Energy and physical resources are integral to the economy.

- Energy transforms raw materials (resources) into finished products
Over 99% correlation of energy consumption with GDP

GDP is in 2010 US$, as provided by USDA; energy use from BP.
Growth in GDP and growth in energy use correlate on a short-term basis as well.

- Energy growth tends to precede GDP growth
  - Suggests energy growth is a cause of GDP growth; new recession ahead
Majority of long-term GDP growth seems to come from growth in energy use

- World economic growth peaked 1950-1965
  - Almost as high in 1965-1975, trending down since
Cheaper electricity production, 1900–1998, contributed to economic growth

Source: R. Ayres and B. Warr, Accounting for growth: the role of physical work.
Where does economic growth come from?

- Two places:
  - 1. *Cheap* energy supply
    - Oil less than $20 barrel, today’s prices
    - Also, growing use of coal at low prices
  - 2. Growing debt
    - Allows customers to buy goods, even if they otherwise can’t afford them
World had oil for less than $20 per barrel prior to 1973

Source: Based on BP Statistical Review of World Energy 2015 data.
Growth in debt started at same time price run-up for oil occurred.
Run up in debt was enabled by falling interest rates
Reason for Leveraging Impact of Cheap Energy on the Economy

Cost of Production  |  Benefit to Producer  |  Sales Price  |  Leveraging Benefit to Consumer  |  Value to Society
My conclusions

- Cheap energy can lead to GDP growth
  - In this case, debt growth is “only” equal to growth in energy consumption

- Run-up in debt is needed to continue economic growth, if energy is expensive
  - Logical reason for this
    - Economic growth requires energy, even if it is expensive
    - Takes debt to get this energy

- Neither cheap energy nor debt run-up can last very long
  - Cheap energy => diminishing returns
  - Continued debt run-up => Ponzi scheme
Now, interest rates are about as low as they can go

- Federal reserve wants to raise rates
  - Meeting December 15-16

- Yields are now rising on bonds with low credit ratings

- Rising interest rates => less borrowing

- Future economic growth needs to come from “cheap energy,” alone
  - No help from rising debt levels
What do energy limits look like?

- Peak oil theorists have one theory
- Another view seems more likely
Peak oil theorists’ view: Based on Hubbert model

Cheap alternative takes over **well before** peak

![Graph showing rate of consumption over time](image)

Figure 30 - Relative magnitudes of possible fossil-fuel and nuclear-energy consumption seen in time perspective of minus to plus 5000 years.

Peak oil view

- Oil prices will rise endlessly
  - High-priced substitutes OK
  - Assumption: High prices aren’t a problem for the economy

- Down slope will be gradual
  - Based on geological decline
  - Assumption: Economy doesn’t matter; geology is all-important
My view

- Downslope comes when we cannot have one of the following:
  - (1) Energy prices that are low enough (< $20 barrel)
  - (2) Rising debt levels

- What happens in this case is
  - (1) Wages stagnate
  - (2) Loss of buying power not made up by more debt
  - (3) Prices of all commodities fall due to lack of “demand”

- We seem to be hitting energy limits, right now!
Falling affordability affects all commodities at once – including natural gas and coal

Based on IMF Pink Sheet data.
Potential for a near-term financial crash

- Financial crash may bring down supply of all commodities
  - Brought on by *low* prices
  - Food, metals, coal, oil, natural gas

- Likely to be hard to restart
  - May “take-out” electricity, too

- *Low prices* are what energy limits really look like
  - Many bankruptcies
  - Loss of jobs
Result is *energy and commodity costs* continuing to rise, but *prices* falling behind.
Need replacement energy supply

- Essentially now
  - If not now, very soon

- Inexpensively
  - Make electricity affordable
  - Keep down debt
  - Not use too much material

- Ideally, also make cheap liquid fuel, using electricity
  - Less than $20 barrel
How cheap? Probably 4 cents/kWh or less; if possible, make liquid fuels < $20 barrel

Retail and industrial based on EIA data; wholesale estimated as 65% of industrial.
Affordability is the **first** energy-related limit of a finite world.

- **We Are Here**
- **Affordability**
- **EROEI Limits**
- **Climate Change**
- **Running Out of Oil, Fuels**

High Commodity Prices Reversing To Low Prices
There are many reasons why energy needs to be cheap

- Competition with other countries
  - High priced oil or renewables makes country uncompetitive

- Competition with free energy from sun
  - Cold countries have extra costs
  - Hard to compete with warm countries
  - High energy prices makes problem worse

- When energy costs are high, they tend to squeeze out other costs
  - Wages and interest costs