Why have long-term interest rates generally fallen since 1981? Why have asset prices risen? Can these trends be expected to continue? The standard evaluation approach by actuaries and economists seems to be to look at past patterns and assume that they will be repeated.

The catch is that energy consumption growth plays a hugely important role in GDP growth. It also plays an important role in interest rates that businesses and governments can afford to pay. Energy consumption growth has been slowing; it is hard to see how growth in energy consumption can ramp back up materially in the future.

Slowing growth in energy consumption puts the world on track for a future like the 1930s, or even worse. It is hard to see how GDP growth, interest rates, and inflation rates can ramp up in the future. More likely, asset price bubbles will pop, leading to significant financial distress. Derivatives may be affected by rapid changes in prices and currency relativities, as asset bubbles pop.

The article that follows is a partial write-up of a long talk I gave to a group of life and annuity actuaries. (I am a casualty actuary myself, which is a slightly different specialty.) A PDF of my presentation can be found at this link: Reaching Limits of a Finite World
After the audience had a chance to answer this question (mostly with yes), I gave my answer: “Yes, indeed, it is possible to build a model that gives misleading results, and not understand the situation.” For example, a flat map works as a perfectly adequate model in some situations. But when longer distances are involved, a globe is needed. A two-dimensional model works for some purposes, but not for others.

The model in Slide 5 is the familiar Supply and Demand model used by economists. According to the model, if Demand increases from $D_1$ to $D_2$, then price will increase from $P_1$ to $P_2$. The rising price, in turn, will allow the quantity produced to rise from $Q_1$ to $Q_2$, based on the upward sloping supply curve $S$. This model is true in some cases, but it is not always true.

Supply and Demand Are Both Affected by Reaching Limits

As the economy approaches energy limits, lack of sufficient growth in energy consumption affects both Supply and Demand. Diminishing returns leads to high costs on the Supply side. Because of this, the cost of producing oil and other energy products tends to rise.

At the same time, businesses find that they cannot pass on these higher costs to their consumers because the wages of consumers don’t rise with rising energy costs. Diminishing returns acts like
Growing inefficiency; it takes more materials, more labor, more tax dollars, and more debt to produce the world’s overall mix of energy products, leaving a smaller amount of resources for producing end products (such as homes, cars, and bicycles) that consumers really want.

Persistent high energy costs lead businesses to try to find workarounds to reduce total costs. A major target for cost reduction is labor costs. If some labor costs can be replaced by lower-paid labor from overseas, or by robots, the company can perhaps make a reasonable profit, even with higher prices for oil and other energy products. **The catch is new lower-cost labor force does not create as much Demand for goods and services as was available before jobs were replaced by robots or sent overseas.** Workers in China and India will buy some goods and services, but the quantity will likely be lower than if the jobs remained in the US, Europe, and Japan.

We end up with a tug-of-war between the high prices that the producers of energy products need and the low prices that the many low-wage workers around the world can afford. Energy products are used in making pretty much everything, including food, homes, cars, and computers. As young people need to live with their parents longer, and as demand moves to lower-waged countries overseas, the lack of buying power tends to pull energy prices down below the cost of production. **Energy prices below the cost of production are just as much a product of reaching energy limits as high energy prices!**

**Peak Oil is Another Two-Dimensional Model**

Before we go on, I should probably offer some more explanation. Some of you may have thought that I would be talking about the Peak Oil story today. I consider the Peak Oil story to be another two-dimensional model. It gives some insights, but it really does not give a good explanation of what can be expected as we go ahead. Its emphases on oil and on high prices are both wrong, in my opinion.

Geologists coming up with the Peak Oil model relied on the incorrect Supply and Demand model of economists. They did not understand that both Demand and Supply are affected, as energy limits approach. They also never considered what the energy needs of the economy really are—total energy consumption needs to grow, if enough goods and services are to be produced for the growing world population. Rising energy consumption is also needed to keep commodity prices high enough to keep production from collapsing from low prices, due to inadequate Demand.

**The Role of Added Energy**

Many of you have heard the saying, “As you sow [seeds], so shall you reap.” In other words, the effort you put in can be expected to correspond to the end product that is produced. This saying is somewhat true if an economy uses only human labor to produce goods and services. For example, if a person digs a ditch for five hours, the result will correspond to effort put in. Increasing the hours of digging to six can perhaps add 20% to the length of ditch that can be dug. (There is the detail that it even takes energy products to make a shovel. Perhaps the example should be digging a ditch with a stick, and thus using only human labor!)

If a person really wants to dig a ditch quickly, he needs ditch-digging equipment and diesel fuel to operate the equipment. The ditch-digging equipment is made with energy products; it also uses energy products while it is
operated. If energy consumption per capita is rising, then businesses, on average, can use increasing amounts of energy to increasingly leverage the labor of the workers they hire. This seems to be what leads to productivity growth.

This is why I talk so much about energy consumption per capita, and the importance of falling prices of energy services (including efficiency gains) to encourage the growth in energy consumption. One example of energy services (whose costs need to fall) would be the cost of heating a 1,000 square meter home (including efficiency gains in furnaces and insulation). Another example would be the cost of transporting 100 kilograms of grain 100 kilometers.

The price of energy services has, in fact, been falling. (Energy services include efficiency gains.)

In fact, over time, the cost of energy services has been falling. The fall in costs more than offset the growing quantity of energy consumed. Thus, the cost of energy services is becoming a smaller and smaller share of world GDP. This falling share of energy products as a percentage of the world GDP seems to be necessary, if the remainder of the world economy is to grow. If the cost of energy products starts to rise, it will tend to crowd out some of the discretionary goods and services that the world economy has been able to add, as the world economy has grown.

Higher Energy Prices Are Damaging to the Economy; Lower Energy Prices Encourage GDP Growth

Energy needs to be consumed by the system, whether workers dig ditches with shovels or with ditch-digging equipment. If energy is very expensive, it is likely that all that employers can afford is the equivalent of shovels for workers to work with. If energy becomes less expensive to use (including efficiency gains), then it becomes possible to scale up the use of tools using energy, and the economy can expand. As a result, workers can become more efficient, businesses can make more profits, and the government can collect more taxes. The falling price of energy services seem to be the major force underlying GDP growth.

Conversely, if oil consumption growth is constricted by a spike in oil prices, we know (based on the work of Economist James Hamilton) that the US economy tends to go into recession. Higher prices make it difficult for
both businesses and consumers to buy energy products. Falling energy consumption is damaging to the economy, because the creation of goods and services depends on the use of energy products.

High Correlation Between World GDP and Energy Consumption

Energy consumption is not mentioned at all on the economists' supply and demand model (Slide 5), but it is clear that energy consumption is highly correlated with economic growth. There is a reason for this: it takes energy products to make both goods and services. It even takes energy to heat and light an office for workers, and to make and power computers.

Economists tend to miss the connection between energy and the economy because they tend to perform their analyses on an individual country basis. The connection between GDP growth and energy growth is less clear on a country-by-country basis because individual countries can reduce their energy consumption by shifting some of their manufacturing to less developed countries, confusing the analysis. The International Energy Agency has concluded that higher oil prices can be expected to have an adverse impact on the world economy as a whole.

The Economy Is a Self-Organized System Operated by Energy
The reason for the strange behavior of energy prices near limits is because the system is very interconnected. It is a self-organized system that gradually changes over time. New customers are added over time. These customers are often also wage-earners. They decide what to buy based on their own wages, and based on other considerations, such as the prices of competing products and whether inexpensive financing is available.

Businesses make decisions based on what they think customers might want. They also consider products offered by competitors. Governments play a role as well, both in regulation and taxation.

Physics indirectly helps determine prices, wages, and profits, because the economy uses energy to make goods and services. If a rapidly growing amount of cheap energy is available, it becomes easy for businesses to make a profit and raise wages. As businesses grow, economies of scale tend to increase profits. Higher energy prices tend to reverse these beneficial effects.

**Oil Prices Are Now Too Low for Many Oil Producers**

Near limits, we reach a situation where no oil price works: Too high for buyers; too low for sellers

Price problem only appears near limit
- Appears "well-behaved" elsewhere
If you are not familiar with energy price trends, it probably would be worthwhile to take a minute to look at the strange price pattern shown on Slide 9. If you are coming from a financial background, you will probably be familiar with the financial disruptions of 2008, but not the high oil (and other energy) prices of the same period. The steep drop in prices corresponds to the time of major financial distress.

Most United States infrastructure, such as interstate highways, pipelines, and electricity transmission systems, were built in the pre-1970 period, when the inflation-adjusted price of oil was generally less than $20 per barrel. Thus, in a sense, most of the oil prices we are seeing in recent years on Slide 9 are high, relative to historical costs. The question becomes, “How high a price can the economy withstand?” It becomes very expensive to replace a worn-out pipeline built with $20 per barrel oil using $120 per barrel oil.

On Slide 9, prices required by oil exporting countries (such as Saudi Arabia, Venezuela, and Norway) seem to be well over $100 per barrel. Such a high price is needed if these countries are to be able to collect enough tax revenue and also have funds for investment in new fields to replace depleting fields.

On the other hand, the economies of the United States, Europe, and Japan do very much better if oil prices are low. They would prefer prices under $50 per barrel. This is the price mismatch mentioned on Slide 9.

Extended periods of low prices can be expected to lead to two adverse impacts over a period of several years:

1. **Falling growth in energy production.** Investment in new fields to offset declining production from existing fields is likely to fall. The big drop in oil prices occurred in 2014, and it is now four years later. Many analysts expect growth in oil production to slow in the next few years, because of inadequate investment. Coal, natural gas, and uranium have somewhat similar problems, with falling prices discouraging reinvestment.

2. **Collapsing governments of oil exporting nations.** Governments of countries that export oil are often very dependent on the high price of oil to collect adequate tax revenue. The central government of the Soviet Union collapsed in 1991, after several years of low oil prices. Lack of adequate tax revenue could cause a similar problem today. Venezuela is particularly at risk, but Saudi Arabia and many other countries could follow.

It is ironic that Venezuela reports the highest oil reserves in the world. These reserves can only be extracted if energy prices are much higher than today. This would seem to require higher wages of non-elite workers around the world. If wages were much higher in countries such as India and Nigeria, they could afford goods such as motorcycles and air conditioning, helping push up world demand for energy products.
It is clear that the growth rate of energy consumption simultaneously affects Supply and Demand.

An important point on Slide 10 is the fact that growing **debt acts as a helper for energy consumption**. It allows consumers to afford goods and services with their monthly wages, and it allows businesses to pay for new tools for workers over the lifetime of those tools. In a sense, debt is the promise of future goods and services made with energy products.

Money is a type of debt. We can print money, but we can’t print cheap-to-produce energy products. Thus, at some point, there can be a mismatch between *promises of future goods and services* and the *quantity of affordable energy products available to create those goods and services*. This is part of what is likely to cause debt defaults.

Slide 11 lists some of the things that seem likely as we reach the limits of cheap-to-produce energy supply. I will describe these issues more, later in this talk.
Let’s look at some pieces of the story in more detail
1. How GDP growth occurs
2. How interest rates and asset prices fit with GDP growth
3. How the networked economy works
4. Why limits seem to be near
5. The economy as a dissipative structure
6. What peak oil and EROEI research got wrong

Slide 12

Slide 12 is an outline of the rest of the talk. This post primarily covers Points 1 and 2. Thus, this article relates primarily to GDP growth, interest rates, and asset prices. Slides are shown for Points 3 and 4 as well.

How GDP Growth Occurs

Slide 13

Without supplemental energy, human capabilities would be at level of chimpanzees

- Humans learned to burn biomass over one million years ago
- Possible to cook food
  - Less time chewing; more time making tools
  - Enabled larger brain; smaller jaws and gut
- Use of extra energy allowed more dense human population
In recent years, it has become increasingly apparent that the ability of humans (and pre-humans) to cook part of our food supply has had a major impact on our ability to be different from other animals. We could eat a wider variety of foods, and we could get more energy value from those foods. Our bodies could evolve in a very different way. Our brains could become bigger, and our jaws and gut could be smaller.

![Supplemental energy has allowed greater range and higher population density](image)

Even back in hunter-gatherer days, humans were using more energy than similar animals. Now, in the industrial period, we are using 80 times as much energy (≈8000/100) as a human-like animal would use, considering the various types of supplemental energy available to us. Some people have described the situation as having 80 energy-slaves for each person. This makes it possible to do tasks, such as farming and digging ditches, in a more efficient way than using sticks as tools.

**How energy consumption growth works**

- Without supplemental energy, the only energy humans have is their own limited energy
- Supplemental energy allows humans to have tools to leverage their human labor
  - The more leveraging, the more goods and services that can be produced
  - Tool examples: Trucks, roads, machines, factories
Besides the usual tools, we have many related ways of using energy, with the goal of eventually providing more goods and services. Energy can be used to organize data on computers. Energy can be used to provide advanced education on topics helpful to growing the economy. If individuals or businesses are paid wages or interest payments, they can use those proceeds to buy energy products, such as a new car, or an overseas vacation. Thus, energy consumption growth affects every part of the economy.

**Energy consumption doesn’t grow by itself. It needs these four enablers:**

1. **Growing debt** (or sale of shares of stock)
   - Making tools has a future benefit
   - Need to pay workers making these tools, before the benefit is available
   - Debt pulls the economy forward; workers can afford to buy goods

2. **Growing technology**
   - Technology enables the use of energy products

3. **Growing businesses and governments**
   - Allows increasingly complex tools like factories, schools, pension plans, police force

4. **Falling price of energy services**
   - Adding energy services becomes increasingly affordable
   - Benefit of efficiency gains needs to exceed higher energy cost because of diminishing returns

Growing debt is extremely important in growing the world economy. I describe the situation more fully in this article: [What has gone wrong with oil prices, debt, and GDP growth?](#)

Technology is what most people focus on, as being the way to move the world economy forward. However, it takes energy products to make the new machines made possible by technology. Without a steady supply of energy products, we cannot maintain existing roads, or the electric grid, or the internet.

**Let’s look more at “growing debt”**

- Lower interest rates clearly enable more debt
- Monthly payment for 30-year mortgage of $300,000
  - At 3% - $1,268
  - At 4% - $1,432
  - At 6% - $1,799
  - At 10% - $2,633

Anyone who has purchased a home knows that interest rates are very important in determining what price of home a particular buyer can afford. Here I show a range of monthly payments, for a 30-year, $300,000 mortgage at various interest rates. It is clear that a person can afford to buy a great deal more house at a low
interest rate than a high interest rate. If interest only loans are available, costs are lower still.

Ten-year interest rates have been falling since 1981, helping the economy to grow

![Graph showing falling ten-year interest rates]

Everyone who works with interest rates is aware of this pattern in 10-year US Treasury interest rates. The peak in interest rates was in 1981, and there has been a downward trend most of the time since that date.

Raising short-term interest rates reliably induces recession

![Graph showing short-term interest rate increases and recession]

The interest rates that regulators can easily adjust are short-term interest rates. When these interest rates are increased, they tend to induce recession. There may be a lag in timing. The increase in short-term interest rates in the 2004 to 2006 period seems to have been instrumental in popping the subprime debt bubble and bringing on the Great Recession of 2007-2009. This is my article relating to this issue: [Oil Supply Limits and the Continuing Financial Crisis](#)
When energy consumption is growing rapidly, and there are productive projects that can be added (interstate highway system, long distance electric grid, interstate pipelines, first-time telephone service for many people, growing number of trucks and airplanes), then it is possible for the economy to grow rapidly.

In this rapidly growing economy, the economy could easily ramp up long term interest rates without damaging the economy because the underlying growth rate was so high. In a sense, the higher interest rates were analogous to inflation affecting food and energy prices. There was so much growth in demand for goods and services that the economy could afford to pay rising interest rates during the period between World War II and 1981.

The period since 1981 is a period when investments have become much less productive, from a point of view of allowing more goods and services to be produced. Instead, growth is coming from selling more services to each
other, and sending more manufacturing to lower-cost parts of the world.

Since 1981, we find ourselves with an increasing amount of old infrastructure that needs to be maintained. Fixing this infrastructure doesn’t really improve productivity. New investments simply keep productivity from falling.

One recent innovation has been the internet. It gives us more information, and it relieves us from the burden of having to use the phone book or go to the library. Thus, it makes us more productive. But in many ways, it is not as important as many earlier inventions, such as the internal combustion engine, the light bulb, and the telephone. There is a temptation to computerize all kinds of data and to expect data mining to solve all our problems. A person wonders what the true cost/benefit is.

Innovations in medicine now allow more 85-year-olds to live to be 86-year-olds and allow more cases of cancer to be cured. But the big changes, brought about by antibiotics and better sanitation, occurred before 1981.

Another growth area has been higher education. The payback is often wages that are barely high enough to live on. How are college graduates who cannot find high-paying jobs going to be able to repay their loans and still get married and have a family?

Admittedly, some investments have been productive. This is especially true when new factories, roads, and ports have been installed in emerging markets. But a large share of recent investments have been aimed at making vehicles more fuel efficient. Or trying to reduce CO₂ emissions. These do not really have a payback in lower-cost goods and services.

Interest on debt can only be paid if the economy is truly growing, and thus has a sufficient margin to pay interest with. This seems to be less and less possible outside of emerging markets. I would expect that this is why long-term interest rates are persistently low.

Since 1981, US GDP growth has fallen despite decline in ten-year interest rates

Peak individual year GDP growth rate (with inflation) was 1978.
The decline in the ten-year interest rates should make homes more affordable. The long-term decline in shorter-interest rates should make vehicles more affordable. In spite of this boost to the economy, US GDP growth rates have persistently fallen. World GDP growth rates have fallen as well.

There is relatively little storage available for commodities of most types, including oil. As a result, even a small change in demand can lead to a major price shift.

I show in Oil Supply Limits and the Continuing Financial Crisis that the peak in oil prices corresponded to the peak in US debt in several categories, including credit cards and home mortgages. Once US debt stopped rising, the demand for oil fell, and prices dropped precipitously.

Quantitative Easing (QE) by the US Federal Reserve began near the end of 2008. It acted to lower interest rates, especially long-term interest rates. These lower interest rates helped get oil prices back up closer to the level required by producers. But once QE stopped in 2014, prices slid back down. As noted earlier, recent oil prices are far too low for most producers. But they do help stimulate the economies of oil importing countries.
If a business adds debt to expand a factory, this may lead to more wages. The chart indicates that growing non-financial debt does not always lead to higher wages. Sometimes it leads to asset bubbles.

Disposable personal income (DPI) is income that individuals receive, including payments such as Social Security and Unemployment Insurance. This amount is netted out for taxes paid. If we divide DPI by population, we get per capita DPI. This amount is not inflation adjusted; it gives us an estimate of how much incomes have been rising, including payments made to compensate for inflation.

Clearly, there have been huge changes in the growth of per capita DPI over time. Prior to 1981, per capita DPI was rising rapidly, as more women joined the workforce, and as companies gave cost of living raises, in an attempt to keep their employees. In several years, per capita DPI was rising at over 10%.

Families with rapidly rising incomes were looking for ways to spend their new-found wealth. This seems to be at least part of the reason for the high inflation rates of this period. Without this rapid run up in DPI, it is hard to see how the oil prices spikes of the 1970s could have occurred.

Now, the economy has slowed greatly. DPI per capita is sputtering along at less than 4% per year. With this low rate of increase in funds available for spending, it seems like the current economy will not be able to support a big spike in oil prices.
If the economy is not really growing, it is very difficult to pay interest. This is why a person would expect interest rates to roughly follow GDP growth. Back before 1981, GDP growth was significantly greater than 10-year Treasury yields. Since then, 10-year Treasuries have tended to yield a little more than GDP growth (including inflation). Very recently, the pattern seems to have returned to the pre-1981 pattern.
If interest rates are lower, more people can afford to buy a given house, or a piece of land, or shares of stock. The additional demand tends to bid up asset prices.

Need to be careful in looking at past asset growth patterns

- Pre-1981 patterns will show artificially low asset price growth, because of increasing interest rates

- Post-1981 patterns will show artificially high asset price growth, because of decreasing interest rates

This should be clear from Slide 29.

Actuaries would like higher interest rates

- Difficult to see how this is possible
- Trend in GDP growth is downward
  - Slower GDP growth is driven by slower energy consumption growth
  - Slower growth in energy consumption indirectly implies falling interest rates or defaults on bonds
Interest rate assumptions often were originally made when interest rates were higher.

Payments to individuals in a particular year act as a way of dividing up goods and services available in that year. If the share of goods and services going to those who are paid interest rises, it will mean fewer goods and services are available for others. History says that it is the non-elite workers that are most likely to be “shorted,” if there are not enough goods and services to go around.

Very low interest rates make for instability in asset prices
• Low cost of borrowing encourages asset price bubbles
• Bubbles can break with either:
  • Small increase in interest rates
  • Increase in oil prices (as in 2008)
• We are now encountering both a short-term interest rate rise and an oil price increase
Historically, rising asset prices have partly offset falling interest rates for pensions
• If both interest rates and oil prices rise, danger is that fall in asset prices may be severe
• Rise in interest rates unlikely to offset impact of asset price decline

Currency relativities and derivatives may also be affected by instability
• Oil prices are positively correlated with many other commodity prices
• Some countries are favorably affected by higher commodity prices; some are hurt by them
• Rapid adjustments put derivatives at risk

How the Networked Economy Works
Energy consumption is key to making goods and services

- **Picking a stone** up off the ground requires energy
  - Usually human energy, but a forklift can also be used
- Any process requiring **heat** requires energy
- **Transportation** requires energy
- **Education** requires energy
  - Teachers and students must be freed from working in fields
  - Tools to make farming more efficient require energy
  - Differing wages of graduates reflect energy differences

*Rising total energy consumption per capita* seems to be key to a growing economy
The economy grew especially well in 1950-1970 period; did very badly in the 1930s

Collapses of early civilizations seem to occur when per capita energy consumption hits a limit

Timeline of typical collapse, based on Turchin and Nefedov’s “Secular Cycles.”
Technology looks like a savior, but it isn’t

- Growing use of technology leads to **wage disparity**
  - Some people receive special training; others don’t
  - Competition with low wage areas of world
  - Some jobs eliminated completely
  - Low wages of non-elite lead to falling demand for goods

- Analysis of prior collapses shows growing wage disparity part of problem
  - Joseph Tainter — Collapse of Complex Societies
  - **Diminishing returns to added complexity**

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**Why Limits Seem to Be Near**

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Today’s wage disparity problems rival those of the 1930s
Since 2001, China has been pulling world economy along with its coal-based economy

- China’s coal production is now falling
- No adequate substitutes

Wind and solar have been adding very little to world energy supply

Wind and Solar are part of “Other Renew.”
Even a decline in coal consumption is a problem, if it causes total energy consumption per capita to fall! Wind and solar cannot possibly make up the shortfall. Also, their installed cost is high, if the cost of intermittency workarounds is included.

Many slides skipped!
Concluding observations

- Financial regulators would like to think that they determine how the economy works.
  - In fact, the operation of economy is largely determined by the laws of physics.

- It is doubtful that interest rates can rise for long, without considerably higher GDP growth

Concluding observations (continued)

- Asset prices are likely to be unstable because they reflect very low interest rates.
  - If interest rates rise, even for a short time, they will likely pop asset bubbles.

- Energy growth seems to be close to stalled.
  - This puts a lid on GDP growth and interest rates.

Concluding remarks (Continued)

- If economy begins shrinking, actuaries may be in the “hot seat.”
  - Why were prior investment yield estimates so high?
  - Shouldn’t someone have noticed the connection between energy growth, GDP growth, and interest rates?
About Gail Tverberg

My name is Gail Tverberg. I am an actuary interested in finite world issues - oil depletion, natural gas depletion, water shortages, and climate change. Oil limits look very different from what most expect, with high prices leading to recession, and low prices leading to financial problems for oil producers and for oil exporting countries. We are really dealing with a physics problem that affects many parts of the economy at once, including wages and the financial system. I try to look at the overall problem.

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259 Responses to How the Economy Works as It Reaches Energy Limits — An Introduction for Actuaries and Others

Davidin100millionbilliontrillionzillionyears says:
May 13, 2018 at 10:51 pm

“US will be ‘very strong’ for next 15-20 years due to shale boom”...

https://www.cnbc.com/2018/05/13/us-shale-story-has-been-very-positive-for-borealis-ceo-says.html

“So we’ve actually got a large project with Total, we’re building a $3.2 billion complex near Houston. And we think that that’s going to be the future. The U.S. for the next 15-20 years looks very promising.”

they are betting $3.2 billion on it... to make petrochemicals from the “shale gas”...

so they are absolutely convinced that they are correct...

Reply

Fast Eddy says:
May 13, 2018 at 11:23 pm

Seriously???