2026 International Summer Course on Environmental and Ecological System Engineering

Part A: Environmental Accounting and Systems Thinking (EAST)

Lecture 5:

Emergy & Economy

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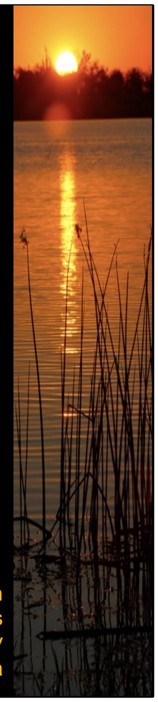
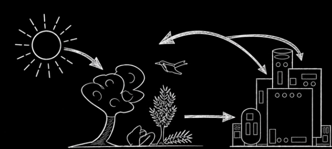


So far we have developed the basic *physical principles of emergy*. Now we move from those physical foundations to *its application in understanding the economy.*

Organization…

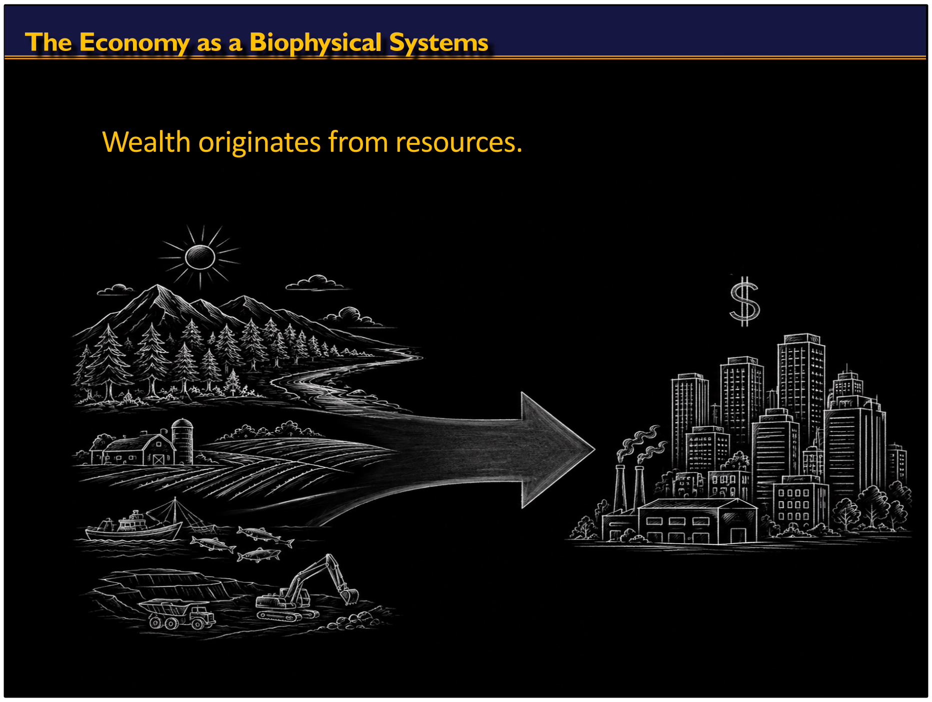
1. Economies are biophysical systems.
2. Money is a claim on emergy.
3. Price and emprice describe transactions from different perspectives.
4. Emprice reveals patterns of economic organization.
5. National emprice links emergy and the economy.



This small graphic was drawn by H.T. Odum in the 1990s as the logo for the University of Florida Center for Environmental Policy.

Although simple, it captures the central theme of today's lecture: the economy is not separate from nature. Environmental resources and energy flows support economic activity.

And of course, the economy feedback to the environment for better or for worse



Most people think of money when they think of wealth.

A wealthy person is someone who has a lot of money.

But what makes a community wealthy? Is it simply a community with a lot of money?

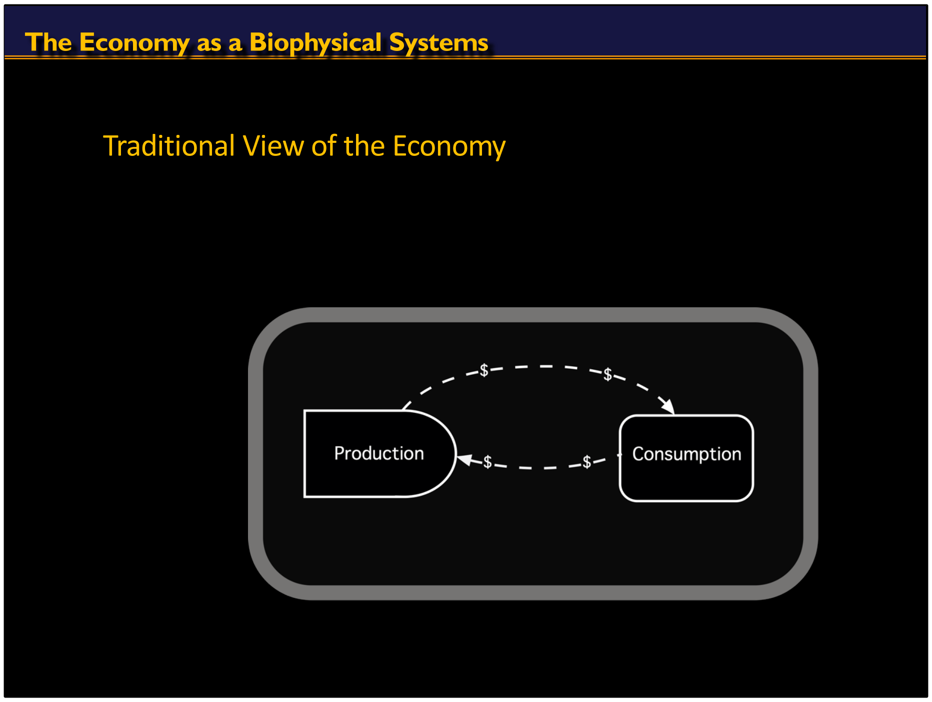
What about a country? Is a wealthy nation one with a large money supply?

I would suggest that money is only part of the story. More important is the availability of resources.

Finally, consider the global economy. Is the Earth wealthy because there is a lot of money circulating?

Again, I would argue that the answer is no.

A wealthy global economy is not one with a great deal of money. It is one that is supported by abundant natural resources.

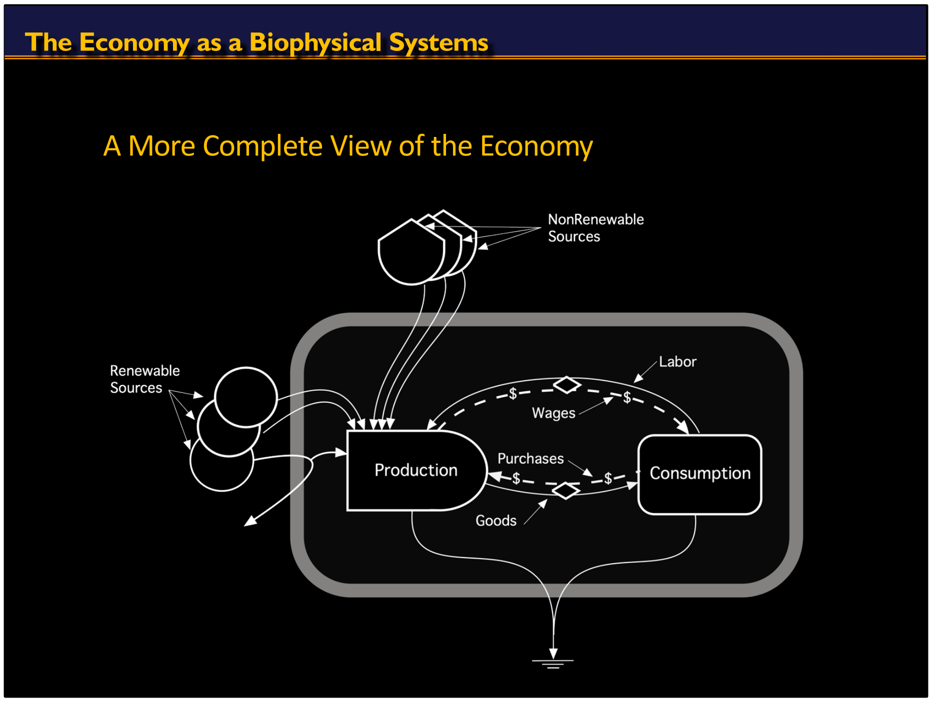


Economists traditionally describe the economy as the production, exchange, and consumption of goods and services.

In its simplest form, the economy is represented as a circulation of money between producers and consumers.

Producers pay wages to households, and households purchase goods and services from producers.

The economy appears to be a self-contained circular flow.



From a systems perspective, something important is missing from the traditional picture.

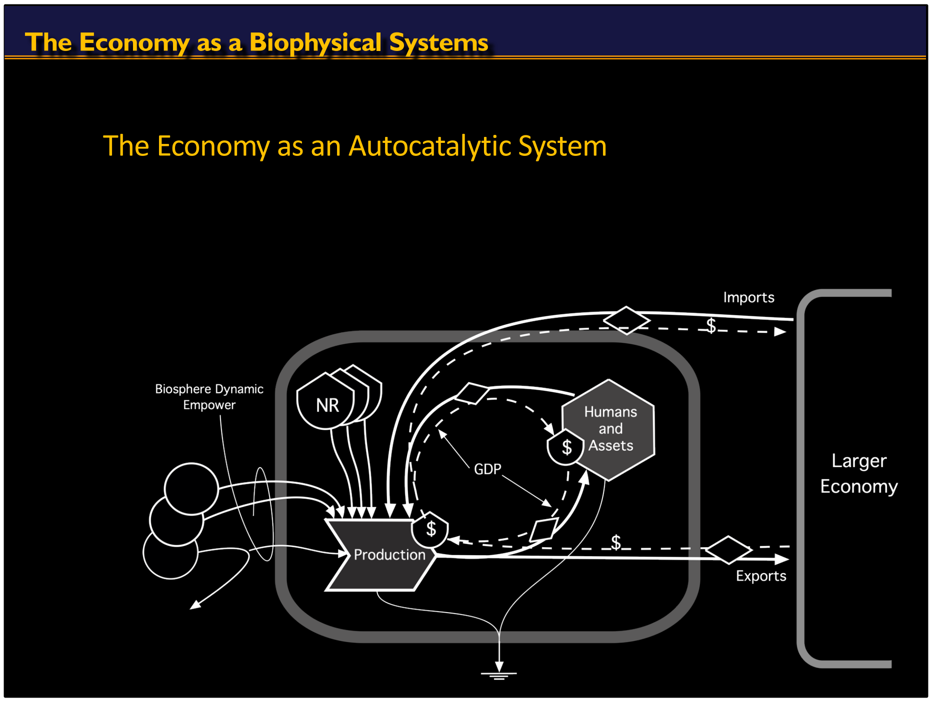
Producers cannot manufacture goods from money alone.

They require energy and materials from the environment, together with labor, information, and services.

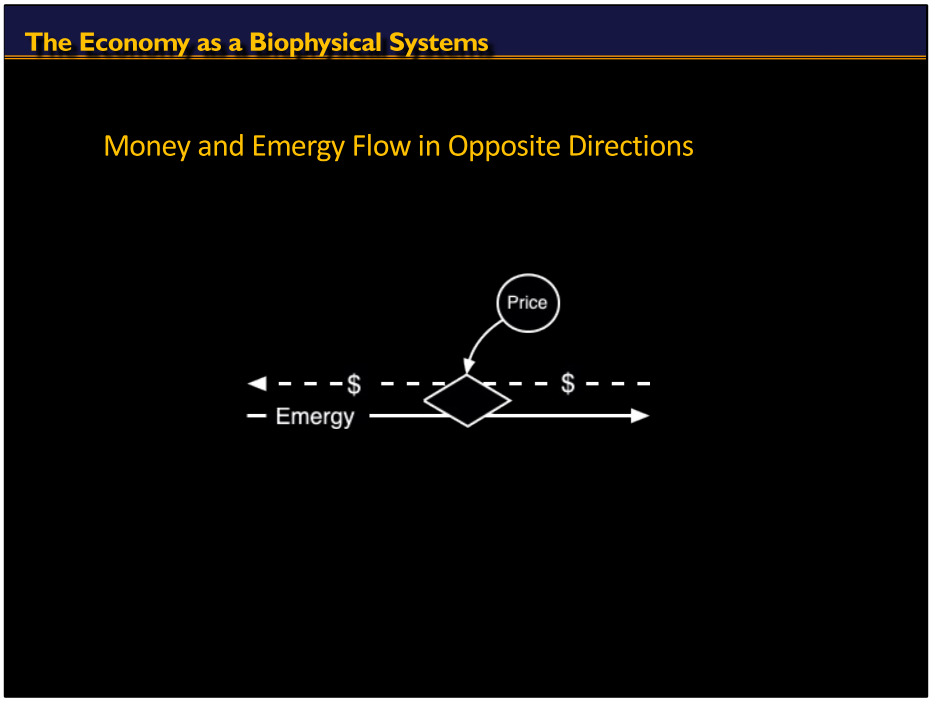
When these resource flows are included, the economy is no longer a closed monetary circle.

It becomes an open system supported by renewable and nonrenewable resources.

Money circulates within the economy, but the economy itself is sustained by continuous flows of emergy from the larger geobiosphere.



In the previous lecture we examined autocatalytic systems in nature.
The economy operates in a similar manner.
Renewable resources, nonrenewable resources, and imports support production.
Production generates goods, services, and infrastructure that support people and economic assets. In turn, labor and services feed back to support additional production.
This reinforcing feedback allows the economy to grow and organize itself.
Like all autocatalytic systems, however, growth depends on continued resource inputs.
Without flows of energy and materials, economic activity declines.
The economy shown here is not an isolated system.
Renewable resources, nonrenewable resources, and labor support production internally, but most economies also exchange resources with larger economic systems.
The box labeled "Larger Economy" represents these external economic connections.
Through imports and exports, local economies become embedded within larger economic systems.
Only the global economy lacks a larger economy with which to exchange resources.



When I first encountered this idea as a graduate student, it completely changed how I thought about economics.

Every economic transaction involves two flows moving in opposite directions.

In one direction move resources, goods, energy, and information.

In the other direction moves money.

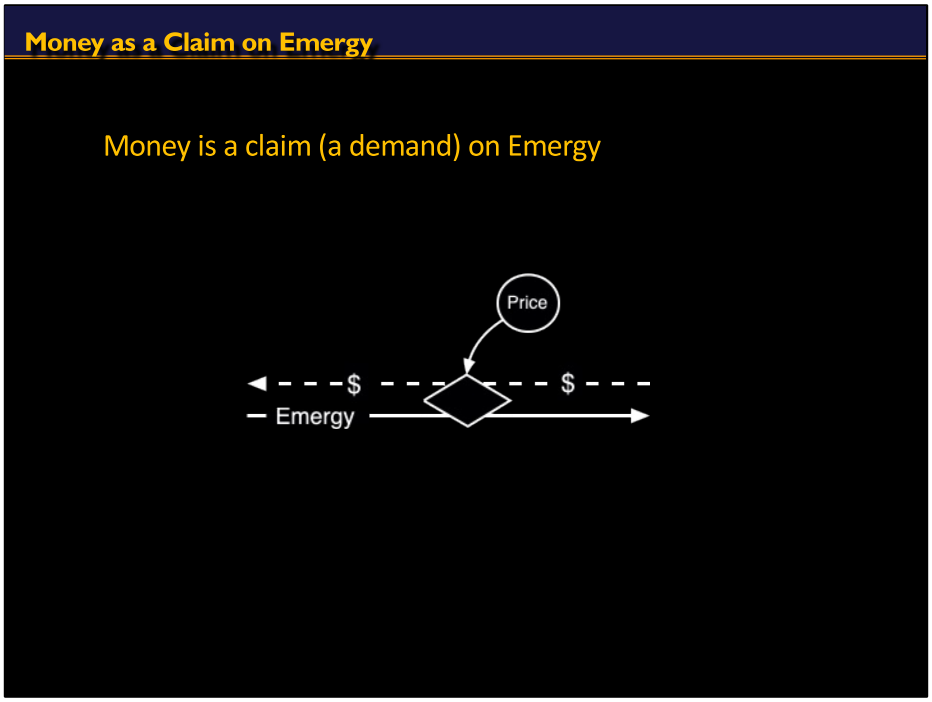
A farmer sells grain and receives money.

A utility sells electricity and receives money.

A mine sells ore and receives money.

Money and emergy flow in opposite directions.

Once you see this, it becomes difficult to think about the economy in the same way again.



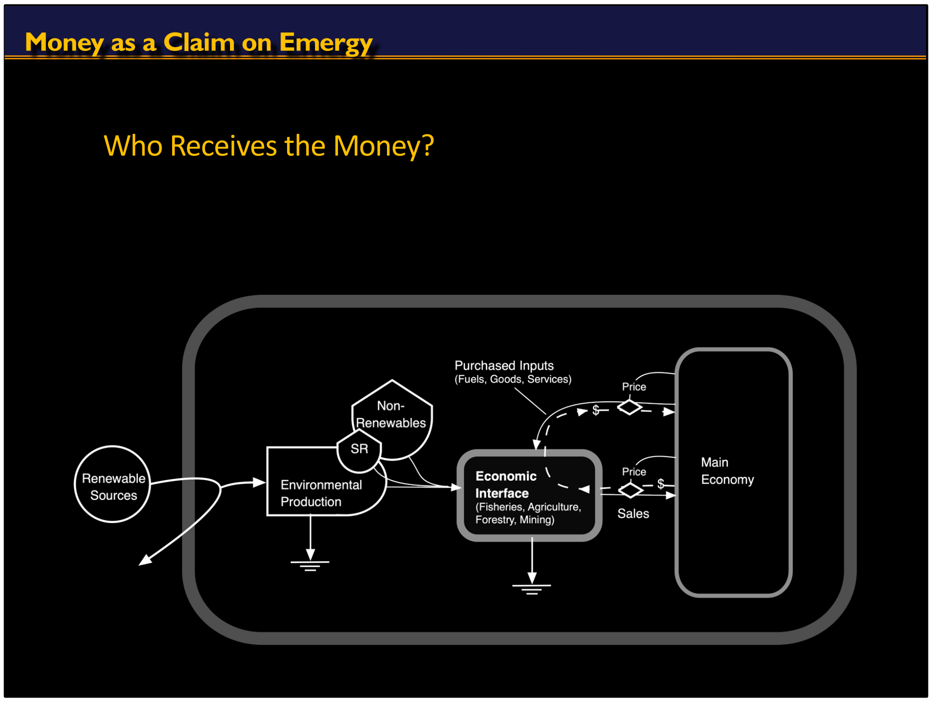
If money flows opposite to emergy, what exactly is money?

It is commonly described as a medium of exchange, a store of value.

From a biophysical perspective, however, money is a claim (A Demand) on emergy

It is a a claim on the energy and material flows required to support economic activity.

Every monetary transaction therefore mobilizes real resources, linking the circulation of money directly to emergy flows.



When we purchase emergy, who receives the money?

Consider a barrel of oil. When we purchase gasoline, are we paying the oil reservoir?

Do we deposit money into the oil field?

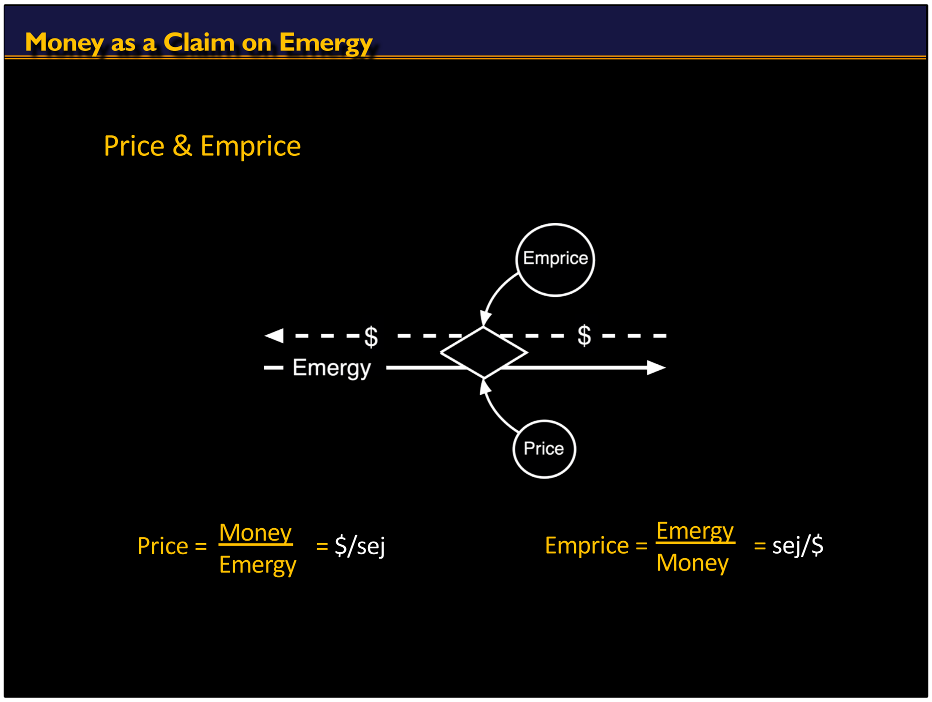
When we purchase lumber, do we scatter money through the forest before cutting the trees?

Of course not.

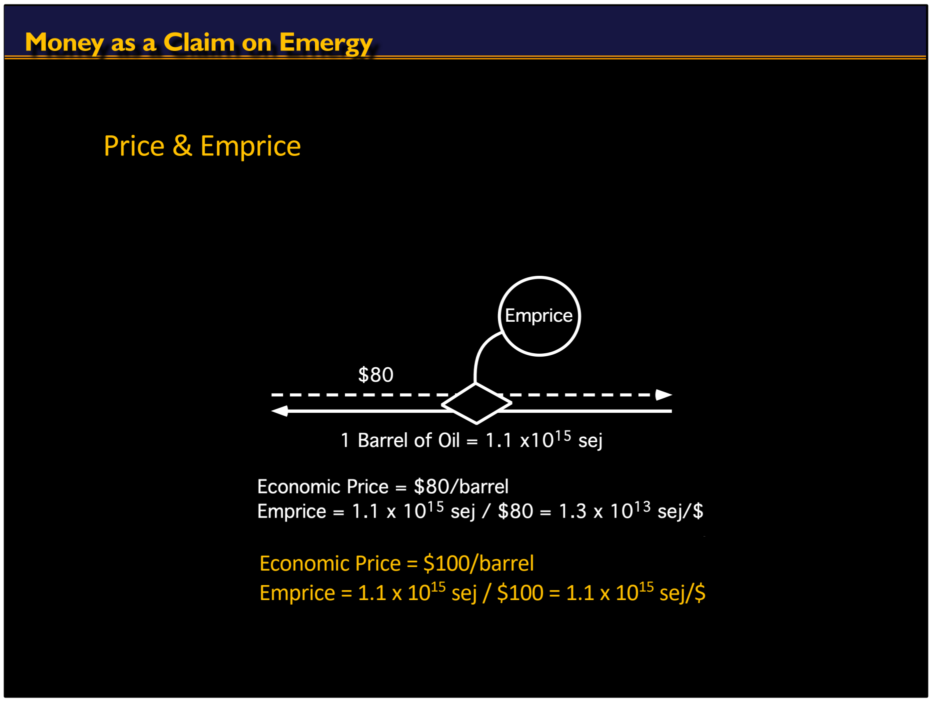
The environment contributes emergy, but the payments are made to people and organizations that extract, process, transport, and distribute those resources.

In this diagram, Notice that the prices are attached to the economic interface, not to environmental production.

We do not pay nature for all that it provides. Nature is not paid for the work it performs.



Price is the amount of money paid for a given quantity of something
Emprice is the amount of emergy you receive for a quantity of money paid
Price and emprice describe the same transaction from two different perspectives.
Price tells us how much money must be paid to obtain a unit of emergy.
Emprice tells us how much emergy is obtained for a unit of money.
There is no new mathematics involved. Emprice is simply the reciprocal of price.
The difference is conceptual rather than computational.
Traditional economics follows the money. It asks how much currency must be spent to obtain a resource.
Emergy analysis follows the emergy. It asks how much emergy is received for each unit of currency.
Price tells us how much money must be spent.
Emprice tells us how much emergy is received.
The two measures describe the same transaction, but from opposite directions.
This is extremely important….. Emprice measures what is received rather than what is paid.
The higher the emprice, the more emergy is obtained for each unit of currency.
Price, in contrast, measures cost—the amount of money that must be given up to obtain that emergy.
Since we humans equate money with wealth, we often assume that price measure value,
higher price is equated with more valuable,
but the opposite is actually true.
The higher the price the less value is obtained.



Consider the cost of oil. If a barrel of oil cost $80, and the emergy content of a barrel of oil is 1.1×10^{15} sej

Then the emprice is about 1.3×10^{13} sej/$ in otherwords the purchaser receives 13 trillion solar emjoules for a dollrs spent.

CLICK… Now if the price rises, to $100/barrel, the barrel still contains the same amount of emergy (1.1×10^{15} sej) and the purchaser only receives 11 trillion solar emjoules for a dollar.

About 15% decrease in value, while form an economics perspective a rise in price is an increase in value.

The emergy contained in the oil has not changed.

Only its market price has changed.

As the price increases, the emergy received for each unit of currency decreases.

From the perspective of emprice, value has declined.

Money as a Claim on Emergy

Emprice of Some Commodities

Emergy, economic price, and Emprice of some energy sources

Item	UEV (sej/unit)	Units	Economic Price ($/GJ)	Emprice (x 10^{12} sej/$)
Natural Gas	1.92E+05	GJ	7.00	27.4
Crude oil	1.75E+05	GJ	13.08	13.4
Coal	9.95E+04	GJ	8.93	11.1
Electricity (Thermal)	2.99E+05	GJ	33.33	9.0
Biodiesel (soybean)	1.77E+05	GJ	29.45	6.0
Ethanol (corn)	9.79E+04	GJ	21.23	4.6

The last column shows the emprice of sources of fossil fuels and the average electricity in the US.

They are arranged from highest emprice to lowest.

What emprice suggests is that one receives more emergy for money spent by purchasing Natural Gas as opposed to corn Ethanol

Money as a Claim on Emergy

Emprice of Some Commodities

Emergy, economic price, emprice and benefit ration of some commodities

Item	UEV (sej/g)	Units	Economic Price ($/g)	Emprice ($\times 10^{12}$ sej /$)
Iron Ore	2.30E+10	g	0.0001	230
Soybeans	2.48E+10	g	0.0004	66
Copper	2.20E+11	g	0.01	23
Phosphate Fertilizer	5.49E+09	g	0.0005	12
Gold	1.48E+13	g	103	0.1
Cell phone	1.52E+11	g	5.29	0.03

The same idea applies not only to fuels, but to all commodities.

Emprice of commodities in the last column show that as they become more refined the emprice decreases.

In other words raw resources like iron ore provide more emergy per unit of money spent.

Compare the cell phone which delivers a very small fraction of the emergy per unit of money when compared to iron ore.

What’s going on here?

We need to explore this apparent dichotomy further.

Most people would say that a cell phone is far more useful than a pile of iron ore

Money as a Claim on Emergy

What Do We Mean by Value?

At first glance, these results seem completely wrong.

Which would you rather have: a pile of iron ore or a cell phone?

Most people would choose the cell phone without hesitation.

Yet the emprice table suggests that iron ore provides much more emergy for each unit of currency.

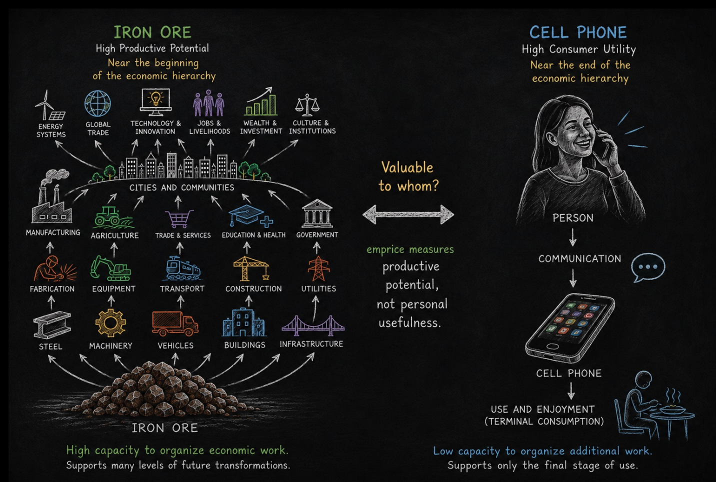
Does that mean emergy is wrong?

No.

It means the two measures are describing different aspects of value.

Interpreting Emprice

Two Perspectives on Value



Iron ore and a cell phone occupy very different positions in the chain of economic transformations.

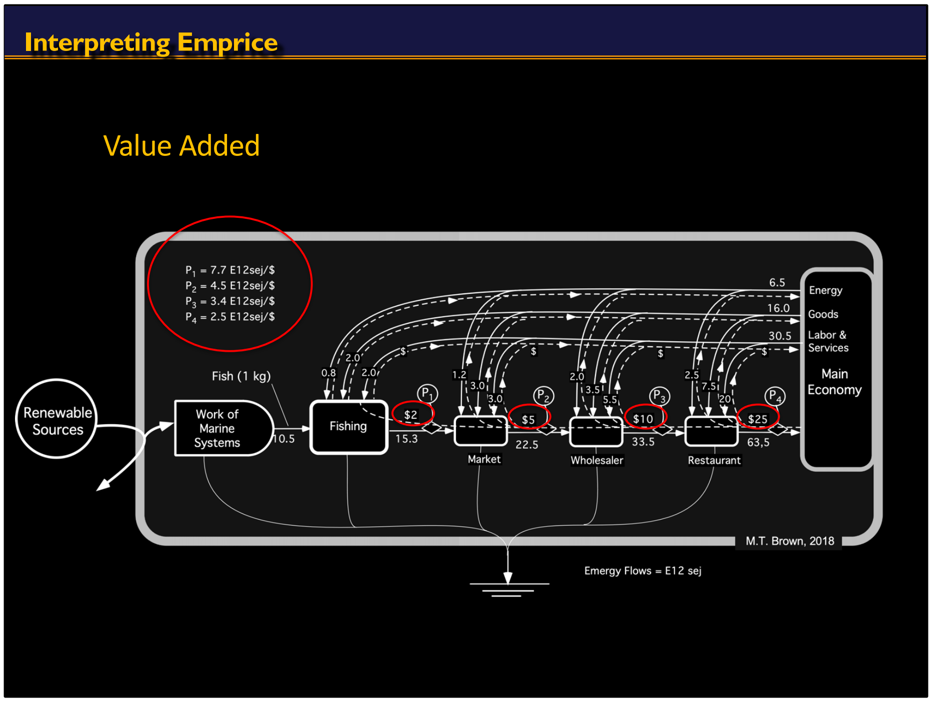
Iron ore is near the beginning.

The cell phone is near the end.

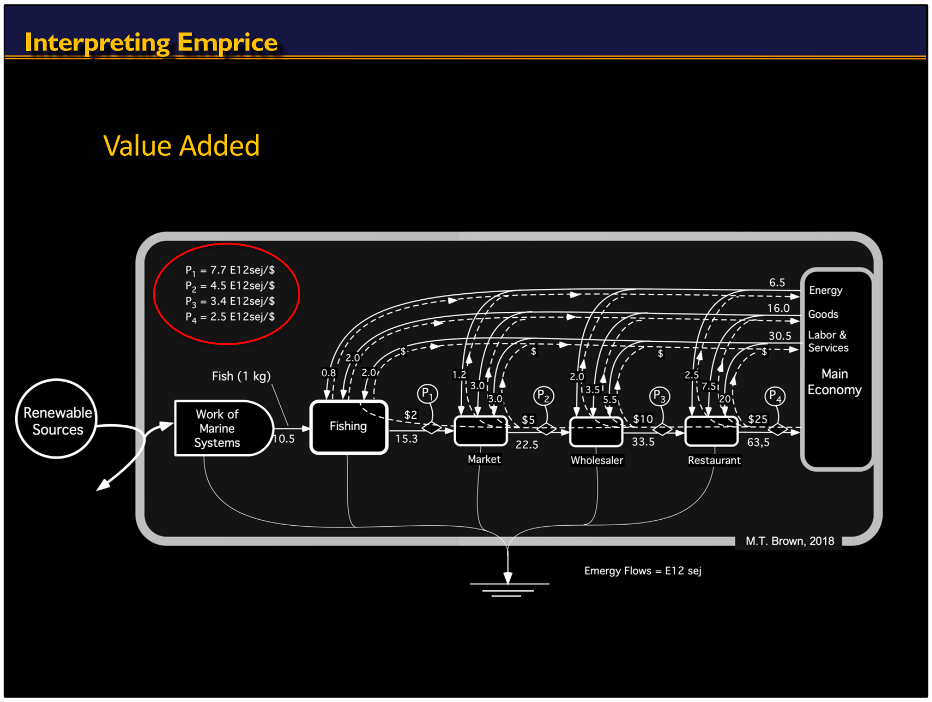
Between them lie mining, transportation, smelting, manufacturing, assembly, electronics, software, distribution, and marketing.

As resources move through this chain they become more useful to the consumer.

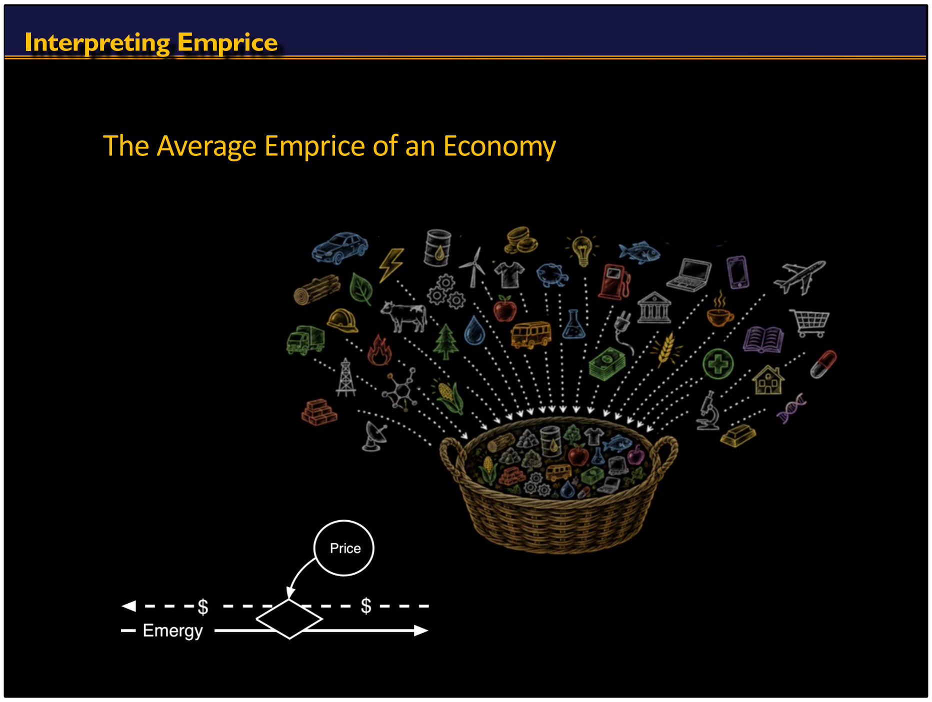
At the same time, their emprice decreases.



The distinction between utility and productive potential becomes much clearer if we follow a familiar product through the economy.
Here we begin with a fish caught in the ocean.
The fisherman lands the fish and sells it for about two dollars.
The fish is then cleaned, transported, refrigerated, marketed, and sold to a wholesaler for $5
The wholesaler sells it to a Restaurant for $10
Finally, it reaches a restaurant where it is prepared, cooked, and served to a customer for about $25.
Notice what happens at every stage.
Additional labor is added.
Additional transportation is added.
Additional services are added.
Additional fuel and equipment are used.
Each of these inputs has a cost, so the selling price increases from transaction to transaction.
Economists refer to this increase as **value added**.
From the traditional economic perspective, this is exactly what we want to see. The product becomes more useful to the customer, and therefore it commands a higher market price.
At this point we might expect emprice to increase as well.
But it doesn’t. as shown in the upper left of the diagram
It decreases.
That is the puzzle we now need to explain.



Now let's examine exactly the same supply chain, but instead of following the money, let's follow the emergy.
Each processing step certainly adds emergy.
Fuel contributes emergy.
Electricity contributes emergy.
Buildings, equipment, labor, transportation, and services all require emergy for their production.
So the total emergy contained in the fish gradually increases as it moves through the economy.
But something else is happening.
The total emergy is increasing, but the selling price is increasing even faster.
As a result, each dollar purchases progressively less emergy.
The fish becomes more expensive.
It becomes more useful.
It becomes more convenient.
But each dollar buys less productive potential than it did earlier in the supply chain.
This is why emprice falls from about 7.7 trillion solar emjoules per dollar when the fish is landed to about 2.5 trillion solar emjoules per dollar when it reaches the restaurant.
Nothing is wrong with the restaurant meal.
The customer is receiving exactly what they wanted.
But the customer is purchasing convenience, preparation, transportation, marketing, and service.
They are no longer purchasing a resource with large potential for additional transformations.
That potential has already been used.



So far we've examined individual products.

But every economy contains millions of transactions every day.

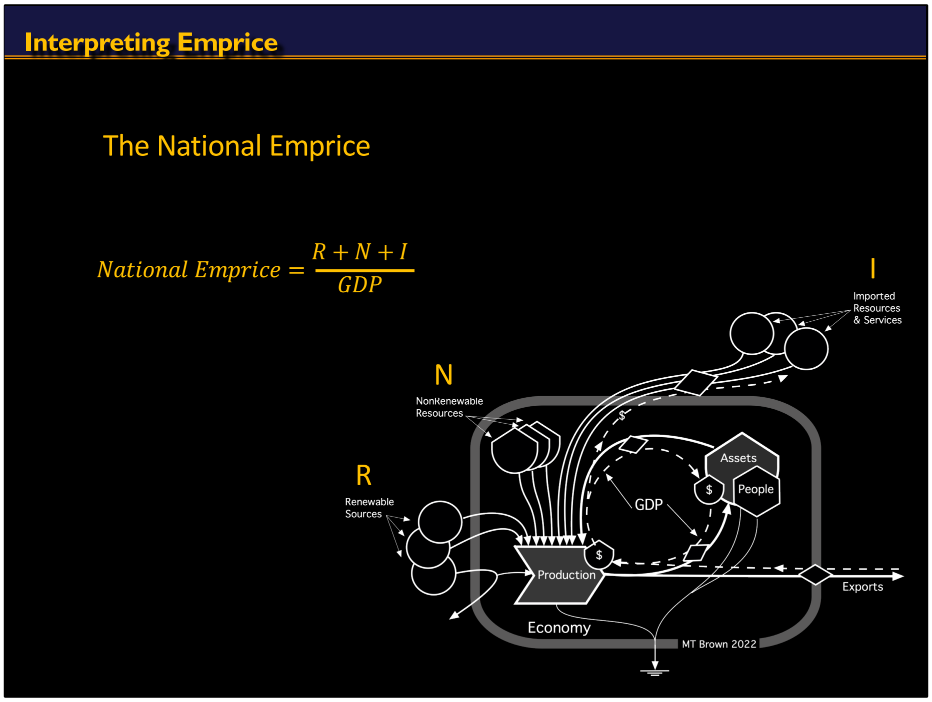
Food is bought and sold.

Electricity is purchased.

Houses, automobiles, computers, medical care, and transportation are all exchanged in the marketplace.

If every product has an emprice, then the economy itself must also have an average emprice.

That average provides a useful reference for interpreting the emprice of any individual product.



National Emprice is computed by dividing the total annual emergy supporting the economy by the nation's Gross Domestic Product.

GDP represents the total annual value of goods and services produced within the economy.

Because both quantities represent annual flows, the time units cancel.

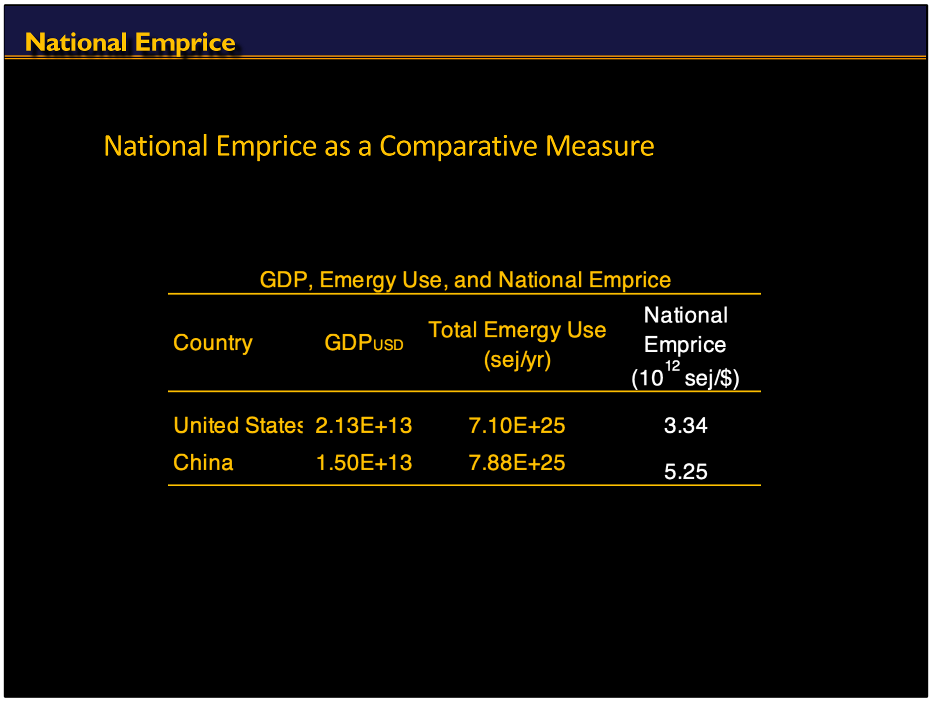
The result is the average amount of emergy obtained for each unit of national currency.

Historically this quantity has been called the Emergy Money Ratio, or EMR.

Here we will refer to it as **National Emprice**, because it represents the average emprice of an entire economy.

Because it represents the national average, it also provides a benchmark against which the emprice of any individual product can be compared.

In the next lecture we will use this benchmark to evaluate products, industries, and entire national economies.



Country	GDPUSD	Total Emergy Use (sej/yr)	National Emprice (10^{12} sej/$)
United States	2.13E+13	7.10E+25	3.34
China	1.50E+13	7.88E+25	5.25

We can now use National Emprice to compare entire economies.

Remember, National Emprice represents the average amount of emergy obtained for each unit of national currency.

It provides a common reference for comparing the relationship between emergy and economic activity in different countries.

In this example, China's National Emprice is larger than that of the United States.

On average, each unit of China's currency commands more emergy than a unit of U.S. currency.

That does **not** mean one economy is better than the other.

Why do these differences exist?

Is it because one economy uses more natural resources?

Does it reflect differences in industrial structure, labor, technology, or international trade?

Or does it reveal something more fundamental about how economies are organized?

These are exactly the questions we will begin to answer in the next lecture, where we extend emergy analysis from individual transactions to the national scale.

Thank You…

Thank You for Your Attention

感谢您的聆听