fall apart, to become mixed up, disordered. Everything we do in life, and life itself, is a fight against entropy – a fight to add structure, order, or logic if you like.

Entropy defines the difference between photons in a field, or from a light bulb, or a laser. There is a lot of entropy – disorder – in cow pasture and light bulb photons. The Pentium's electrons and the laser's photons dance in exquisite synchronicity with lots of entropy stripped away. There is nothing in the BTU numbers that reveals the differences here - - though to repeat, they can all be counted as BTUs. You can count exactly the same number of BTUs of photons from a laser and a fireplace, but the former photons can perform magical feats from welding to eye surgery to carrying gigabytes of data. We only see the difference in what we can do with those BTUs of photons, or electrons, and what we pay for them.

To strip entropy – to have more ordered energy -- takes technology. And, importantly, it takes energy-consuming technology. The more entropy you strip away with clever machinery and electronics, the more energy you consume to get that result. The energy consumed along the way is ridiculously labeled "waste" in our current energy lexicon. It is not "waste," it is a cost – one anchored in laws of physics. What we mislabel as "waste" are the costs – both energy, equipment and capital costs – that the universe extracts from us in the pursuit of less entropy.

We will never get enough of the technologies that produce and use higher-value, lower entropy, BTUs. And while I am confident that policies that treat all BTUs as equal are ultimately doomed to failure in the long run; in the short run, misguided all-BTUs-are-equal policies can cause serious economic harm. Which brings us to the 5th Principle.

Principal #5: It's about the technology.

Energy is never really about raw resources. Both energy supply and demand are primarily determined by technology. Technology, hardware, that strips entropy making laser welding and surgery possible. And the technology that can find and extract oil from the

Arctic Ocean and the Athabasca sands, heat from a strange heavy metal (uranium), or electricity from moving water, wind or sunlight.

Today's technologies are able to tap conventional, or near conventional resources that exist in such staggering quantities that the idea of an enduring energy resource shortages has no meaning. Total known hydrocarbons, deep-water oil, heavy oils, shales and coal measures in thousands of billions of barrels in North America alone. Carbohydrate resources, wood, corn, and sugar cane annually grow hundreds of billions of barrels equivalent. Wind, sun and uranium take the numbers in to the troposphere. Man's millennia-long search has always to create clever technologies to extract and deliver energy from abundant resources

And it is technology that will finally, and shortly, allow us to bridge the long-standing divide in our energy economy – our oil-based transportation and electric-based everything else. I refer to the plug-in hybrid vehicle, something rarely noted outside of techno-circles just five years ago.

As you all know, plug-in hybrids create the option to choose the electric grid, when convenient, over fuel in a tank. Emerging battery technology makes this a realistic option for short-distance urban driving. A pint of oil is displaced with every kilowatt-hour taken from the grid. Urban trips account for billions of such pints.

The rap on hybrids is that they're more hype than hope. But most of what makes today's hybrids expensive – their silicon and digital technologies -- is just like what initially made early computers expensive. But in this case high-power versions. Silicon and digital trends are always towards cheaper, perhaps more rapidly than many realize.

One should note asan aside – particularly relevant to Canada -- that oil will remain essential not just for the majority of ground-based transport, but central to aviation for decades yet. The technology of nuclear energy may, similarly and in a complementary fashion, help to economically tap the thousand billion barrels of oil in the tar sands not viable with today's technology solutions. Which leads to the 6th Principle

Principle # 6 Cheaper is better

All things equal…money matters. Cheaper is the single best metric for how clever the technology employed to accomplish the specific goal.

But when it comes to energy prices, our policies are schizophrenic. One on hand, alternative energy advocates revel in, even blatantly praise, high-priced oil as the long-needed stimulus for favored non-oil sources. On the other hand, all consumers, and most economists, chafe if not rebel at higher prices.

Over the long-run, governments (at least free governments) prefer, and technology enables, ever cheaper energy for society. Even if in the short-run, geopolitics, regulations, capital investment cycles, speculation, and just bad luck can whipsaw energy prices. Lower prices are, on average, a good thing, not just for consumers, but for poor nations, for technology progress, and for national security.

This last point deserves much more elaboration than time permits: cheap oil is the single most effective way to minimize how much money flows to parts of the world we worry about. Lots of extra cash in the wrong hands buys us a lot more trouble. A sustained world price of $70/bbl price versus say $30/bbl sends to the Middle East a cumulative additional cash windfall of over $15 trillion. The oil is there. It will be sold. The only fundamentally effective way to prevent a staggering wealth transfer is to have the free world's energy policies, oil in particular, single-mindedly focused on lower prices. Ultimately this is only achievable through technology.

Demand for oil is not going away any time soon - certainly not in the timeframes any policies can sensibly address. Which brings us to the 7th and last Principle

Principle #7 Energy: demand always rises; which is a good thing

This Principle is really the product of the preceding principles.

Throughout every period in human history, outside of pandemics and total wars, or the equivalent of both in totalitarian societies, energy demand has risen. Technology progress brings economic and social progress. Rising energy consumption is a surrogate for the use of new technologies, of rising affluence, and well-being and, perhaps counter-intuitively, of ever-better environmental quality. Essentially all approaches to minimizing environmental impacts consume energy, and require wealth. Wealthy countries are always better environmental stewards. They can afford it. The energy and environmental trends are long-run and show no evidence of changing. Only the modern day equivalent of Flat Earthers believe, or wish, that we live in a time when these trends have ended.

You doubtless have seen in these seven principles the position occupied by those of you engaged in the global electricity enterprise. You are ensuring the supply of the vital foundational fuel of the 21st century economy.

Over the next 50 years, the world's energy consumption will double. Electricity demand will grow faster. In other words, while liquid fuels will remain important for a very long time, the truly daunting challenge, largely ignored in the current flap over oil, is to be found in meeting the world's appetite for electricity. It isn't that it is foolish to ignore nuclear energy in this equation – it's just not conceivable.

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