Suppose we agree how to calculate EROIs … so/now what?

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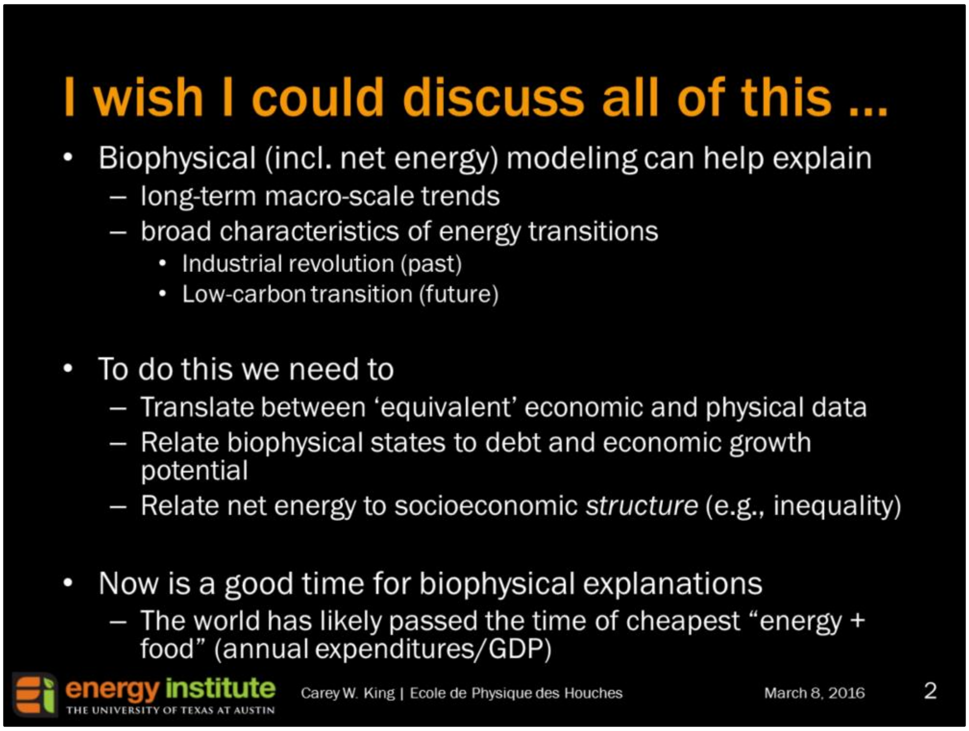

Slide of motivation and background. Bullets are mostly self explanatory.

I will later support the claim that the world has passed the time of cheapest "energy + food"

But I think I only have time for …

- Biophysical (incl. net energy) modeling can help explain
  - long-term macro-scale trends
  - broad characteristics of energy transitions
    - Industrial revolution (past)
    - Low-carbon transition (future)

- To do this we need to
  - Translate between ‘equivalent’ economic and physical data
  - Relate biophysical states to debt and economic growth potential
  - Relate net energy to socioeconomic *structure* (e.g., inequality)

- Now is a good time for biophysical explanations
  - The world has likely passed the time of cheapest “energy + food” (annual expenditures/GDP)

Motivation that new thinking is needed in macroeconomic modeling, in particular as it relates to energy and debt.

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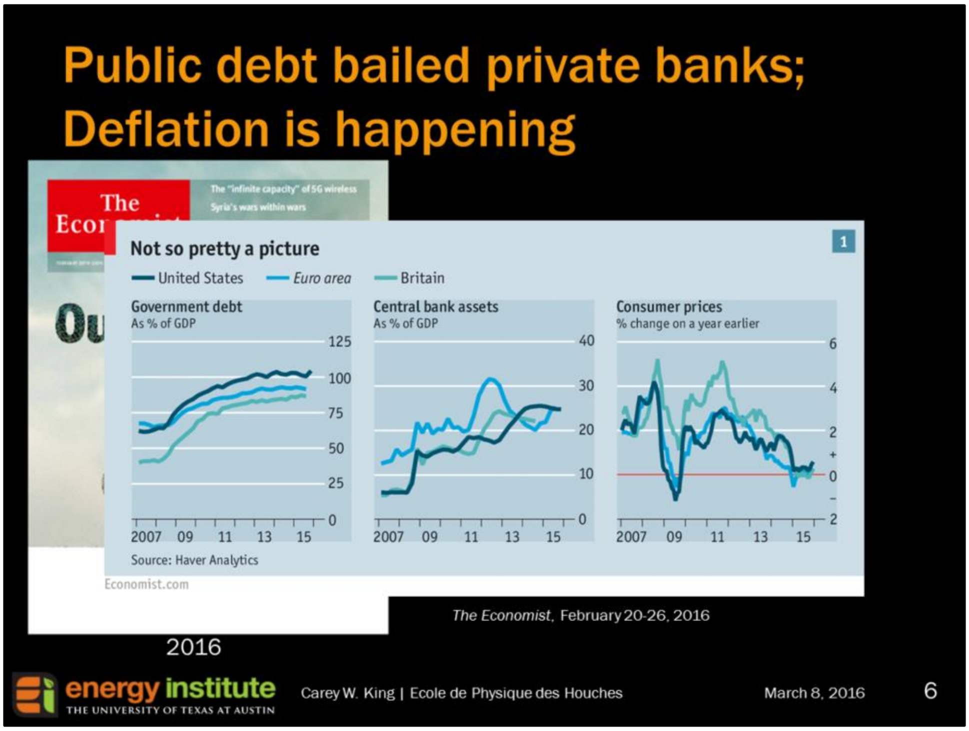
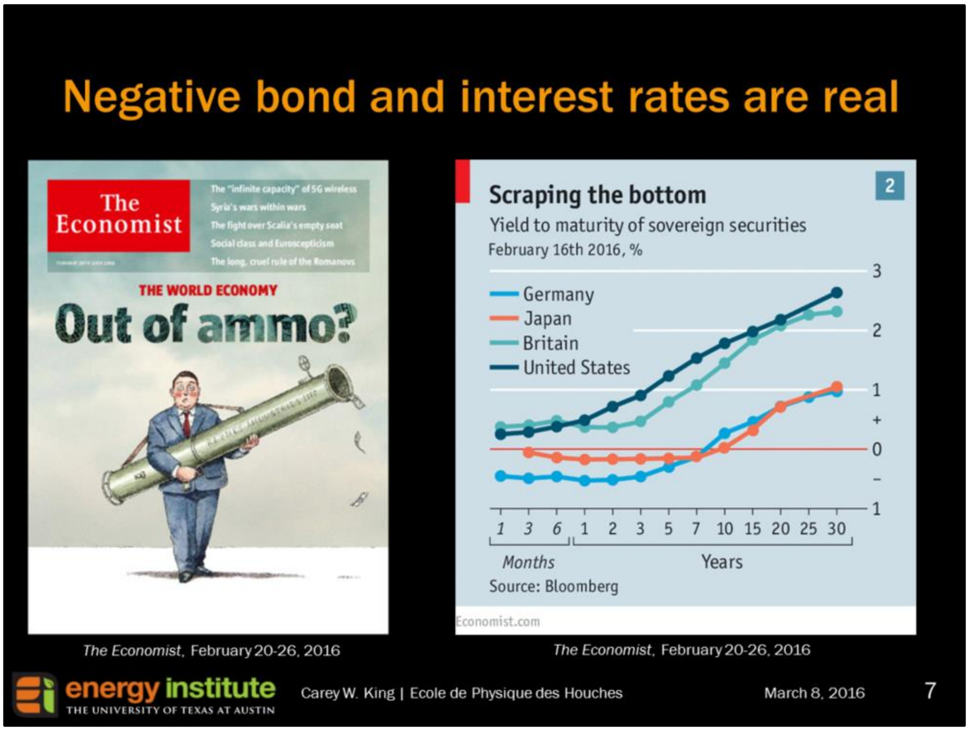
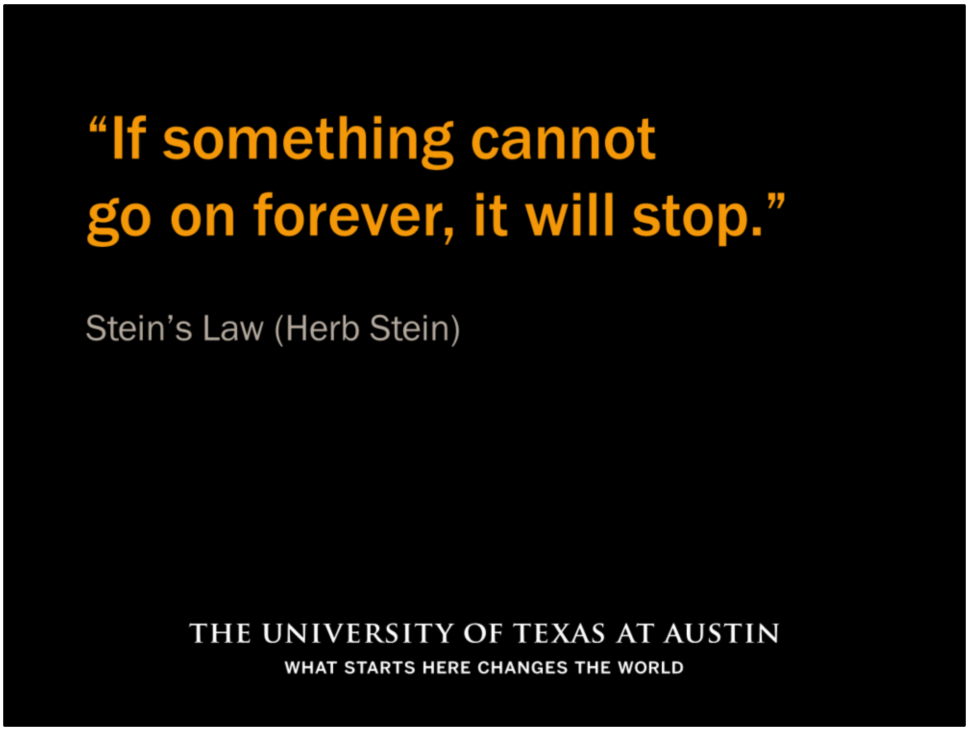


Emphasizing that there are trends occurring in the world economy that have no precedence in terms of indicators occurring simultaneously (high public and private debt, low interest rates and central bank assets (loans), and deflationary pressures).



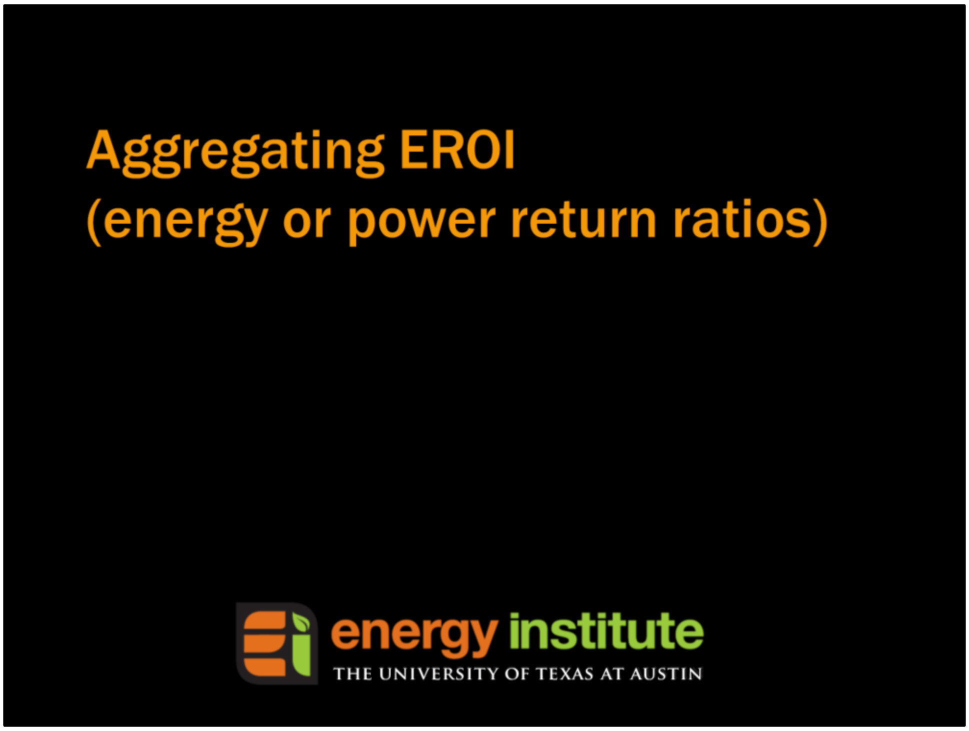
Emphasizing low interest rate and (near) deflationary situation. This Economist article indicates that Japan and Germany have many government bond maturities (out to 7 years) that have NEGATIVE yields (e.g., you pay them to borrow your cash).

Are trends related to energy really behind the unprecedented combination of values of the various economic indicators?

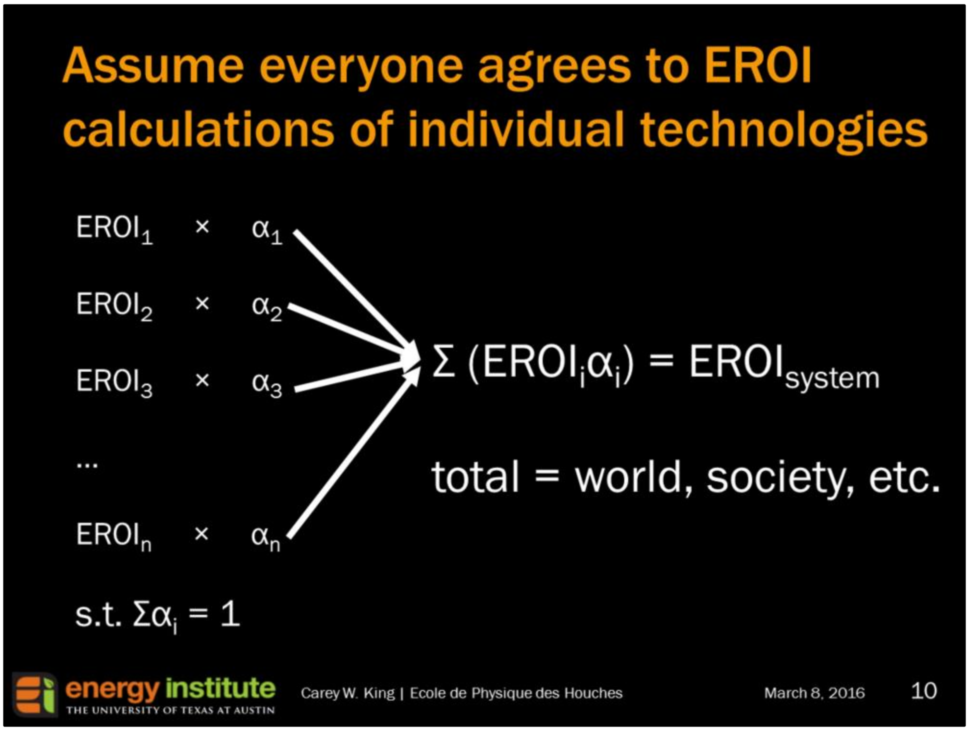


I use this quote to justify thinking that energy and food costs cannot decrease forever (e.g., energy and food will not be free), so:

1. How much are we spending on energy and food?
2. How low can those costs go?
3. How do we know if we've reached the lowest costs?
4. What happens if we reach a low point in energy and food costs?

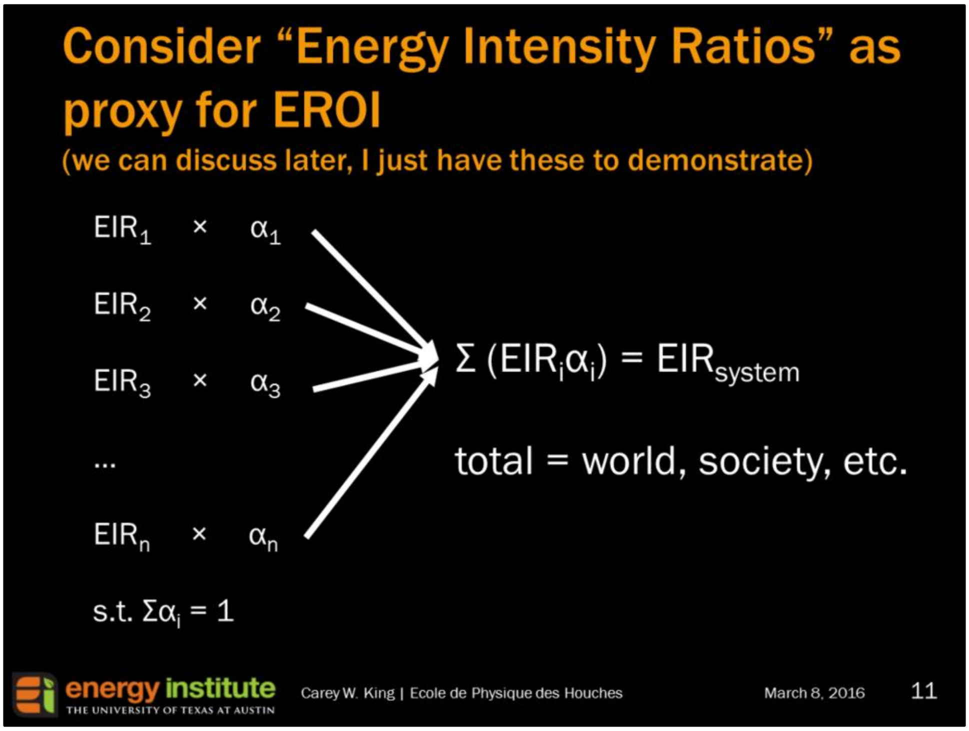


I’m going to discuss how you aggregate individual indicators of “net energy”, say for individual technologies or individual energy commodities, into a single number for the entire economy.



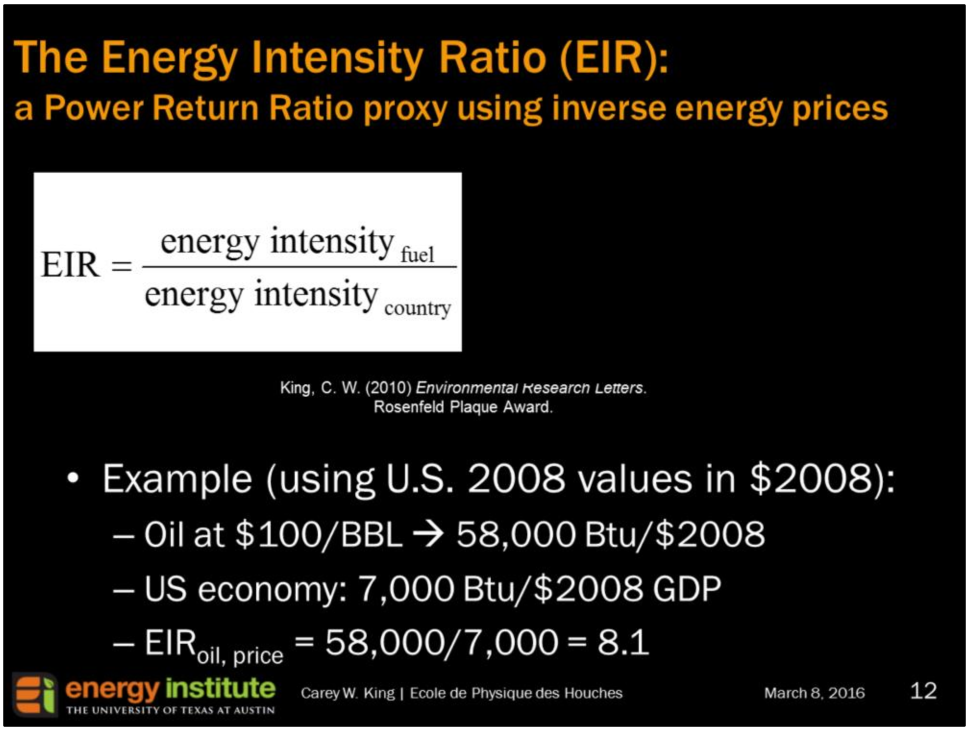
EROI = "energy return on energy invested", and here I use it as a generic concept that EROI ~ (energy output from an energy technology) / (energy input to produce energy).

The ideas is that there are many EROI_i, and you have to weight them in some way to come up with the "EROI of the overall energy system", or the "EROI of society or the economy".



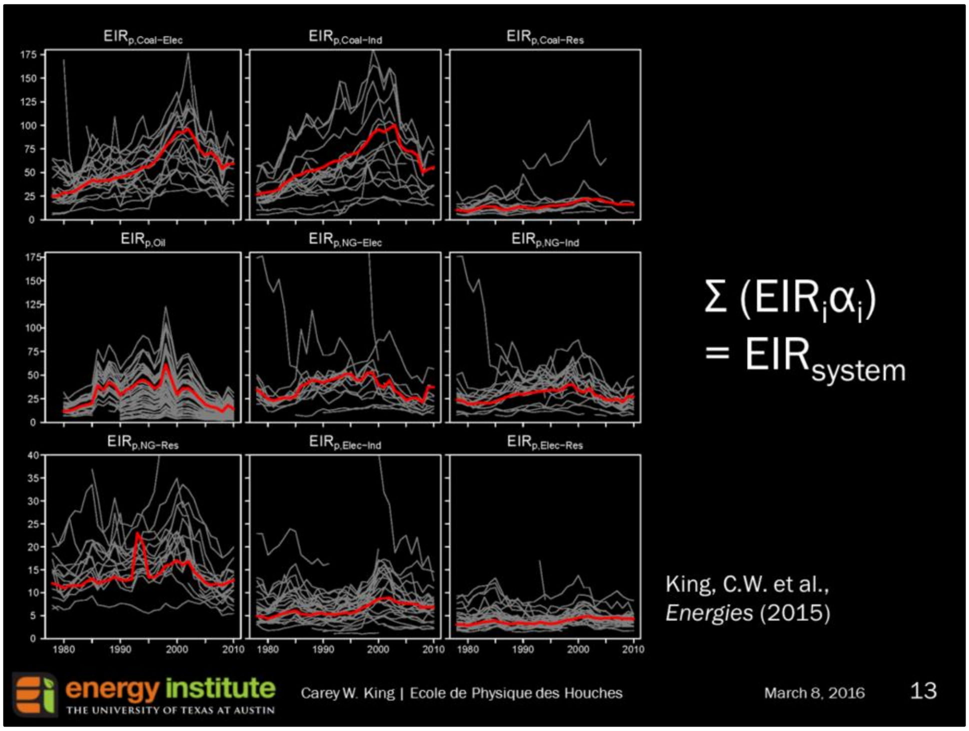
Here I say to consider what I call the "Energy Intensity Ratio" as a proxy for EROI of multiple energy commodities. They are different in terms of underlying data you would use and the mathematical calculation, but they represent a similar concept. EIR by definition just uses energy prices whereas EROI, since in theory it is based on life cycle concepts, can use pure energy data.

EIR defined on next slide.

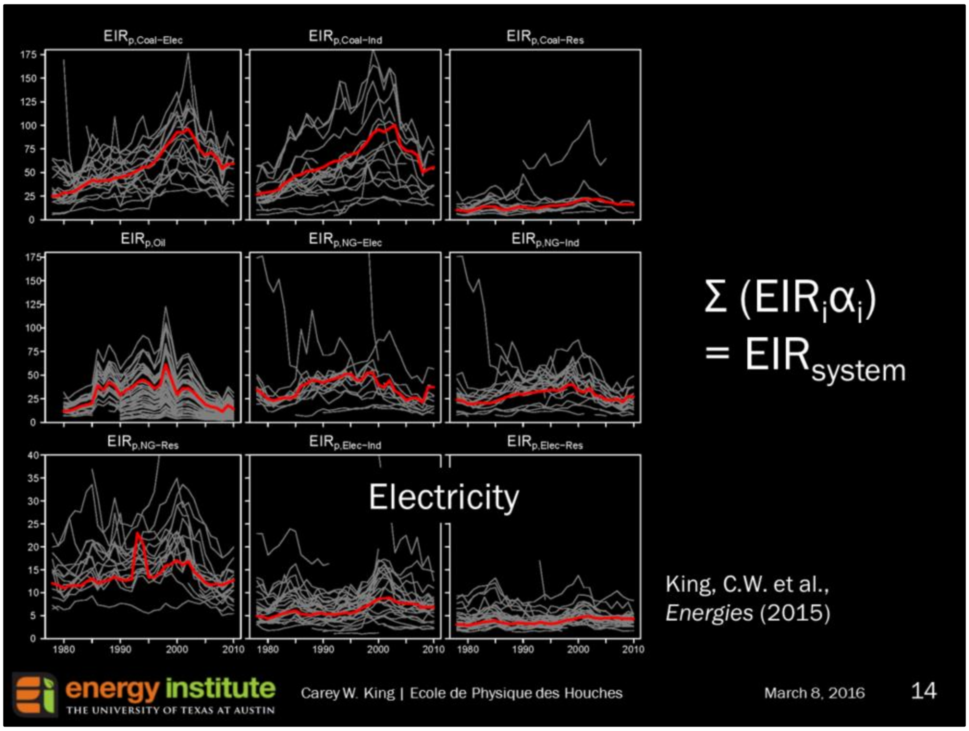


Definition of EIR. See King, C. W. (2010) in *Environmental Research Letters.*

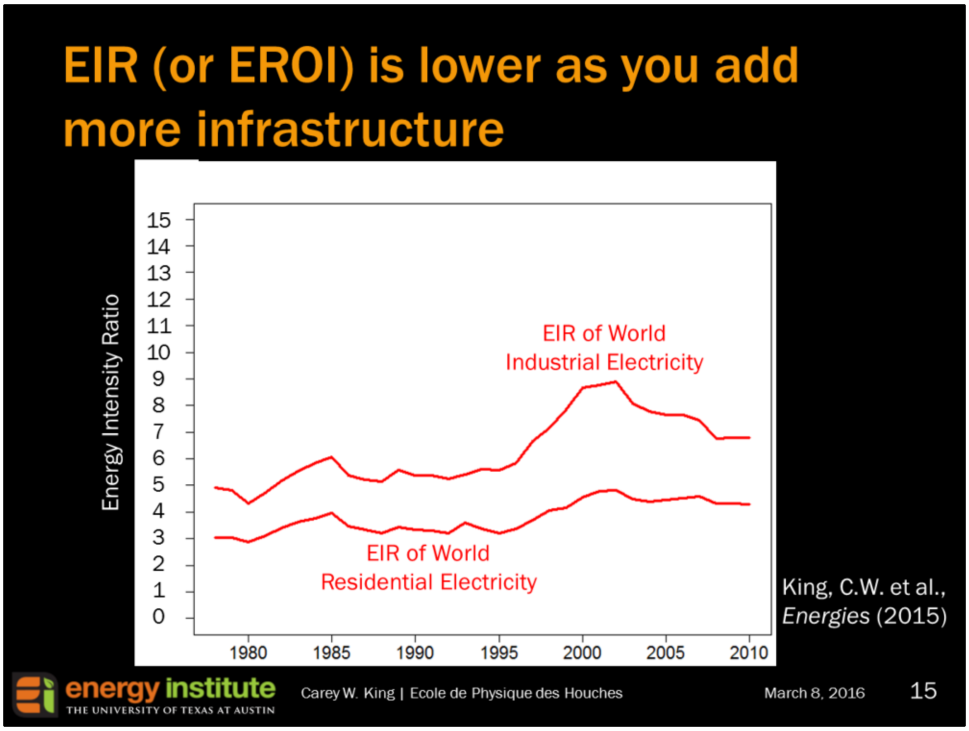
“EIR_oil,price” means the energy intensity of oil based upon its price.



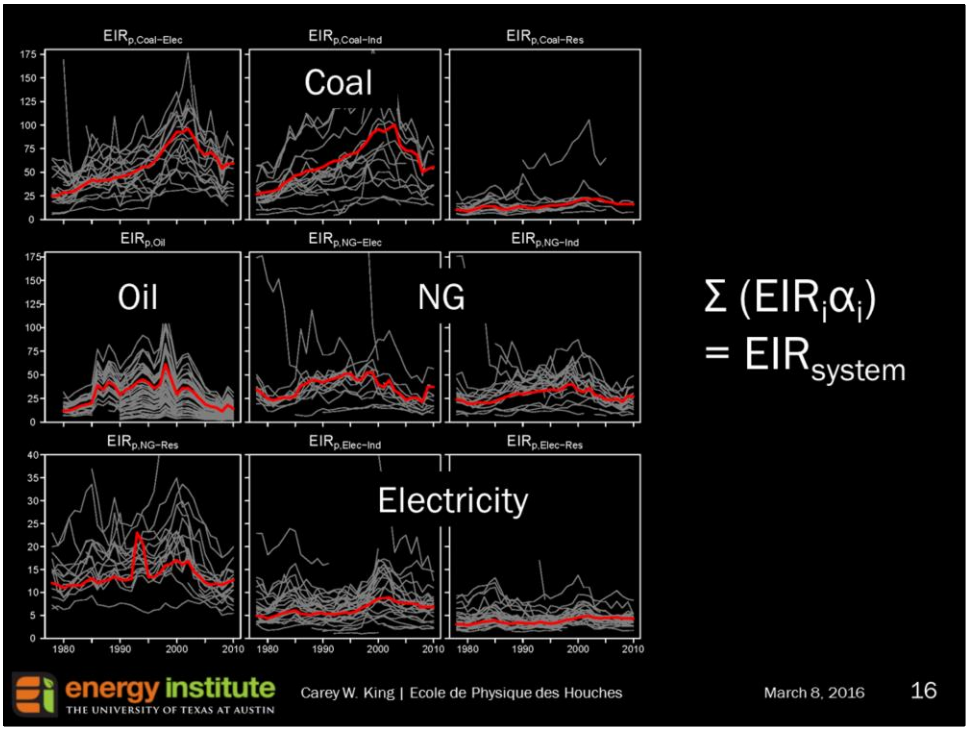
From my 2015 paper in the journal *Energies* (Part 1 of a 3-part series), the EIR of 9 different energy commodities that are sold to different consumers (e.g., industrial consumers versus residential consumers).



I'm pointing out electricity as an energy commodity here specifically as an example. There is electricity sold to industrial customers and residential customers. Compared on next slide.



Here we see that the EIR of "industrial electricity" of the world is > the EIR of "residential electricity". Another way of saying this is that industrial electricity is cheaper than residential electricity.



EIRp,Coal-Elec
EIRp,Coal-Ind
EIRp,Coal-Res
Coal
EIRp,Oil
EIRp,NG-Elec
EIRp,NG-Ind
Oil
NG
EIRp,NG-Res
EIRp,Elec-Ind
EIRp,Elec-Res
Electricity
Σ (EIRiαi)
= EIRsystem
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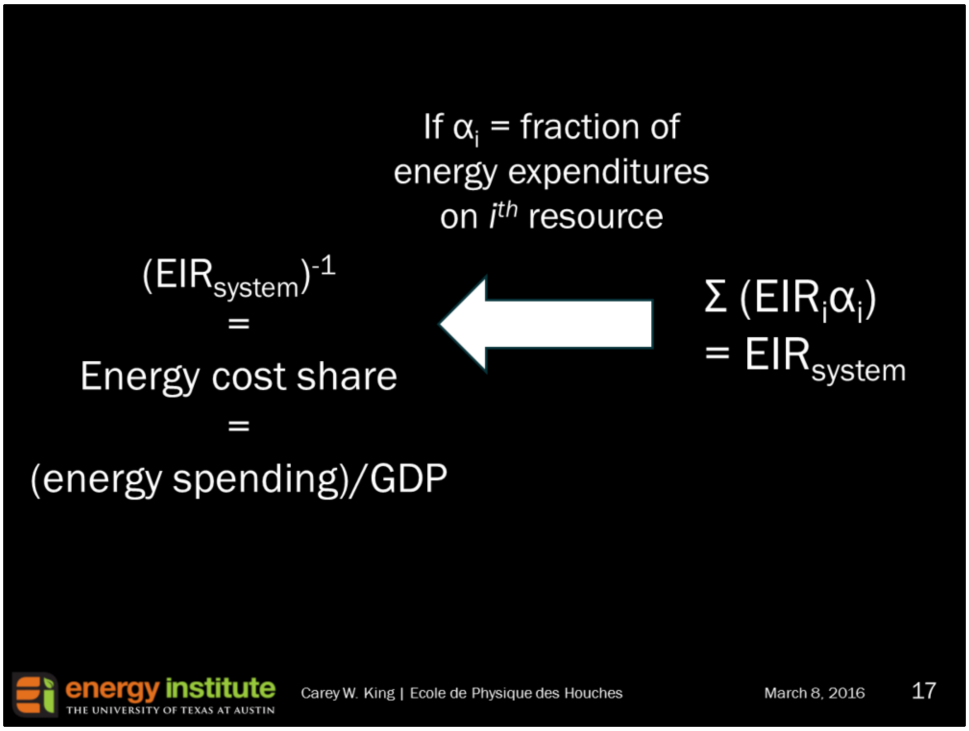
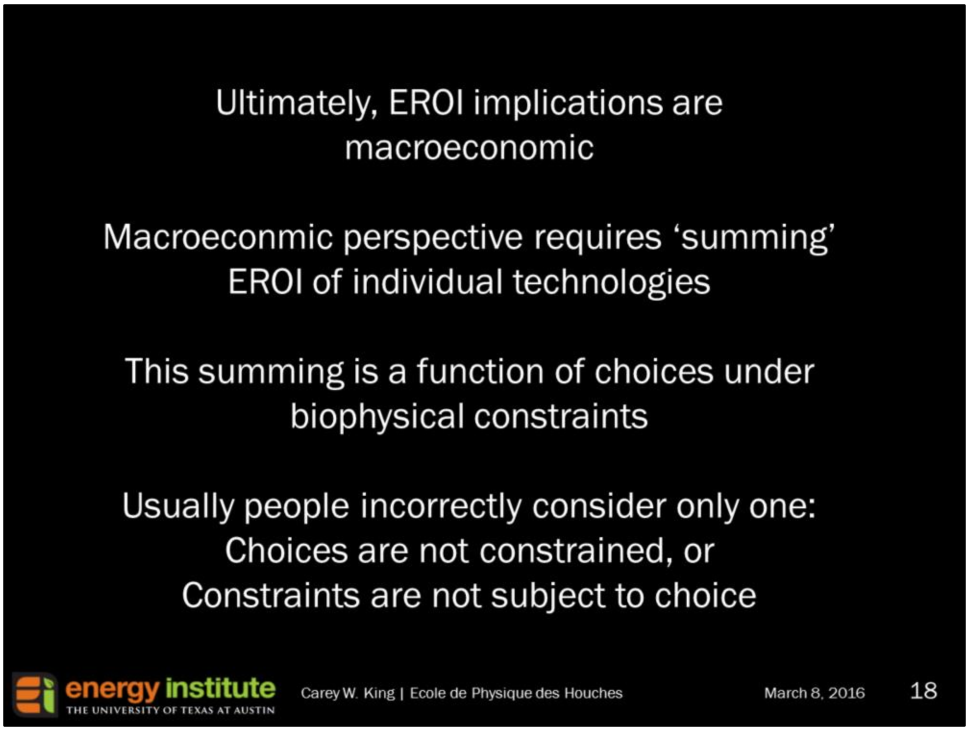


What I think is the best way to weight individual metrics of net energy (e.g., EIR, or EROI) is by the fraction of total spending on energy that occurs for that commodity or technology. In this way, when you calculate the “average”, or aggregate, it becomes equal to the inverse of all spending on energy divided by GDP (or the net output of the economy). In this way we include the concept of consumer choice, that is to say, that consumers chose to consume a certain amount of oil, NG, electricity for all kinds of reasons.

Some people consider aggregating each EIR, EROI, etc. by the fraction of total energy consumed in the form of that commodity. This is more independent (not completely independent), of consumer choice and energy quality (e.g., oil is priced higher in MJ/$ than coal for various reasons related to the qualities of each commodity). It is not as clear to me how to use this aggregate metric as that which best governs societal structure, but surely both ideas could be tested.

Nontheless, I think it is important to link individual net energy metrics (for individual technologies or commodities) to a single metric for the overall economy, and relating to total energy spending is the most straightforward way (I think) to do that because it is another number we can find in the economic data.



Here I'm emphasizing that although people usually are calculating the net energy (e.g., EROI) metrics of individual technologies, commodities, or industries (e.g., oil and gas), ultimately the reason why we should be studying net energy concepts is to understand their macroeconomic implications. We need to understand how much energy issues constrain our social and economic choices.

So …

Let’s consider Energy and Food cost shares over time

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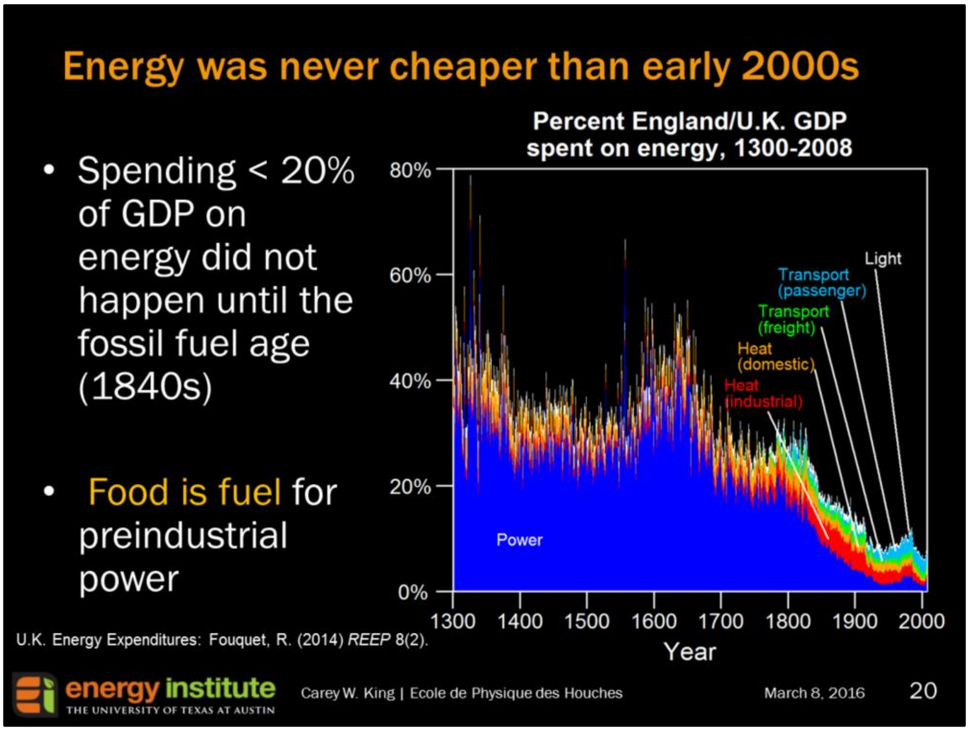
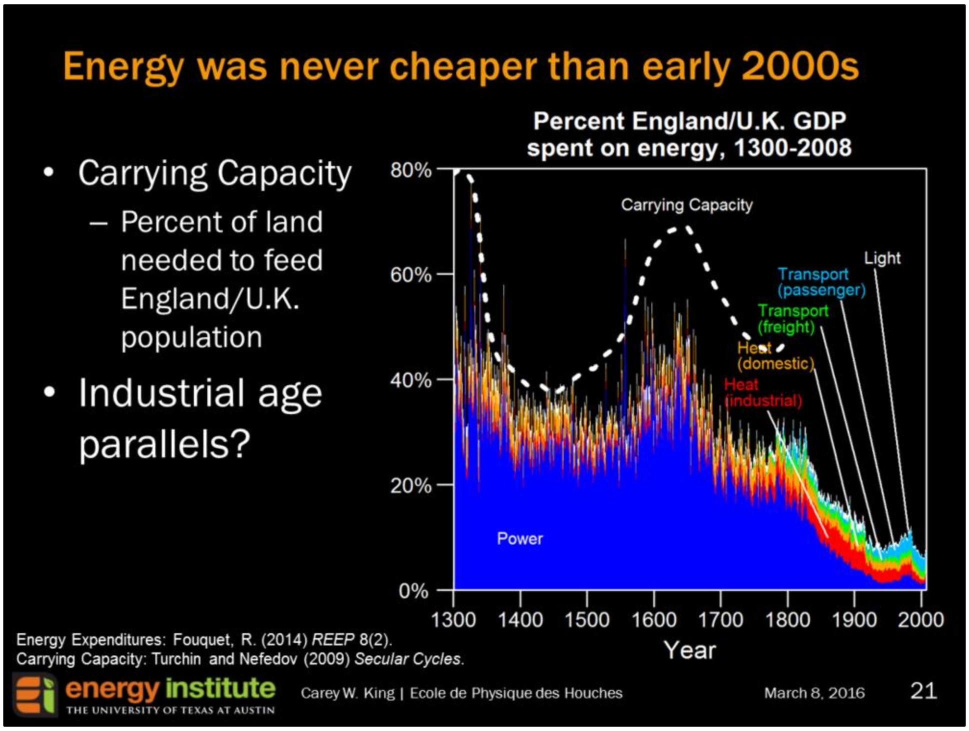
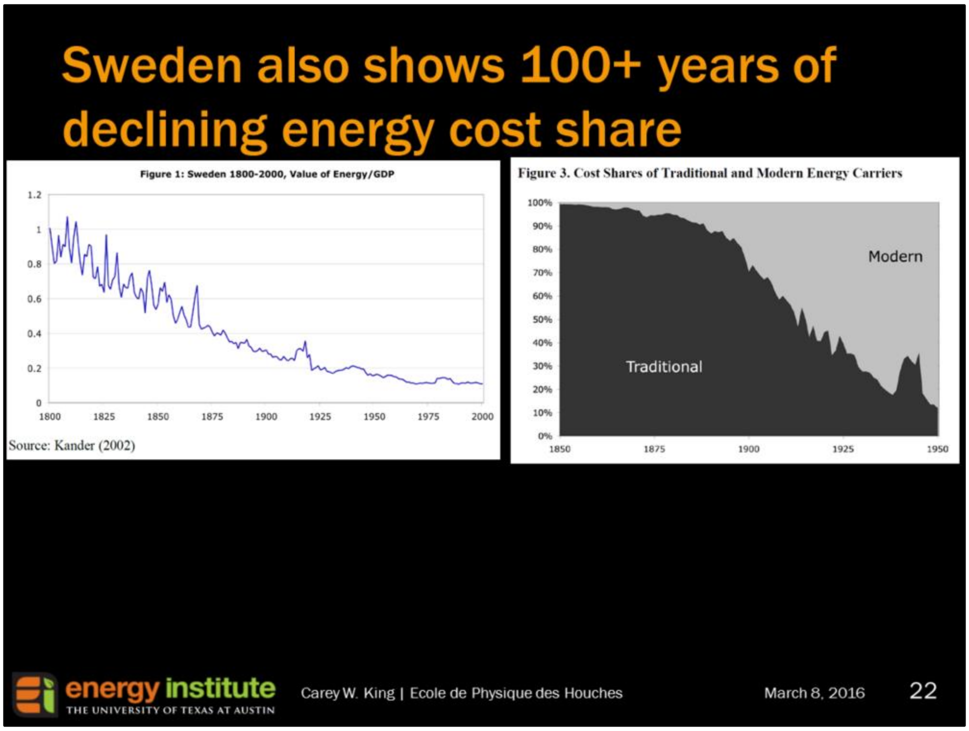


This shows the overall long-term trend of England/UK for energy spent on each energy service as a fraction of GDP. “Power” = physical work, which is not included food consumed for humans performing physical labor, much of it in farming.

The lowest number in the chart is for 2005, and the last year calculated in this chart is 2008.

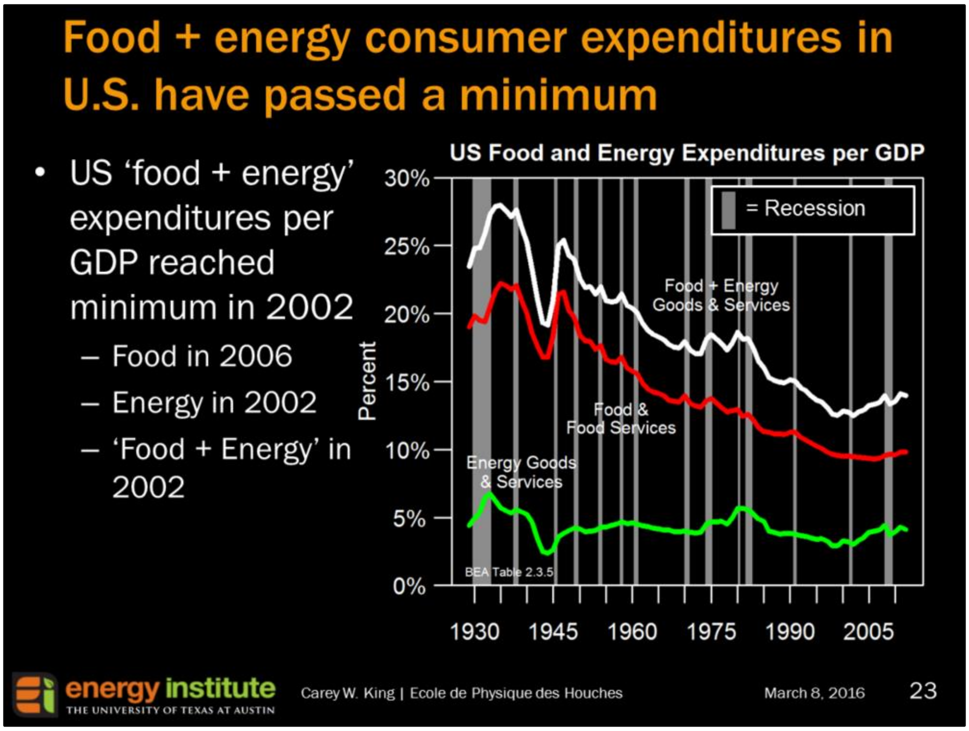


This figure adds "carrying capacity" which is the percent of land needed to feed the England/U.K. population. A value of 100% means that the population is (theoretically) at a maximum.

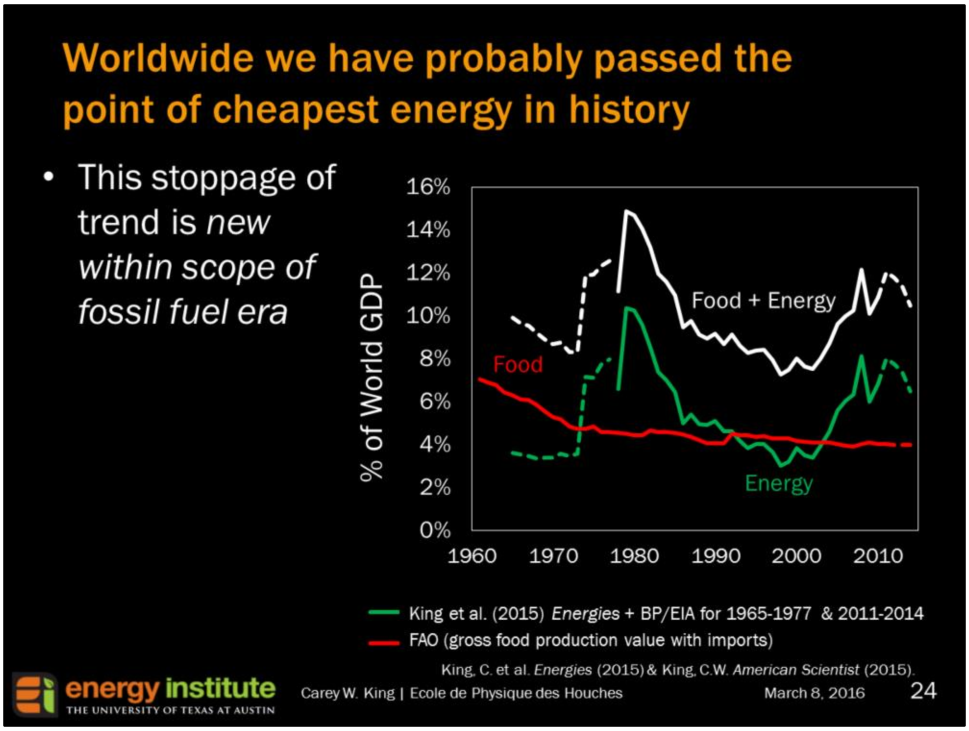


This is a similar calculation to that shown on the previous two slides, except this is from Astrid Kander and characterizes spending on energy in Sweden. Correspondence with Roger Fouquet (created the data for the England/UK time series) and Astrid indicated that the preindustrial energy spending relative to GDP was higher in Sweden largely due to higher heating needs.

The trends gets continuously lower over time, but seems to have leveled off after the 1980s.



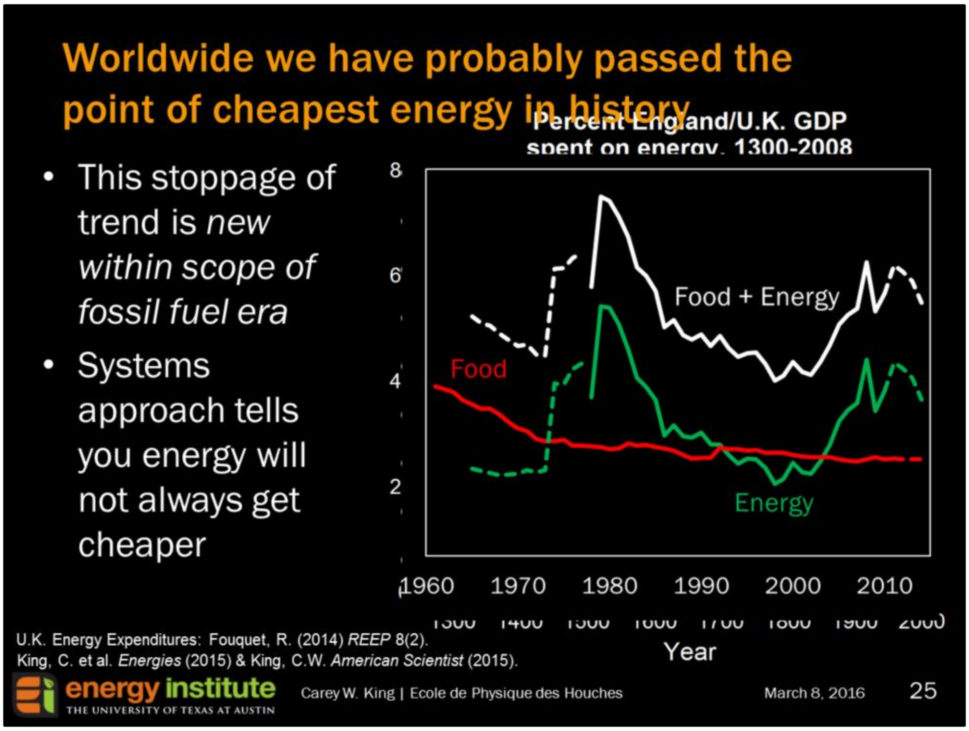
Using data from the Bureau of Economic Analysis (annual data start in 1929) we can also track the cost of "food and energy" (as core needs), over time. The lowest value in the sum of "food and energy" services in for the year 2002.



This figure summarizes two different data sets on the global level. The figure is from my 2015 article in *American Scientist*):

1. The estimate of global spending on energy in: **King, Carey W.**, Maxwell, John P., and Donovan, Alyssa. **Comparing world economic and net energy metrics, Part 2: Total Economy Expenditure Perspective**, *Energies,* **2015**, *8*, 12975-12996
2. The estimate of global food expenditures from the Food and Agriculture Organization (FAO) at the producer price level (e.g., cost of food production, not cost that consumers pay at the grocery or restaurants). The cost of consumer food (at least for OECD countries) had a clear increasing trend from the early part of the 2000s..

The main takeaway from this slide is that GLOBAL food + energy costs seems to have hit a low point (relative to GDP) around the year 2000. They were close to the same low level just before the oil embargo of 1973.



This slide uses an animation to put the global trend (of food and energy costs) superimposed over the long-term trend (1300-2008) of costs for energy of energy services in England and UK. This puts current costs into perspective such that I conclude that near the year 2000 was probably the cheapest "food + energy" costs in history.

Since 2000 energy costs are up (mainly due to oil) and food production level costs (from FAO) are no longer decreasing after the middle of the decade of the 2000s.

BIG QUESTIONS:
If the basic "food and energy" costs have been declining since the start of the Industrial Revolution, but seemed to have reached a nadir (ow point) around the year 2000, then:

1. If much of economic growth, as we think of it for developed countries, has largely been associated with substituting human labor with machines (capital) and fuels, is this substitution reaching its limits?
2. What does this mean for the future, including the capabilities for transitioning to a low-carbon economy?
3. Is hitting the low point in "food and energy" costs an explanation for the increasing debt (e.g., debt/GDP ratios) of both governments and consumers, the post-2008 reaction by central banks to lower interest rates to near zero, and bond yields to be negative for some shorter term maturaties (e.g., Germany, Japan)?

4. Is inequity, increasing since the 1980s for the U.S. and Europe, a reaction to fundamental physical constraints after the 1970s (e.g., increasingly equitable distribution within developed countries could no longer continue because physical availability of resources per person was no longer increasing exponentially)?
5. Are the various major trends of the world reaching an unprecedented combination of levels because they would naturally converge due to energy-economic feedbacks: (i) aging population along with slower population growth, (ii) debt, (iii) interest rates, (iv) aging infrastructure, and (ii) stagnant or rising "food + energy" costs?

Net energy (or energy cost share) can inform the low-carbon transition

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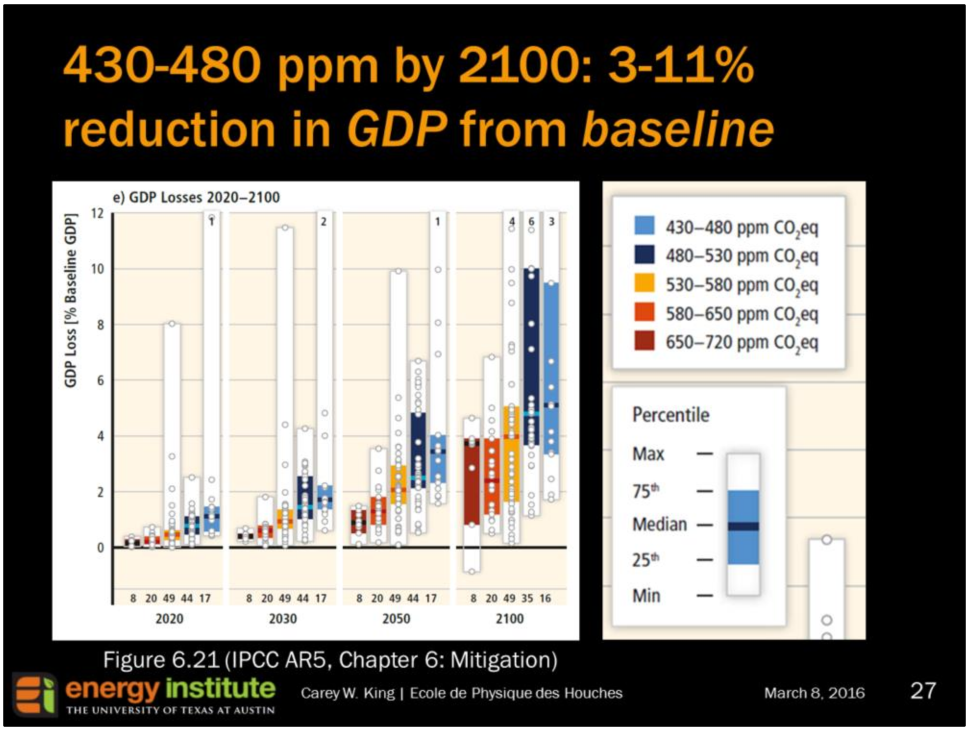
In this set of slides discussing a low-carbon transition, I make the case that current macroeconomic thinking (e.g., computable general equilibrium models and their derivatives) do not sufficiently inform us as to the dynamics and feedbacks that we should expect during a low carbon transition. In particular, they don't properly account for the *rate* of transition (and also debt, not discussed here).

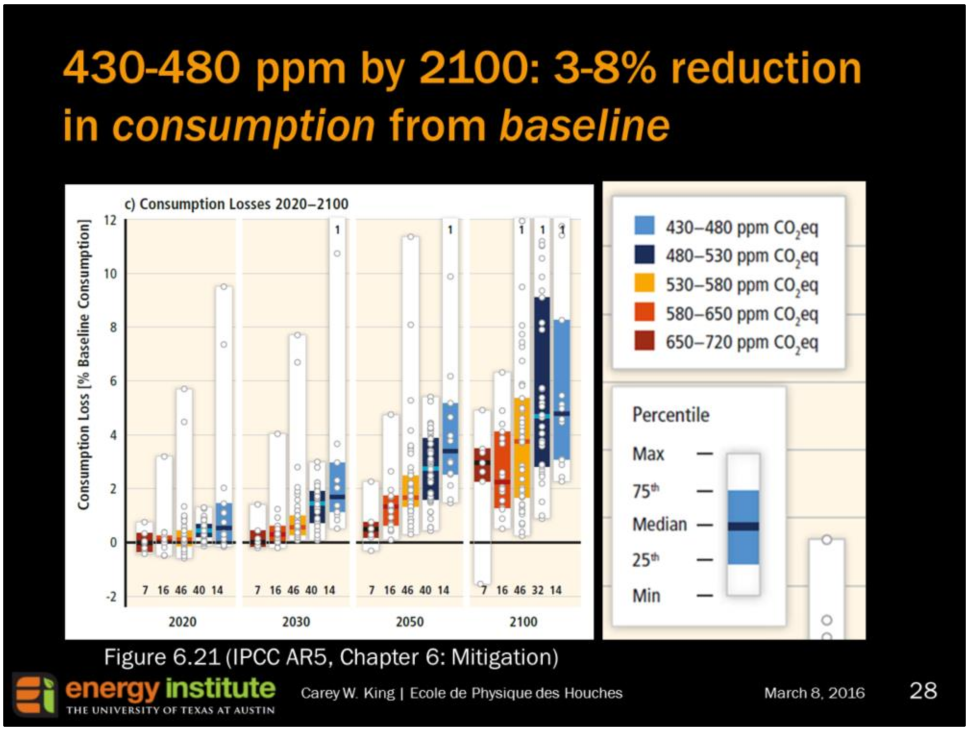


This is Figure 6.21 from Chapter 6 of the IPPC Fifth Assessment Report (AR5) on the topic of carbon mitigation.

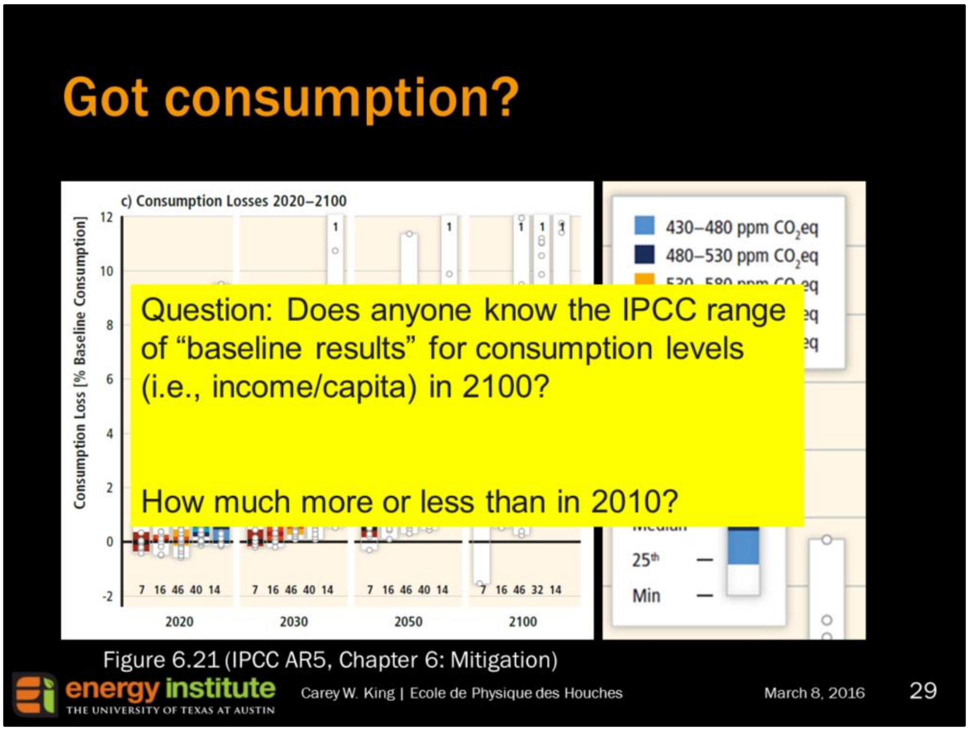
The figure shows the "GDP Loss [% Baseline GDP]" which is the percentage reduction in total GDP, for the year indicated and for the target CO2,eq concentration indicated (e.g., level of carbon mitigation), calculated by the various integrated assessment models that inform the IPCC. The Chapter 6 explains the "baseline scenarios" as [see Box TS.6] "Scenarios of how the future develops without additional and explicit efforts to mitigate climate change". Box TS.6 and Figure TS.7 indicate that most scenario projections use the UN population (low to medium) variants that end up with 9-10 billion global population by 2100.

Figure TS.7, not shown, and text of Chapter 6 indicates that the 2100 GDP/person is projected (in the baseline scenarios) to be typically 3X to 8X the size of GDP/person in 2010.

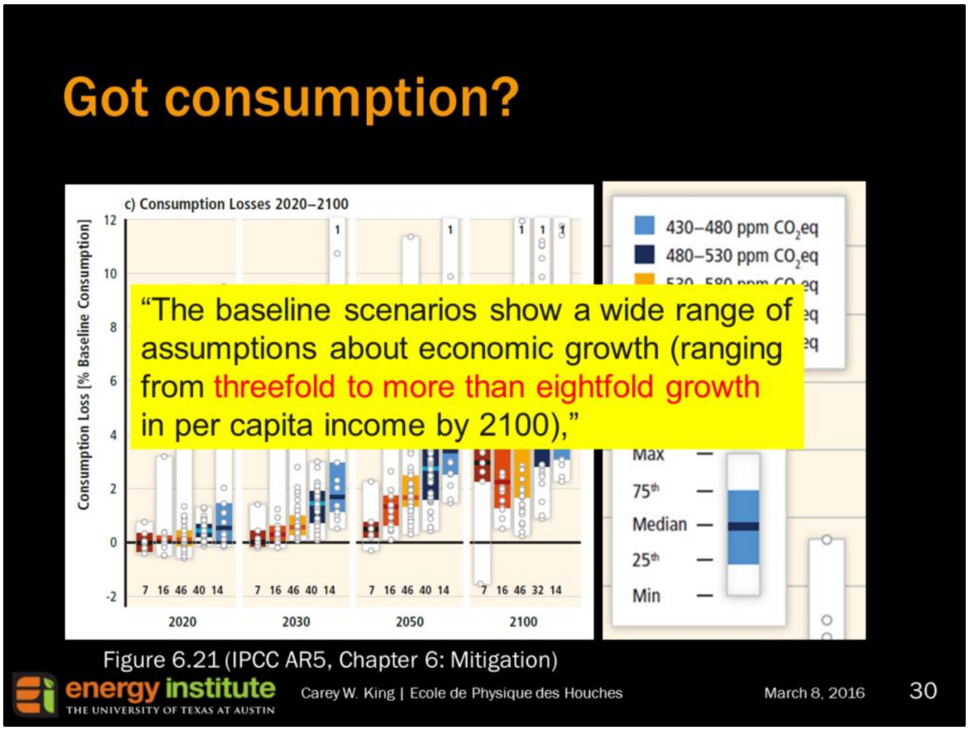
The main takeaway from this chart is that even full carbon mitigation (e.g., stabilizing the atmosphere at 430-480 ppm CO2,eq) is assumed to only reduce global GDP in 2100 by 5% (median) and only 3 simulated scenarios show a reduction of > 12% (they are off the chart in Figure 6.21). These are small reductions in GDP so that full mitigation (assuming 5% less) then shows GDP/person in 2100 (for 430-480 ppm target) to be 2.85X to 7.4X the size in 2010 instead of 3X to 8X as in the baseline scenarios.



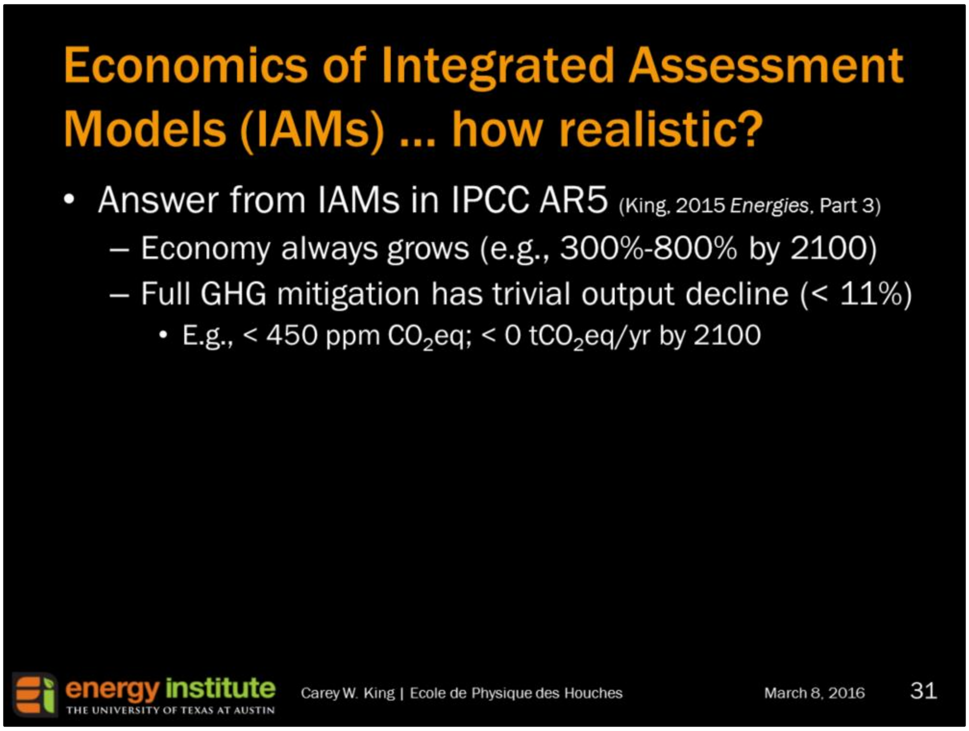
(Also Figure TS.12) Here I switch the chart to "consumption loss [% Baseline Consumption]" from the previous chart that was "GDP loss" because some of the language in Chapter 6 refers more to changes in consumption instead of GDP. GDP is normally composed of a few components (consumption, investment, government spending) and consumption is the largest component.



Here I emphasize what was already stated in the notes for slide 27, and that is to ask (the audience) if they are aware of the growth assumed (not calculated) in the baseline economic scenarios.

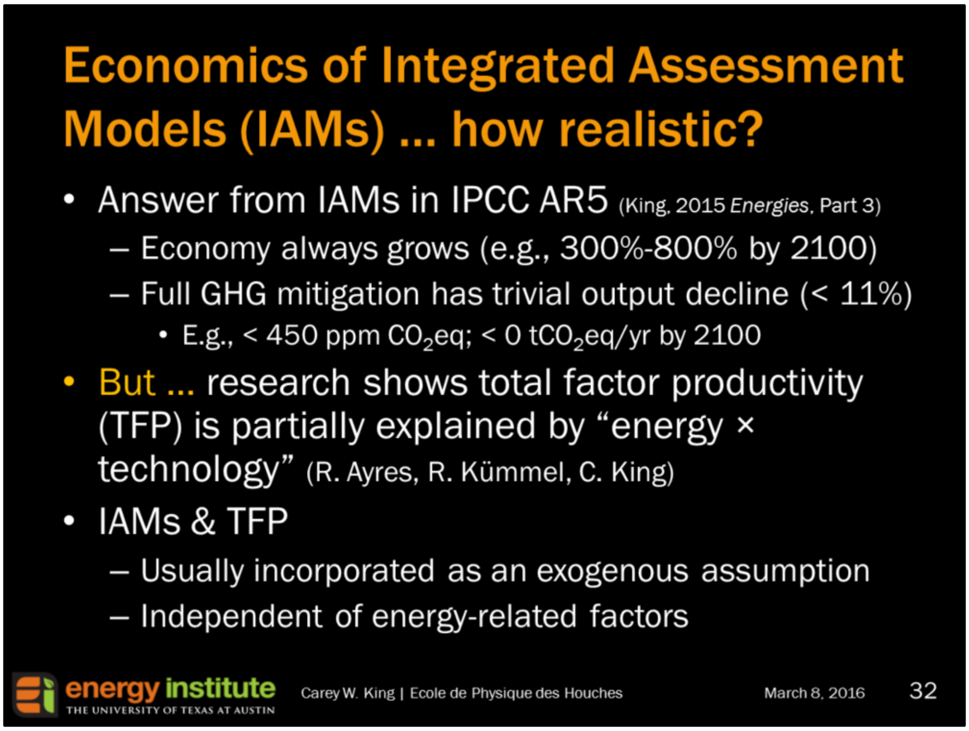


Here I state language from Chapter 6 that states that the baseline economic scenarios (it turns out by exogenous assumption) assume economic growth that reaches 3X to 8X higher income/person by 2100 as compared to 2010.



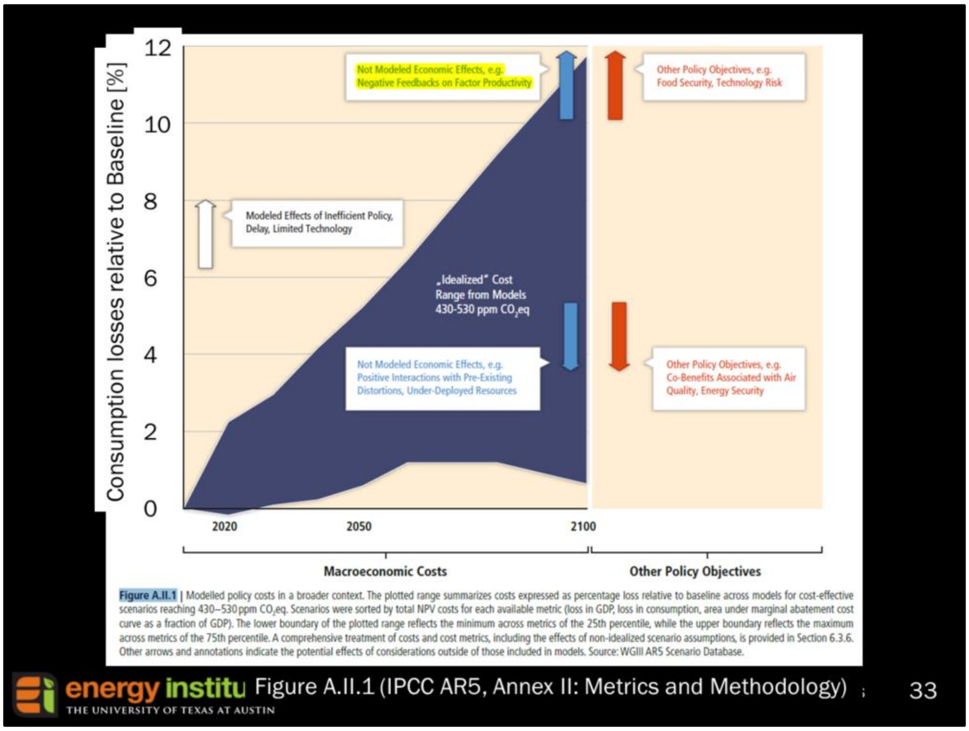
Here I ask how we should think about the assumptions that go into Integrated Assessment Modeling (and specifically the economic assumptions and methods of the IAMs).

The conclusion I draw from the Integrated Assessment Model modeling exercises is that they imply that no matter what level of carbon mitigation you do (higher magnitudes imply also higher rates of change in the economy to meet targets by 2100), the economy still grows tremendously larger by the end of the century. The "results", or rather assumptions, make carbon mitigation costs appear to be trivial. In other words, the economy is assumed to grow no matter what.

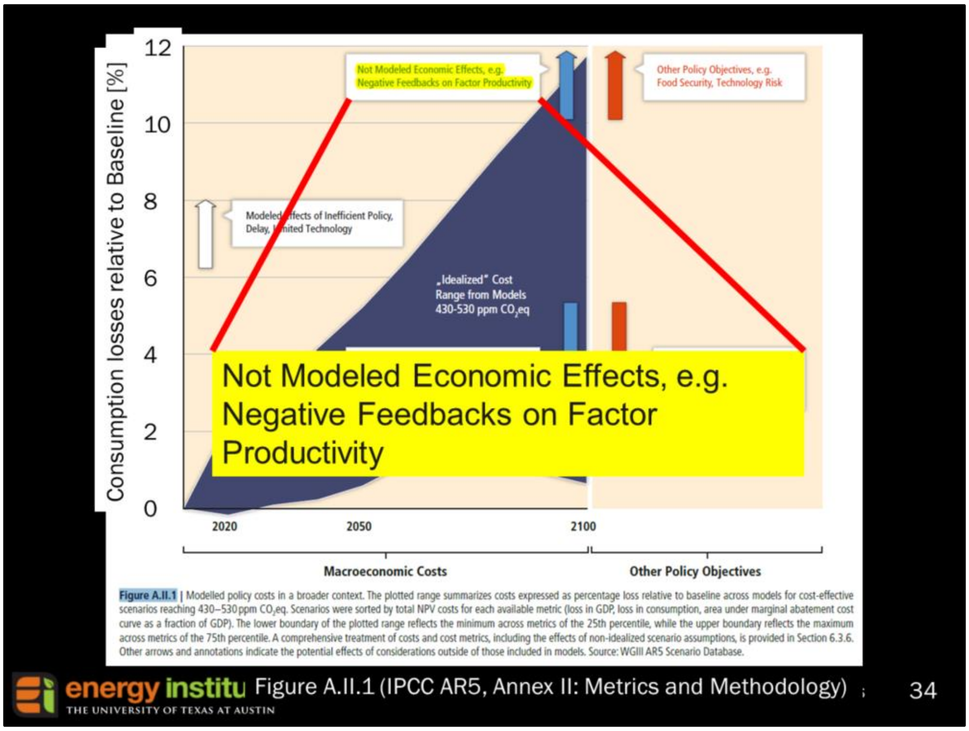


There is a body of literature that is attempting to better explain economic growth more as a function of "energy" (or exergy) and technology (e.g., the efficiency at which machines convert primary energy into energy carriers and then energy carriers into energy services). Reiner Kummel (Germany) and Robert Ayres (formerly of INSEAD, France) are the biggest proponents of these methods. Effectively what is shown by the work of Robert Ayres is that if you include "useful work" = "exergy * efficiency" into your "production function" that is an assumed form of an equation for GDP that is a function of capital, labor, and "useful work", then you can largely explain historical GDP (say for the U.S. and some other major developed economies) without a large "residual".

Usually the GDP "production function" is ~ (total factor productivity)*(labor)*(capital) ~ TFP*L^(a)*K^(1-a), and thus there is no explicit account for energy, yet we know that machines (e.g., capital) require energy carriers (e.g., electricity) in order to operate. The increase in TFP is usually *assumed* as an annual rate of increases in the IAMs (e.g., e.g., 1.4%/yr to 1.6%/yr). However, if we can better describe economic growth not by assuming TFP but by modeling "energy x efficiency of conversion" then we should do so, and particularly because a transition to a low-carbon economy is largely a transformation of the energy sector (e.g., away from fossil fuels or with CO2 capture and storage systems).

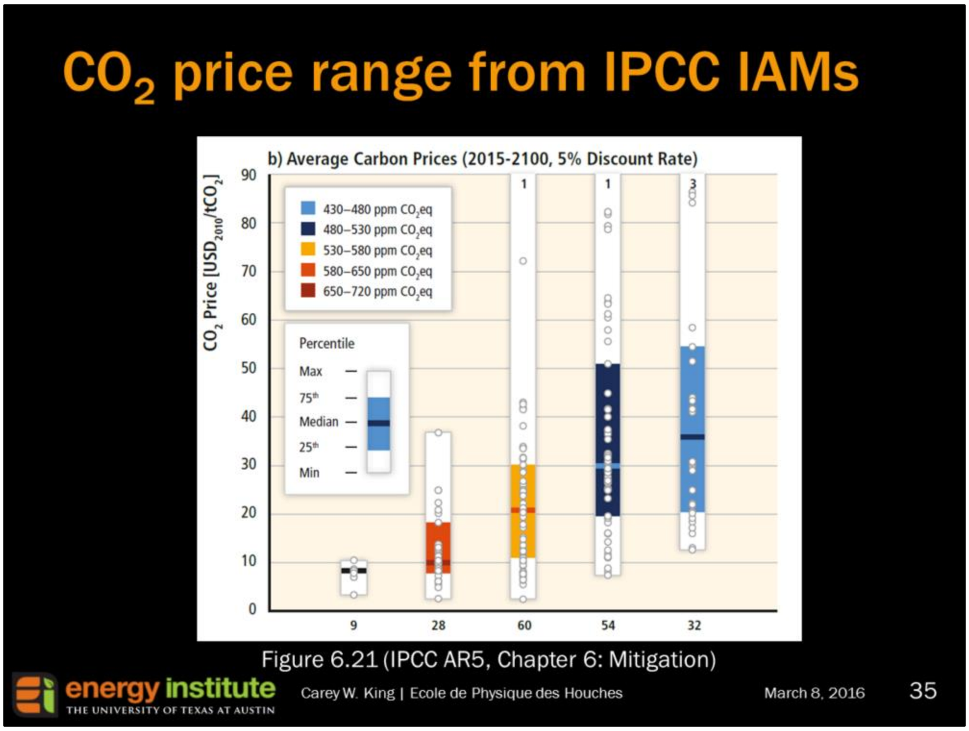


Here I show an Appendix figure from the IPCC AR5, Figure A.II.1 in Annex II, that shows examples of some factors that are and are not considered in the economic modeling of the IAMs.



Here I highlight the most relevant "not modeled economic effects" for my discussion. Here the report is indicating that the economic modeling does not include any "negative feedbacks on factor productivity". This is a major limitation of many current "equilibrium" macroeconomic constructs.

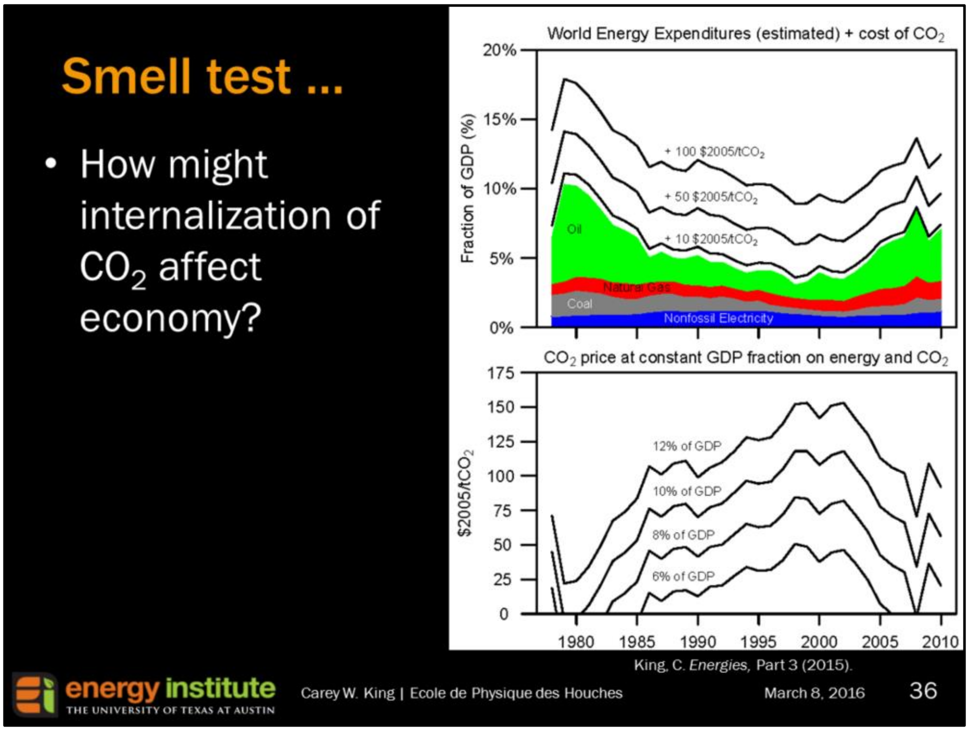
That is to say, if we transform the energy sector to a low-carbon system to mitigate CO2 emissions, the economic models assume that total factor productivity (TFP) is NOT reduced. However, if we believe that GDP growth, and mainly via eliminating much of the assumption of TFP, can largely be described by "exergy x efficiency of conversion to services" (per Robert Ayres discussed on slides 31-32), then we can posit that a reduction in GDP might occur if we were to (i) reduce the amount of available exergy and/or (ii) reduce the efficiency of conversion of exergy to services. One example of reducing the energy conversion efficiency is CO2 capture and storage, CCS (e.g., it is less efficient at turning a unit of fuel into a unit of electricity), however, the purpose of CCS is to provide a new service (e.g., the reduction of CO2 emissions per unit of electricity), so it is reasonable to expect that it takes energy to provide a new service.



This part of Figure 6.21(b) in the IPCC Chapter 6 on Mitigation shows the range of calculated CO2 prices from the modeling. That is to say, these are the prices of CO2 that would need to be charged for CO2 emissions in the future in order to induce a change to a low-carbon economy. The prices are listed here are “average” 2010 USD per metric tonne of CO2 calculated as a single number in 2010 using a net present value calculation (here at a 5% discount rate). This does not mean that the price never gets higher than say 50 USD_2010/tonne for the 430-480 ppm case.

Figure 6.21(a) (not shown) in the IPCC report indicates that CO2 prices in 2011 for the 430-480 ppm scenario would be in the range of 1,000 to 3,000 USD_2010/tonne of CO2 (in an economy assumed to be much larger and of course emitting CO2 at much lower rates). However, at a 5% discount rate a CO2 price of 1000 USD_2010/tCO2 in the year 2100 converted to a value in the year 2010 is = (1000)/(1+ 0.05)^90 = 12.4 USD_2010/tCO2. Similarly, a price of 3000 USD_2010/tCO2 would be 37 $_2010/tCO2.

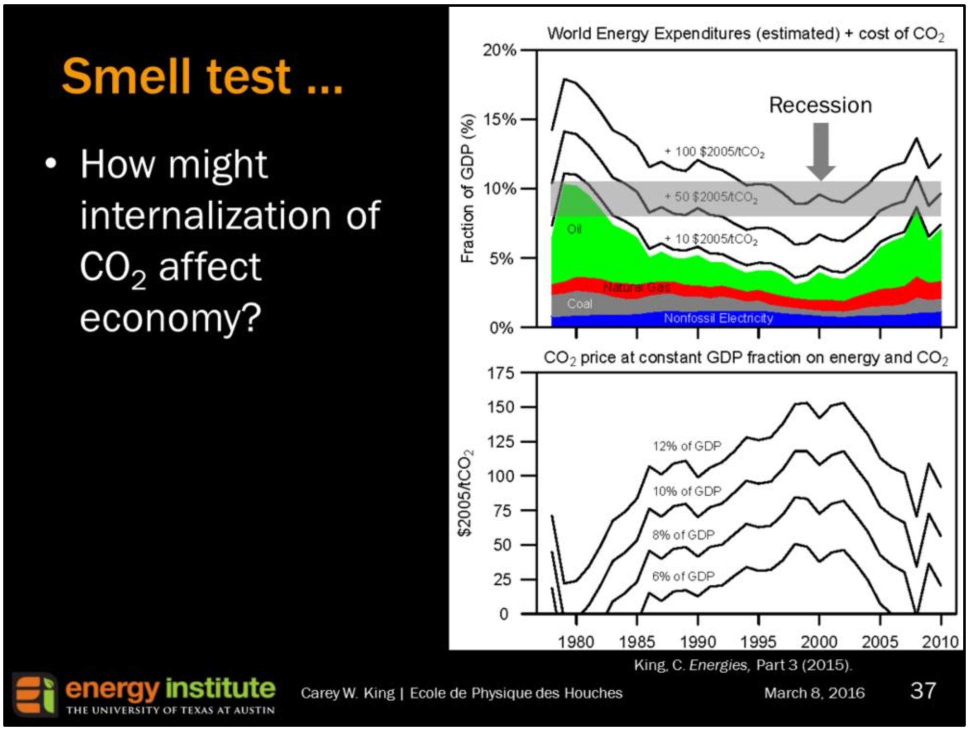
In the next series of slides I use the median average (present value) CO2 price of about 35 $_2010/tCO2 (for the 430-480 ppm scenario) to contemplate internalizing this CO2 price into fossil energy.



Here I use a figure from my Part 3 of my papers (3 parts) in the journal *Energies* published in 2015.

TOP FIGURE:
Shows my estimate of the spending on energy (for 44 countries worldwide that represent > 95% of GDP) divided by GDP of those countries. On top of this expenditures, I show how much it would additionally cost if we were to charge 10, 50, and 100 dollars per tonne of CO2 emissions (in real 2005 dollars, since those were units used in the paper) from coal, natural gas, and oil. As an example, in 2010, each \$10/tCO2 adds expenditures of 0.56% of global GDP.

BOTTOM FIGURE:
The bottom figure will be explained on the next slide.

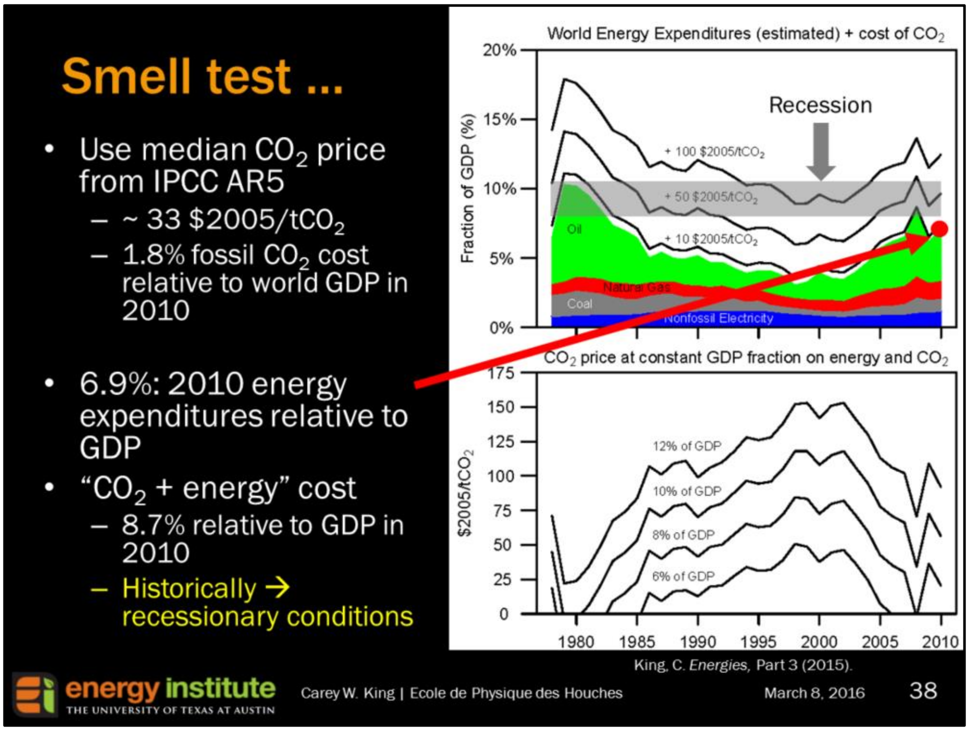


Some economists consider that if energy expenditures increase too quickly and/or reach certain high values, then there is a feedback to the rest of the economy that can cause recession. There are only 2 time periods after World War II in which spending on energy (globally, or for developed countries) exceeded a value equal to 7-8% of GDP. These two times were (i) 1979 and the early 1980s and then 2008 (spending about 8% relative to GDP). Both were times of great change in the economy with questions about how energy relates to economic growth, and questions about the economy more generally.

BOTTOM FIGURE (represents a thought experiment):
Consider that energy prices, and thus expenditures, rise and fall due to various physical, technological, and political factors. Consider that there is a level of spending on energy, represented as a percentage of GDP, above which the economy is in recession and below which the economy is growing. Thus, this level is a 0% growth rate (neither growing nor shrinking, but maintain the same rate of economic output).

The bottom figures shows the CO2 price that corresponds to the situation in which we know the spending on “energy + the cost of CO2” relative to GDP at which the economic growth rate is 0%/yr. Thus, when energy is expensive, then the CO2 price would need to fall to keep “energy + CO2 expenditures” at this growth threshold. When energy is cheaper, the CO2 price could be higher.

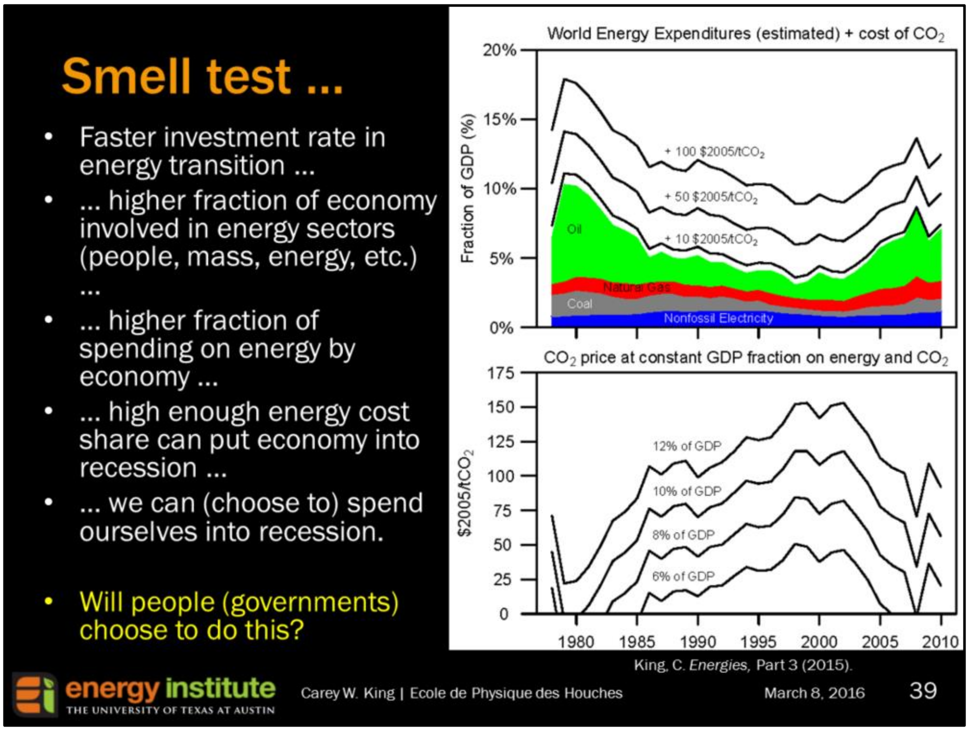
For example, if we assume that the growth threshold is 8% of GDP, in the years 1979-1982, the CO_2 price would have to be zero (or really negative) to maintain growth. In 1998 when energy expenditures were low, the CO_2 price could be high, say near 75 $\$_{2005}/tCO_2$. And then again in 2008 the CO_2 price would need to be approximately 0 $\$/tCO_2$ because energy spending was approximately equal to 8% of GDP.



This slide contemplates internalizing the present value CO2 price from the IPPC reports into the energy spending for the year 2010 (the last year of my calculation in the figure of this slide).

I use approximately 33 $_2005/tCO2 which adds "CO2 spending" equal to approximately 1.8% of world GDP. Spending on energy from my calculations is equal to about 6.9% of GDP. Thus, the "energy + CO2" spending would have been (hypothetically) 8.7% relative to GDP. This is > 8%, and the only two times in modern history at which spending on energy was > 8%, the developed world was in recession.

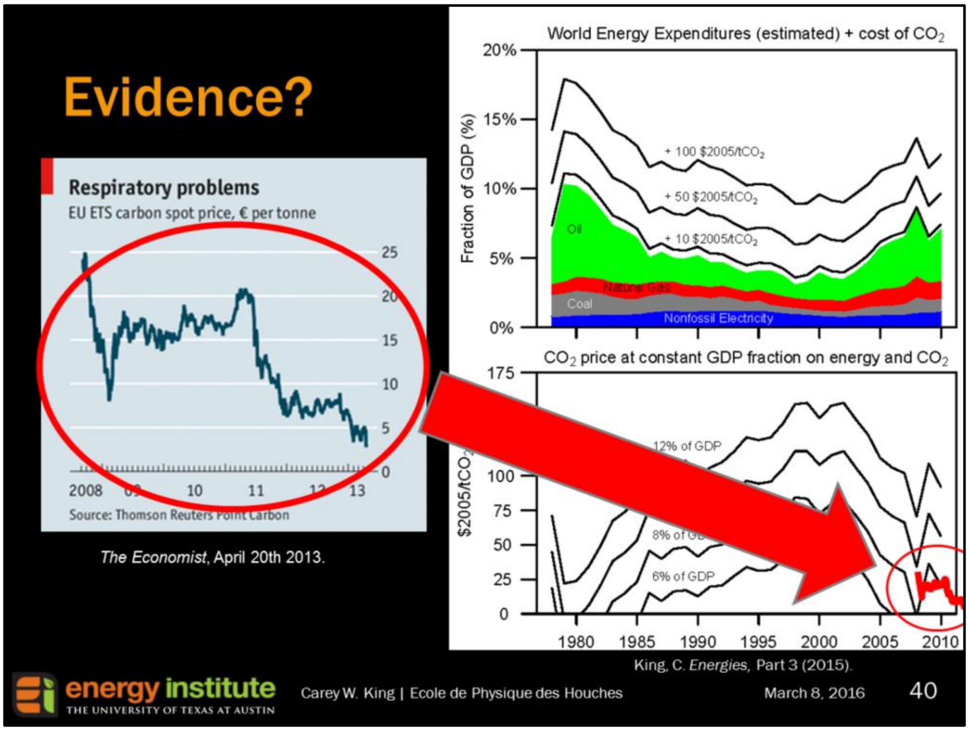
So we could ask ourselves, would we indeed choose to charge ourselves 33 $_2005/tCO2 in conditions such as 2010?



This slide posits the reasoning that needs to be included in macroeconomic modeling of a transition to a low carbon economy (really, macroeconomic modeling in general).

The faster a transition to a low-carbon economy (or the more mitigation is performed in a given amount of time, say by 2100), then more inputs (labor, materials, energy, services, etc.) are allocated to that transition. Thus, more people become part of the "energy and CO2 mitigation sector" and less people become the pure consumers of the outputs from that sector. We should thus expect prices, and thus expenditures, to increase more the faster is the transition. Thus, we could choose to transition so quickly as to increase prices, and expenditures, faster than we can adjust our consumption efficiency, such that the economy goes into recession. It is this dynamic feedback that is NOT incorporated into most macroeconomic modeling, but this feedback needs to be included.

This shift in resources for a low-carbon transition is in some sense the opposite of the Industrial Revolution in which the size of the "energy sector" (which included food and agriculture) became smaller relative to the "other" sectors by substituting machines and fuels for animal and human labor in agriculture. The agriculture sector became absolutely larger, but the rest of the economy became even larger still with a higher proportion of people working in "non-energy and non-food" sectors over time.



Is there any evidence that CO2 prices (if and where they exist) would respond to macroeconomic conditions in such a way as to avoid inducing recession (e.g., if economic growth is slow and/or if energy is expensive, the CO2 price responds by getting smaller)?

There is not much evidence due to a lack of CO2 prices in the markets, but the European Trading System (ETS) provides some evidence of this CO2 price response to economic conditions. The ETS spot price (converted to $_2005tCO2) is imposed upon my figure indicating how CO2 prices might theoretically respond to total energy expenditures. The ETS CO2 price for 2008-2010 was around 15 to 25 $_2005/tCO2, and this price is quite close to an 8% threshold (e.g., if "energy + CO2" spending is equal to 8% of GDP, then growth is near 0%/yr). Of course my figure here is for the world but the ETS only affects certain industries in Western Europe. However, this simple thought experiment is consistent enough to warrant further investigation.

In essence, before the Great Recession, European (and other) countries thought (i) the economy always grows, (ii) the economy is becoming less dependent on energy (e.g., decreasing values of "energy/GDP"), (iii) new low-carbon technologies are coming to fruition, and thus (A) we can reduce CO2 emissions without impacting the economy and (B) we can induce CO2 emissions reductions by having a cap-and-trade system where the CO2 price will increase to induce the needed technological and behavioral change.

But what happened was the opposite. The economy didn't keep growing per pre-2008 history (of 20-30 years), and thus the CO_2 price didn't keep increasing. The Europeans are 9so far) meeting their CO_2 emissions reductions but not because the economy is growing with high technology change, full employment, and high CO_2 prices, but rather because the economy did not grow as "expected". Thus we know we can reduce CO_2 emissions if we reduce the size of the economy (e.g., slow GDP), and that is what countries want to avoid. We have yet to prove we can grow the economy and reduce GHG emissions, globally, over an extended period of time and on a trajectory consistent with political pledges (e.g., stabilizing GHG emissions < 480 ppm $CO_{2,eq}$).

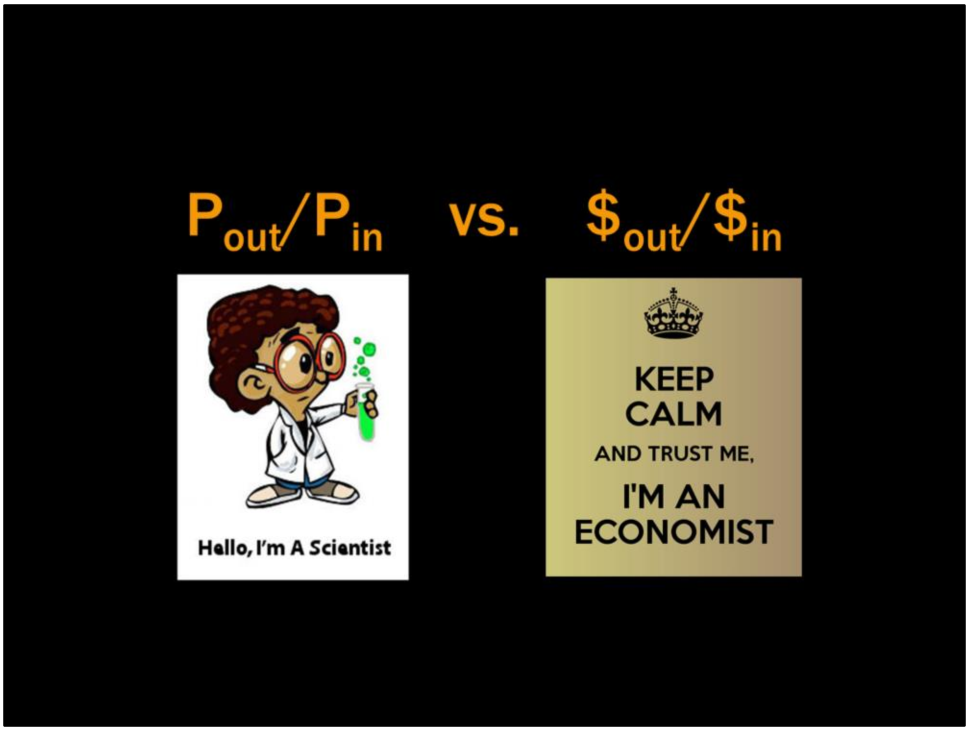
Thus, we need energy-economic modeling that allows us to better understand this feedback and dynamics.

Macro-scale power flows for macroeconomic modeling

(e.g., of low-carbon energy transition)

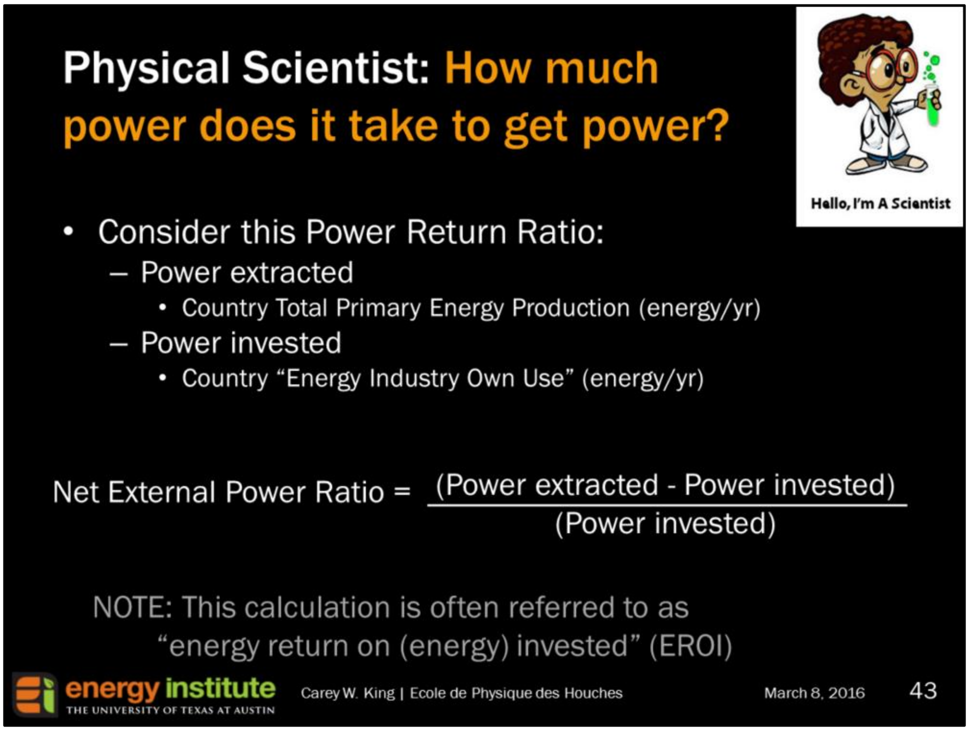
energy institute

THE UNIVERSITY OF TEXAS AT AUSTIN



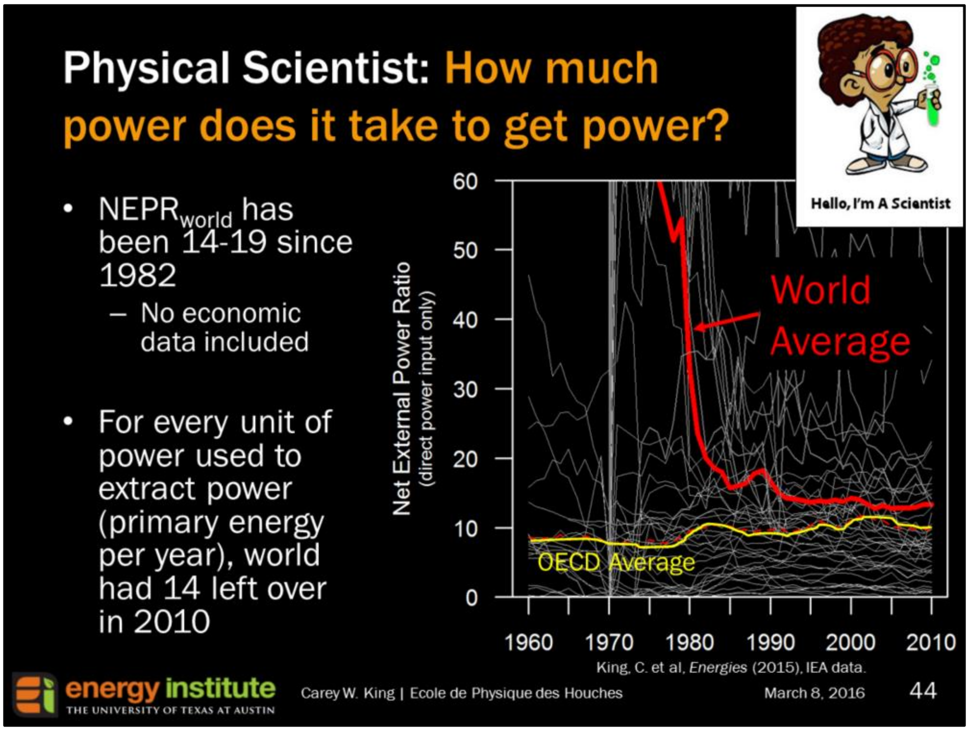
In this next section the goal is to discuss (mostly hypothesize) what should be the relationship between a "return on investment" from power versus money. That is to say should there be a relationship between

(1) annual power production of the economy (which is by definition from the energy sector) divided by annual power inputs of the energy sector and
(2) annual monetary output (e.g., GDP) of the economy and the monetary inputs of the energy sector.



In my 2015 paper (noted below) I calculated the "power return ratio" as defined in this slide. The data input into the calculation are only in units of power (energy/yr) and come from the International Energy Agency data. This number is calculated for the 44 countries in my study (for which IEA has sufficient data). This calculation is described in Section 2.3 of the reference below.
Many people call this calculation "energy return on energy invested" (EROI), but as I discuss in Part 1 of my 2015 3-part series in *Energies,* if you are using annual energy flows as the core data, you are really discussing power (e.g., energy/yr), so I explicitly call the calculation a power ratio rather than an energy ratio.

Reference:
King, Carey W., Maxwell, John P., and Donovan, Alyssa. **Comparing world economic and net energy metrics, Part 2: Total Economy Expenditure Perspective**, *Energies,* **2015**, *8*, 12975-12996.



This figure (from my paper, but showing slightly more data here) shows the calculation of Net External Power Ratio (NEPR). The world average is based upon weighting each country by its fraction of world primary energy production. Each thin line represents the time series for a given country.

Most of the countries with low NEPR < 20) are net energy importers. The number of countries with data before 1980 are significantly fewer than for after 1980, so the calculations here are most accurate for after 1980. Sometimes countries go in and out of the data set such that the fluctuations in the world average can be caused by averaging fewer countries in some years.

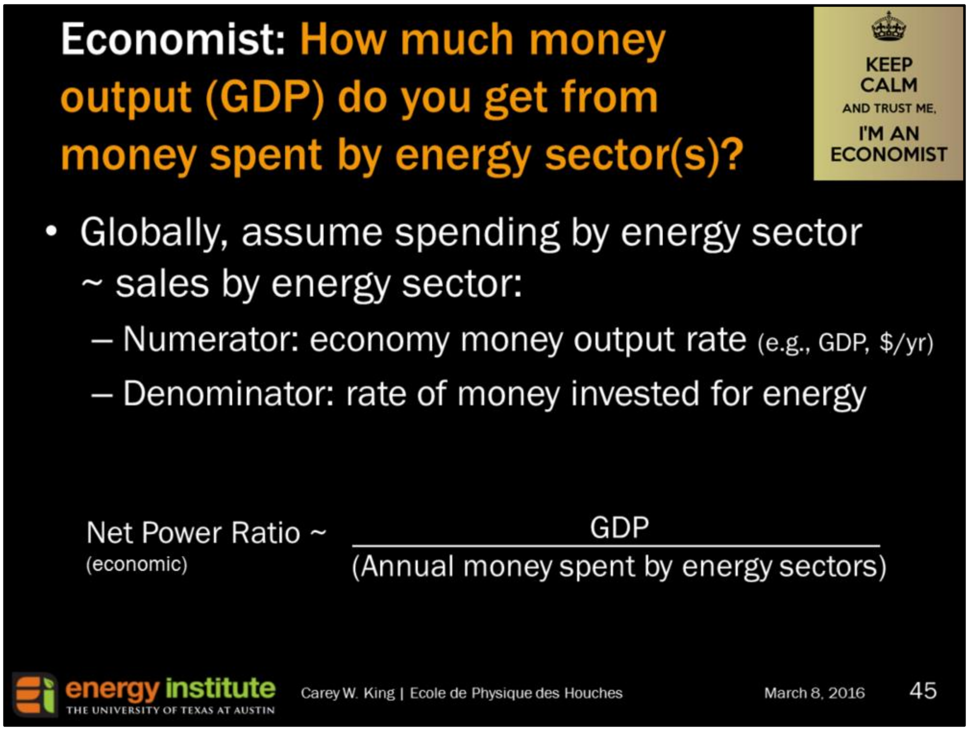
In theory the minimum value mathematically possible for NEPR is zero, and that would occur if the energy industry left no extra energy available for any other industry (per conservation of energy). However, in the data, a few countries have a negative value (Denmark 1975, 1976, 1980; Portugal 1970-1973, a few years in the 1990s and 2000s) which I hypothesize are due to energy imports (e.g., they did not produce energy but still consumed energy by the energy industries that refined oil products and operated power plants).

Important takeaways are that NEPR > 20 before 1982 and < 20 after 1982. This "simple" assessment is probably the one we can make with most confidence. Further research would be needed to understand the global trend before 1980, but this might not be possible (perhaps fundamental data are lacking). There are several hypothesis that could explain the trend of NEPR_world declining to around 14-16 after 2000 and then staying around that number:

1. It could indeed be the case that the "easy" energy in terms of the quantity of direct energy input requirements being low for "easy" energy, is over, and now we've reached some sort of asymptote. This is an expectation (e.g., Spindletop in East Texas would have used a small amount of power input, mostly from human labor, relative to power output).
2. Of course the implications are that there are still other non-energy inputs required, and these might not be consuming energy directly, but taking up a larger share of inputs (e.g., services, automated machinery, etc.). Thus, capital is substituting for direct energy inputs.

3. The data are no good (further discussions with IEA could clarify how the underlying data are obtained).
4. Other ?

Reference:
King, Carey W., Maxwell, John P., and Donovan, Alyssa. **Comparing world economic and net energy metrics, Part 2: Total Economy Expenditure Perspective**, *Energies,* **2015**, *8*, 12975-12996.
Data are available by download from my website: http://careyking.com/wp-content/uploads/2015/11/Kingetal_Energies_Supplemental_WorldEconomicAndNetEnergyMetrics.xlsx

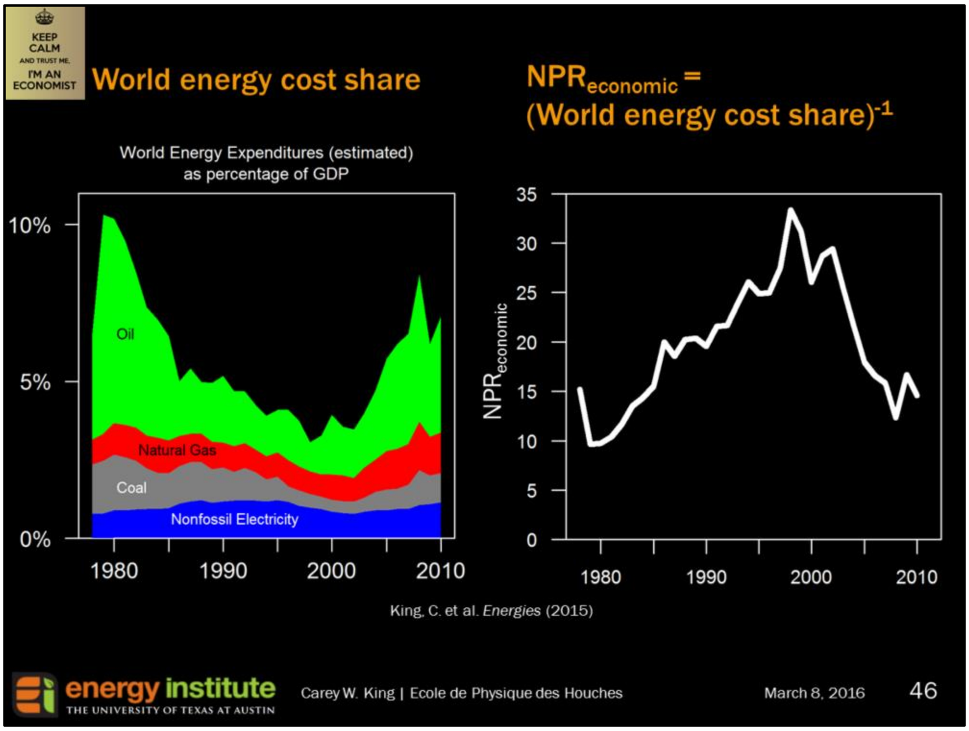


From King et al. (2015) *Energies* Part 2 (see http://careyking.com/publications/) I use the estimated annual energy expenditures of the world as an ASSUMED value (not completely true) of the annual sales by the energy sector of the world. I calculate here the "net power ratio", and I call it "economic" because it is based purely on economic information. This NPR is by definition just the inverse of the quantity "energy spending / GDP", as shown on next slide.

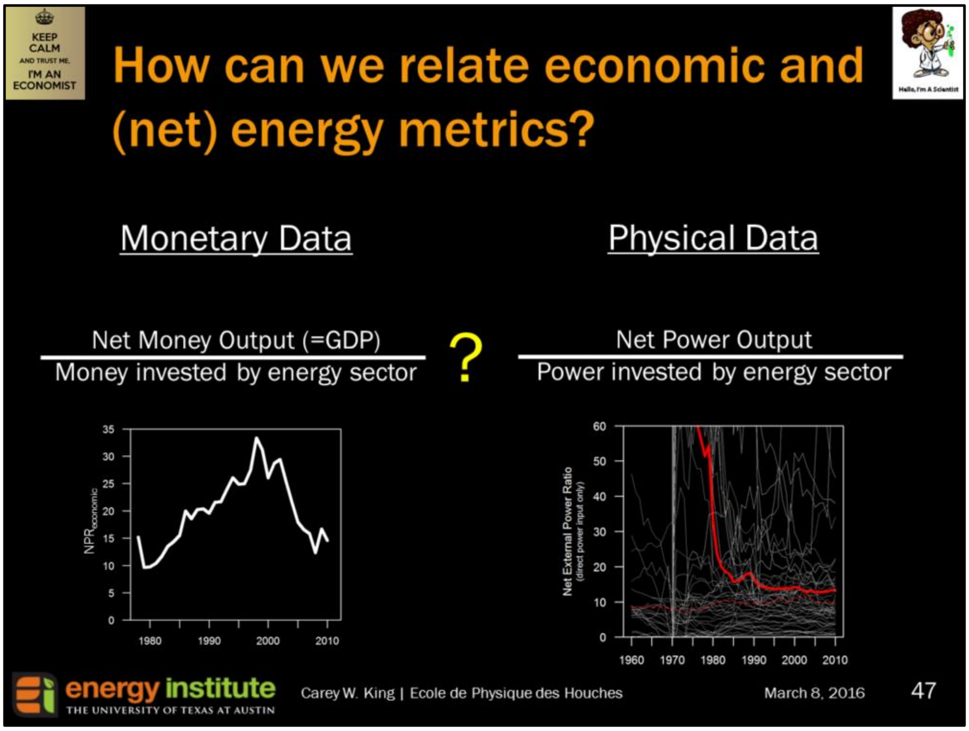
The goal with this calculation is to come up with the "most equivalent" metric of NEPR (previous slides) except use units of money flows instead of power. So I'm specifically phrasing energy spending to think about how much "net output" (in money) from the entire economy comes from all "monetary spending" (in money) to produce energy within the entire economy. This is similar (but a little different) to NEPR which is how much "net power output" comes from the energy sectors of the economy relative to the "total power input" needed to produce the energy.

A more accurate analog to NEPR_direct is possible from monetary data if you have data from input-output tables of each world economy, but these largely only exist for developed countries. The more accurate representation for NPR_economic is that expressed in [[**King, Carey W. Information Theory to Assess Relations Between Energy and Structure of the U.S. Economy Over Time**. B*iophysical Economics and Resource Quality*, **2016**, 1 (2), 10. doi: 10.1007/s41247-016-0011-y.]]

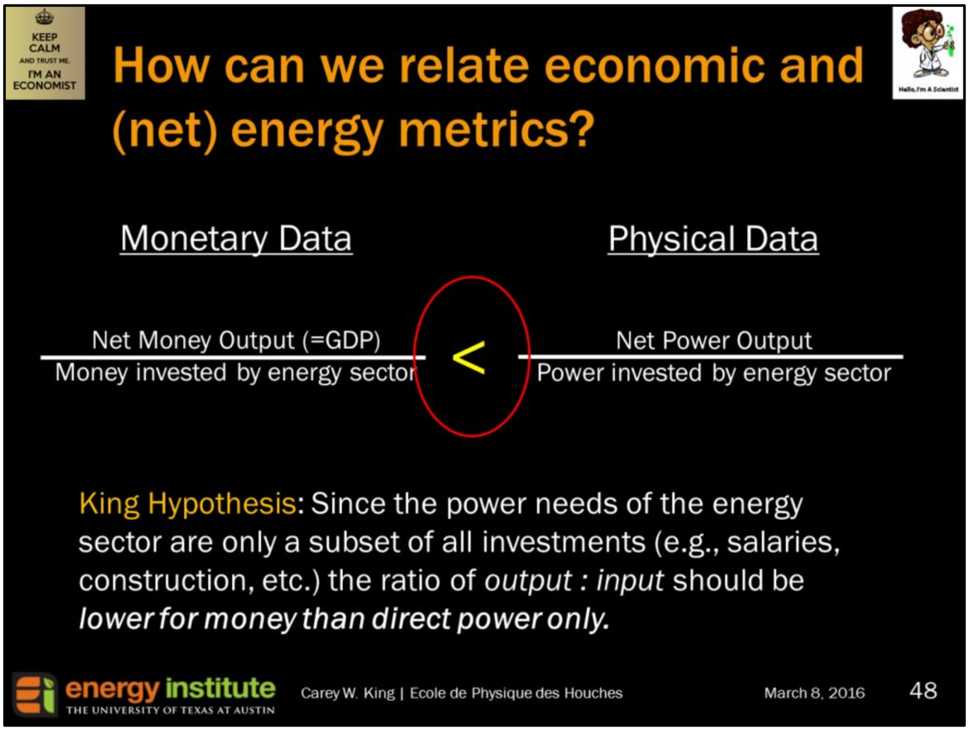
It is important to be able to take the global perspective on these types of calculations so we are not “caught” thinking that the entire world operates as only a small number of countries (e.g., U.S., European countries, Japan).



Nothing new to show here except that NPR_economic (right) is the inverse of the value of the calculation shown in the figure on the left.



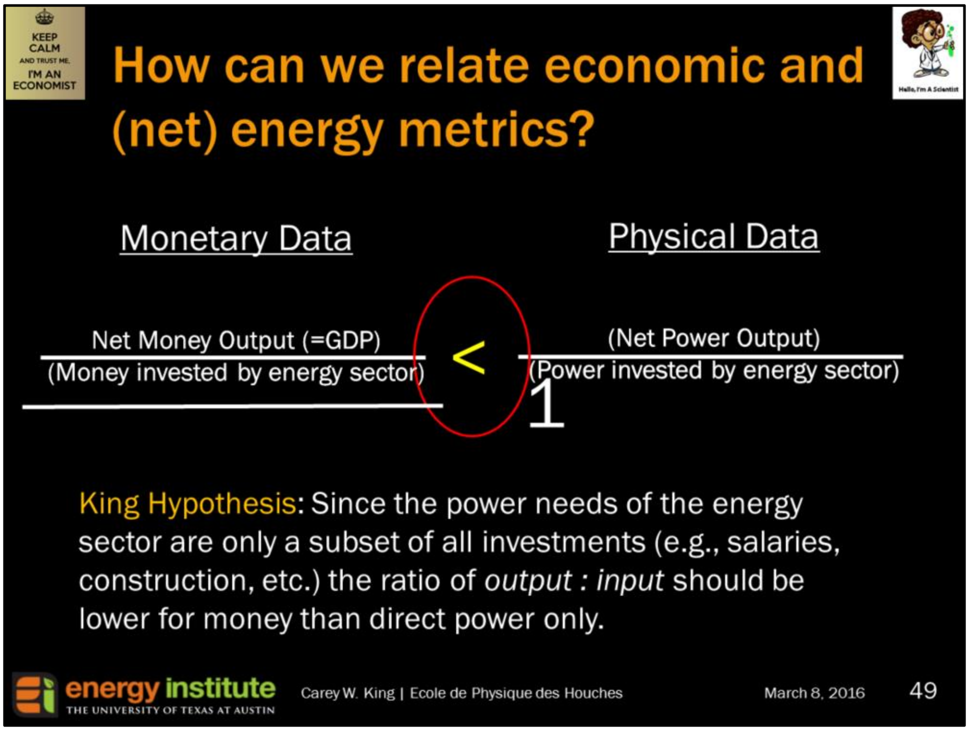
This slide is meant provoke the question of if there is, or should be (theoretically) a fundamental relation between an output:input ratio of the energy system (based upon units of money, left) and an ouput:input ratio of the energy system (based upon units of power, right).



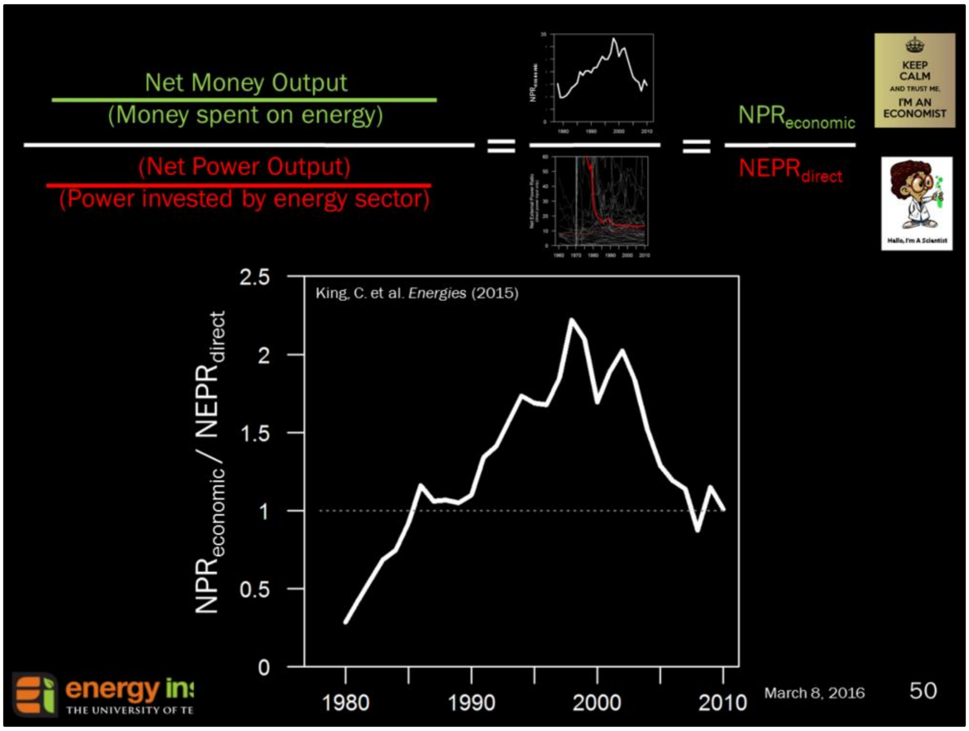
My hypothesis is that the monetary-based output:input ratio should be LOWER than the one based upon power. There are a few reasons for this, and some have to do with what is inherently assumed in the calculation of two metrics. Recall, both metrics (money based and power based) are trying to describe only the energy sectors, broadly.

Reasons:

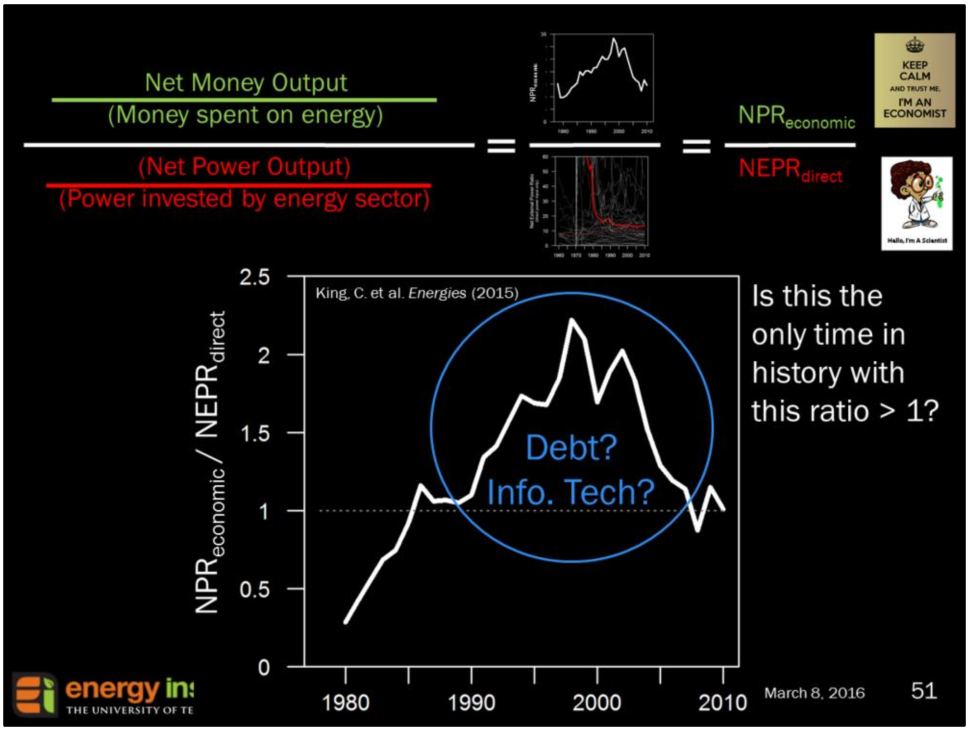
1. The power-based metric (NEPR_direct) ONLY includes power inputs and power outputs. There is no inclusion of “indirect energy” inputs (e.g., the energy it takes to make concrete, steel, etc. that are used in energy infrastructure and activities). Obviously there are many other inputs and costs to energy life cycles (that might be measured in various units of kg, money, etc.): materials, labor, services (engineering, geology, regulatory, contracts), etc. Thus, by including more inputs via translating them to units of energy, the value for NEPR_direct can only get SMALLER.
2. The money-based metric (NPR_economic) by definition is based upon prices of energy commodities (e.g., oil, NG, coal, electricity). Thus, included in these prices is theoretically all of the costs of production (plus rents and profits) if we assume the prices generally represent the marginal cost of production. This “marginal cost of production” argument is likely more the case for oil than the others. Electricity likely more includes the cost (+ markup) rather than marginal price.



This chart is setting up the plot that I will show in the next slide. It uses an animation to move the metric on the right (physical data) underneath the metric on the left (monetary data) so that my hypothesis is that this “ratio of ratios” should be less than one on the next slide.



The top of the slide shows the calculation that is plotted in the figure. The hypothesis is that this plot should show values less than 1 (one). Clearly the numbers are greater than one from 1985 through 2007. Then the numbers are approximately one for 2008, 2009, and 2010.

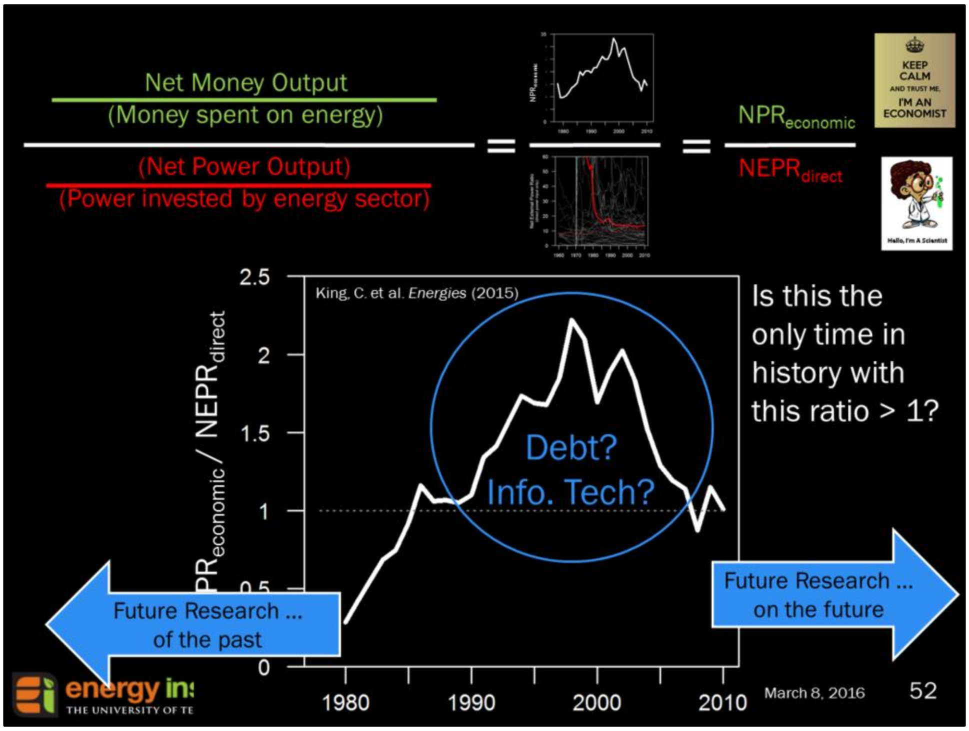


There are interesting questions as to why my hypothesis does not seem to hold here (hypothesis is that NPR_economic / NEPR_direct < 1), and here are my ideas:

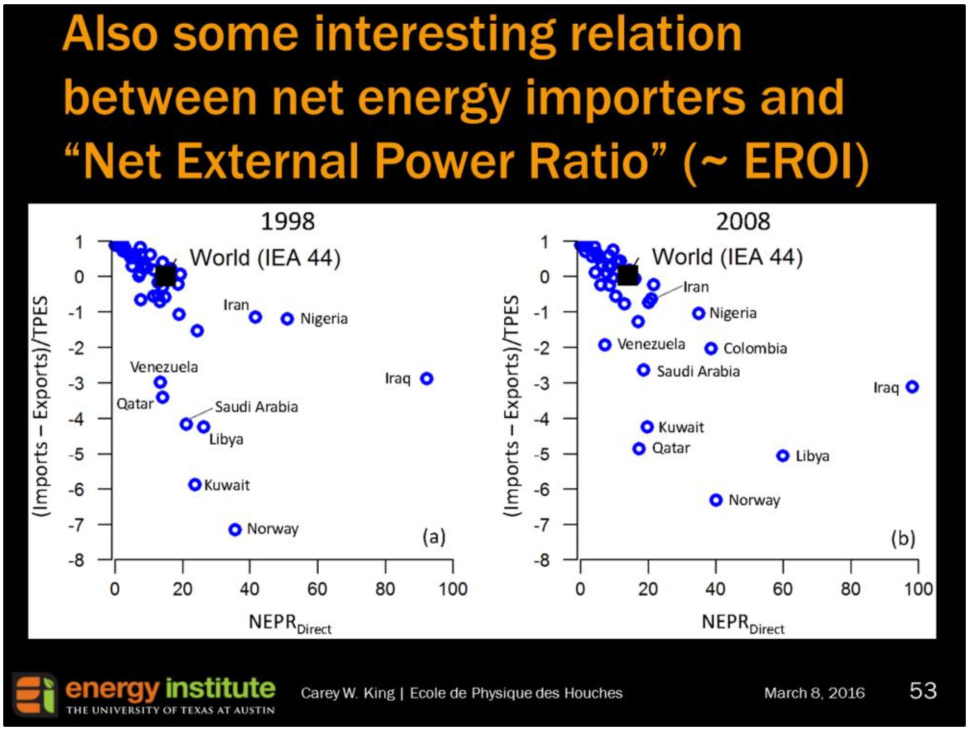
1. My hypothesis is for an "equilibrium condition". That is to say that it assumes there can be no dynamic effects such as overshoot (e.g., going past a set point, temporarily, before oscillating around a set point). We should expect there to be dynamics, but the question is even with these dynamics, why would this plotted ratio ever be above 1?
2. The dynamic effects might not be from overshoot, but they might be simply delays from past investments. That is to say, I invest in an oil production and energy efficiency in the early 1980s, and it produces the ability to have relatively cheap energy (in units of money) for 1 or 2 decades.
3. The hypothesis perhaps does not account for the concept of debt. Debt can be seen as a promise today for returns in the future. By taking on public debt (e.g., by governments), then GDP increases. The U.S. during the span of the 1980s did quite a bit of "deficit spending" perhaps helping to inflate GDP from what otherwise would have been.=
4. Related to debt is that central bank interest rates were essentially at their highest levels is history in 1980 in an attempt to solve "stagflation" (low economic growth combined with inflation). Then from the early 1980s until the 2008 Great Recession, interest rates were "somewhat steadily" reduced (say during the term of Alan Greenspan as the U.S. Federal Reserve Chairman). In essence, companies

could take out loans, possibly not even be able to repay 100% of the loan, and then refinance the loan at a lower interest rate than they received several years earlier. In essence, economic "growth" could occur simply by what Hyman Minsky would call "speculative investment" which means that a business could stay viable not by repaying its loans, but just from refinancing.

5. Possibly the economy changed structure significantly due to increased use of computers and information technology that produced high economic returns relative to returns on energy.



Increased research is needed to effectively simulate the economy's transition from preindustrial to industrial society, and see if we can ALSO replicate the phenomenon of reaching the lowest "food and energy" cost, relative to GDP, that occurred around the year 2000. Future research of the past should be able to clearly show that this ratio plotted in the figure was DEFINITELY always < 1 for all of human history. This would then support that this short modern time period where the ratio is > 1 was an anomaly.



This slide is showing what seems to be an interesting relationship between the net external power ratio (NEPR_direct) of a country and its tendency to be a net energy importer or exporter. Here, the y-axis represents the fraction of net imports relative to the total primary energy supply (TPES), or consumption, or a country. If a country imports more energy than it exports, then that country has a value > 1 on the y-axis. If the country is a net exporter of energy, then it has a negative value on the y-axis.

The calculation for the world average NEPR (say from slide 44, and representing data from 44 countries at > 95% of world GDP) is approximately 15 for 1998 and 2008, and the world net imports is near zero (by definition has to be zero, but there are some statistical differences and missing countries). The years 1998 and 2008 are shown as they are they represent a years of cheap and expensive energy, respectively, for which I have consistent data for NEPR_direct.

Interestingly, there are no countries that are net energy importers that have NEPR_direct > 20. This seems to imply that if it takes to much energy to produce energy in your own country, you tend not to export it (e.g., perhaps because it is not cost competitive on world markets …). Countries that are known major exporters of oil and/or natural gas seem to have NEPR_direct > 20, or greater than the world average.

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