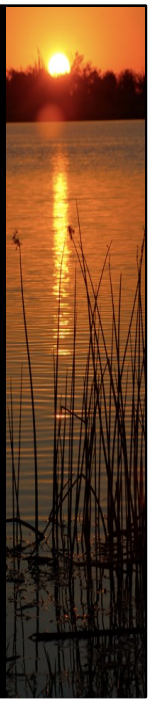
2026 International Summer Course on Environmental and Ecological System Engineering

Part A: Environmental Accounting and Systems Thinking (EAST)

Lecture 7:

Emergy at the International Scale



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In this lecture we move from the concept of emergy to the practical calculation of available energy.

Organization…

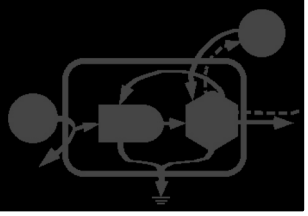
The National Emergy Accounting Database (NEAD)

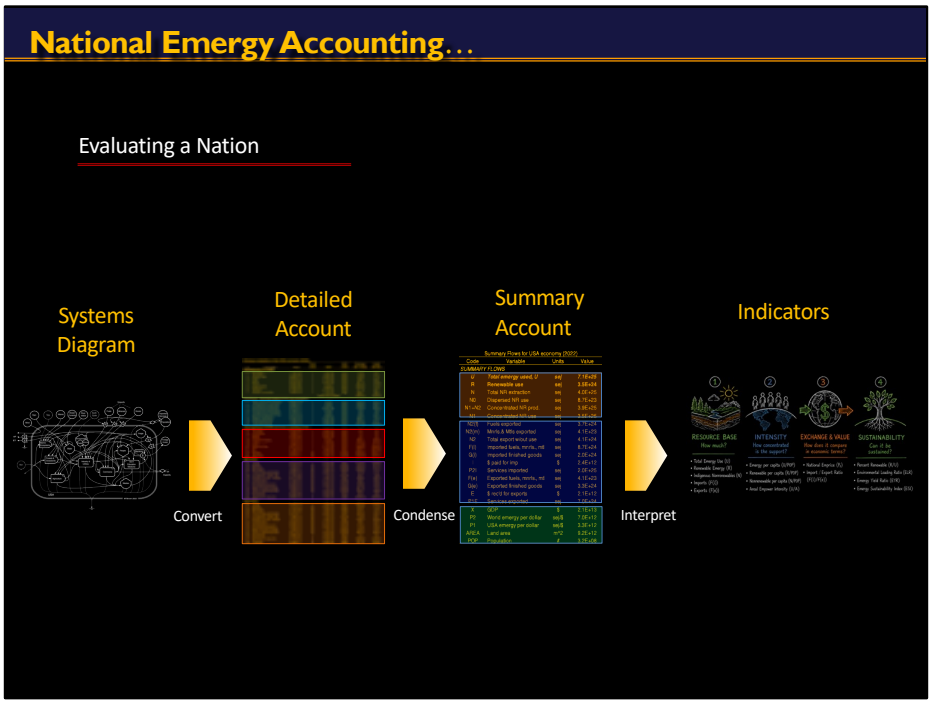
Looking for patterns among nations

International Trade

Resource Imperialism

International Debt





In the previous lecture we learned how to evaluate a single national economy.

We began with a systems diagram, measured every important resource flow, converted those flows into emergy, and calculated a set of indicators describing the nation's resource base and sustainability.

But there is an obvious problem.

A national emergy evaluation is a major undertaking.

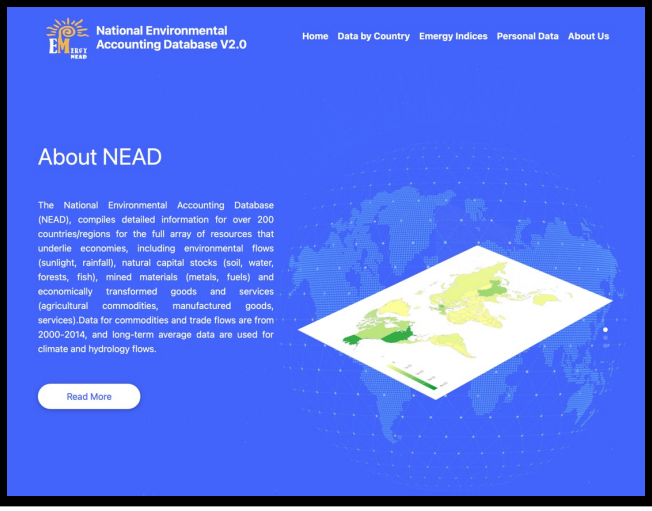
Each analysis requires collecting hundreds of data items, evaluating dozens of resource flows, and carefully organizing them into a consistent accounting framework.

Doing this for one country is a significant amount of work.

Doing it for every country in the world would require years of effort.

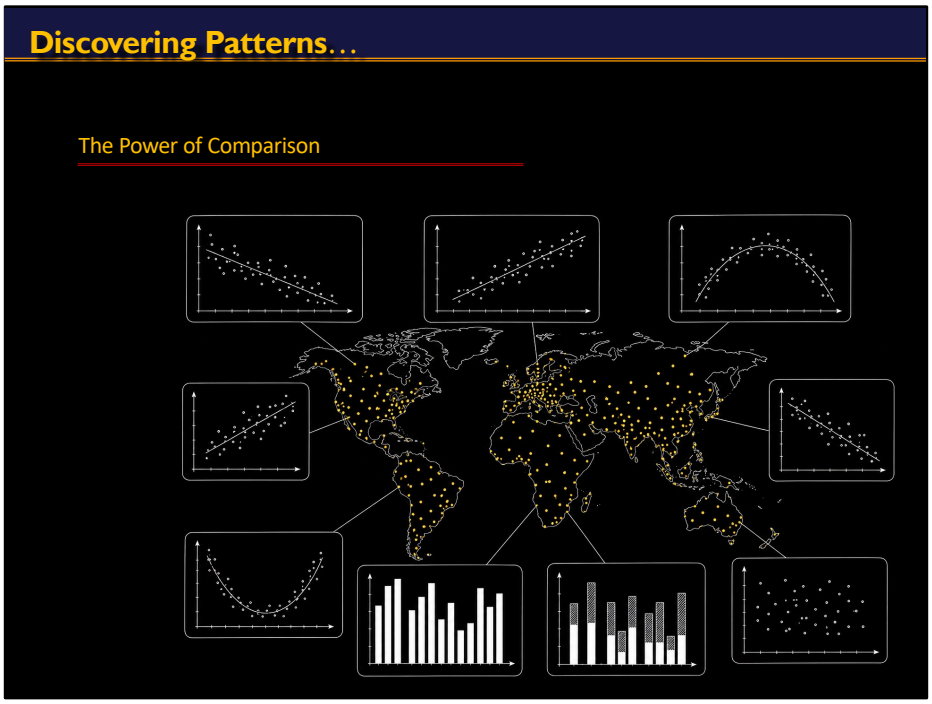
National Emergy Accounting…

The National Environmental Accounting Database



NEAD

The NEAD was developed at the University of Florida as part of a project funded by
The United Nations Environmental Program
After its initial development, it was handed off to Beijing Normal University under the direction of
Gengyuan Liu



At first glance, NEAD looks like a large collection of numbers. But the real value of the database is not the numbers themselves.

Its value comes from the fact that every country has been evaluated using the same accounting framework.

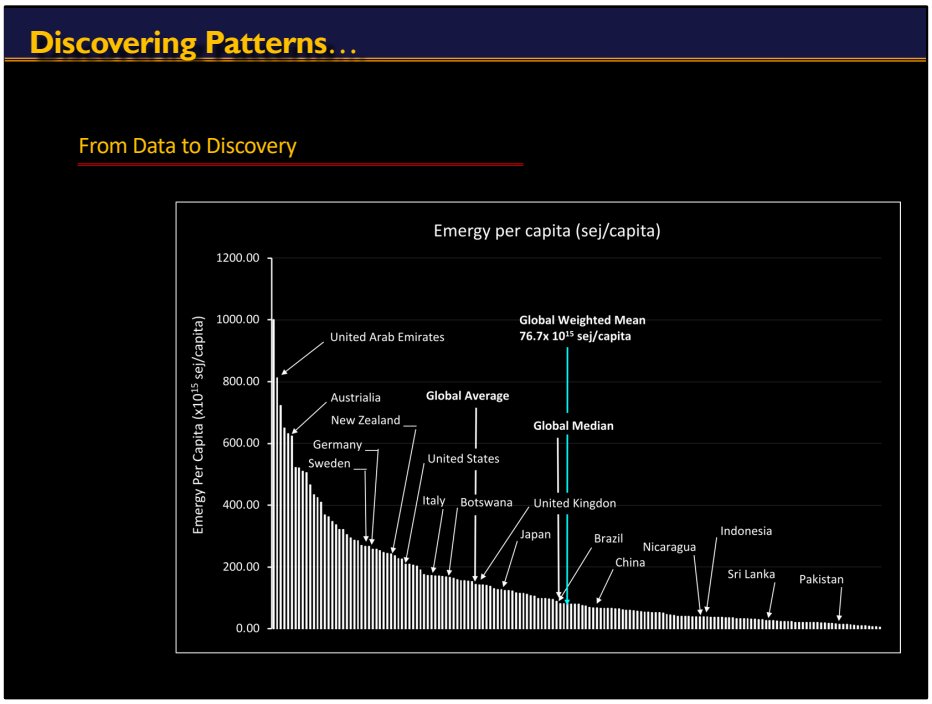
Once that is done, we can arrange the countries according to any emergy indicator and immediately begin to recognize patterns.

Some countries cluster together. Others stand apart. Relationships that are invisible when examining a single nation suddenly become obvious.

These patterns generate new scientific questions.
Why do some countries have much higher renewable support than others? Why do some currencies represent much more emergy than others? Why do some nations consistently gain emergy through trade while others lose it?

In other words, the database is not simply a collection of national accounts.

It is a tool for discovering how the global economy is organized.



We are now looking at the first of many ways the database can be explored.

Here, the countries have simply been arranged according to emergy use per capita.

Before NEAD, seeing the world's economies organized in this way simply wasn't possible.

National emergy evaluations existed for individual countries, but there was no consistent framework for examining them together.

Immediately, we see that countries are not randomly distributed. Instead, they form a clear pattern across nearly two orders of magnitude.

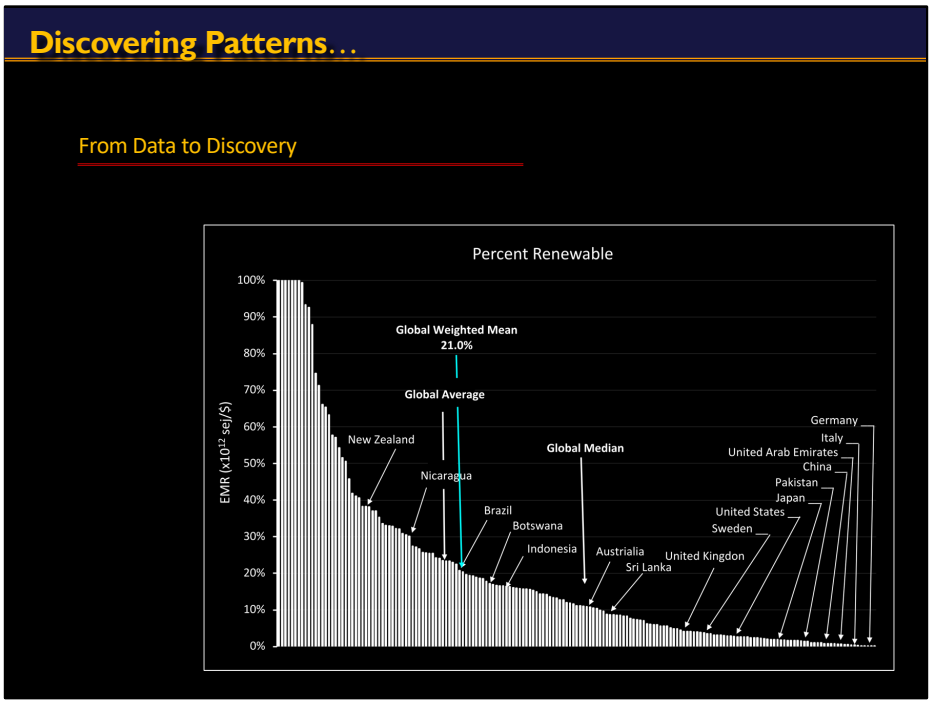
Some nations receive enormous amounts of emergy for each person, while others operate with much smaller resource bases per capita.

The graph itself does not explain *why* these differences exist. But it tells us that the differences are real, and it immediately suggests new questions.

Are these differences controlled by resource availability? Population density? Climate? Economic development? Or perhaps some combination of all of them?

This is the power of looking at many countries simultaneously. The database transforms individual national accounts into a global laboratory for understanding how human economies are organized.

Quantity, however, is only part of the story. We also want to know where that emergy comes from.



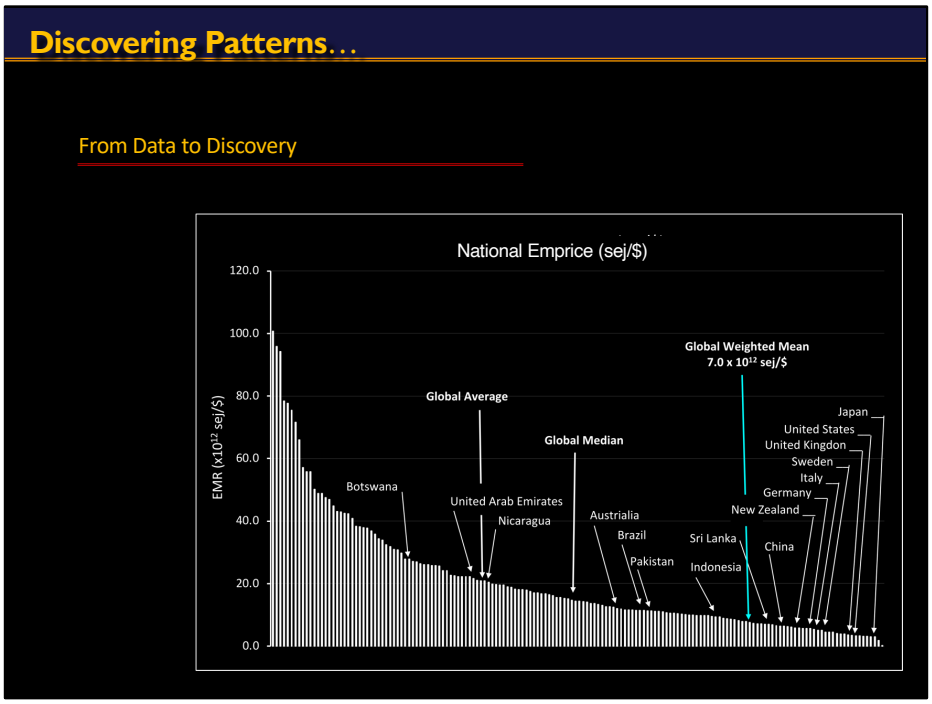
This graph ranks the same countries according to the percentage of their total emergy that comes from renewable resources.

We introduced percent renewable in the previous lecture as one of the fundamental indicators of national sustainability. Here we see how dramatically it varies among nations.

Again, the graph does not tell us why these differences exist. Geography, climate, natural resources, population density, and economic development all play important roles. But by arranging the data in this way, the variation becomes immediately apparent.

Looking at these countries together also reveals another important point.

There is no single "typical" nation. Instead, countries span a broad continuum, from those supported largely by renewable environmental inputs to those that rely almost entirely on nonrenewable resources and imported emergy.



The third pattern concerns money.

Here the countries are ranked from high to low National Emprice.

Once again, the pattern is not random. Countries with smaller monetary economies, larger informal sectors, or stronger dependence on local environmental support often have higher National Emprices.

Developed industrial economies generally have lower National Emprices because a large GDP is supported by a smaller amount of emergy per dollar.

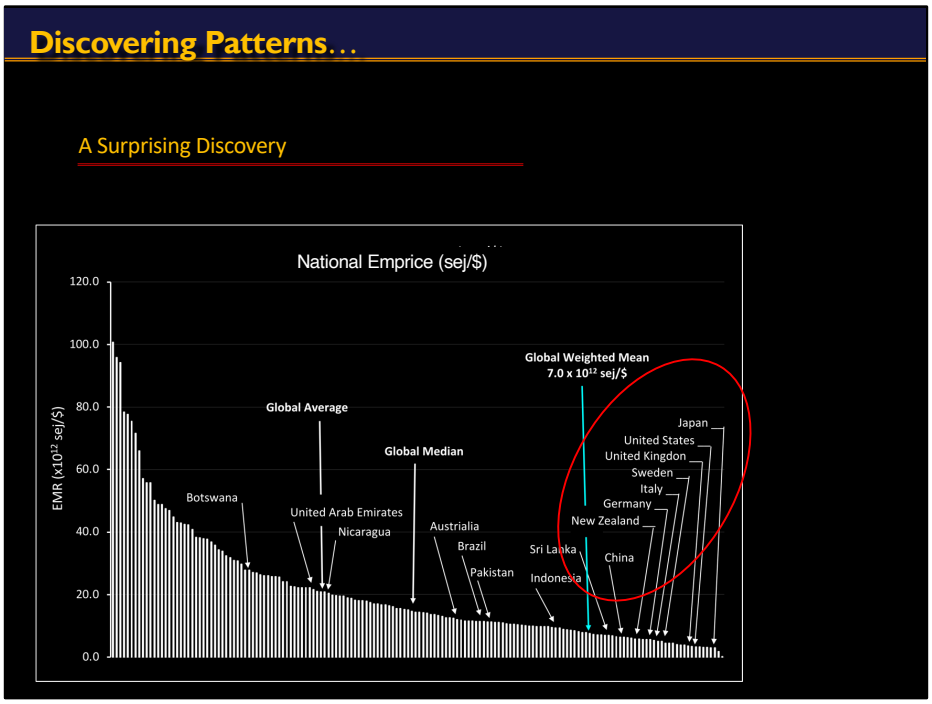
This does not mean that a low National Emprice is “better” or that a high National Emprice is “worse.” It means that national currencies are connected to very different biophysical foundations.

That difference becomes extremely important when countries trade.

If one dollar represents one amount of emergy in one country, but a very different amount of emergy in another country, then equal monetary exchange may not be equal biophysical exchange.

This is the point where national accounting becomes international analysis.

The first two indicators described natural resources. The next indicator describes the relationship between those resources and the monetary economy.



This pattern is surprising…. Why should wealthy industrial nations have the lowest National Emprices?

Many people expect wealthy industrial nations to have the highest National Emprices because they produce advanced technologies and generate large economies.

In fact, we observe exactly the opposite.

Most developed industrial economies are found toward the lower end of the graph, while many developing nations lie toward the upper end.

The reason is that National Emprice measures **emergy per unit of currency**, not wealth.

Developed economies generate very large monetary outputs.

As a result, each dollar represents a relatively small amount of the total emergy flowing through the economy.

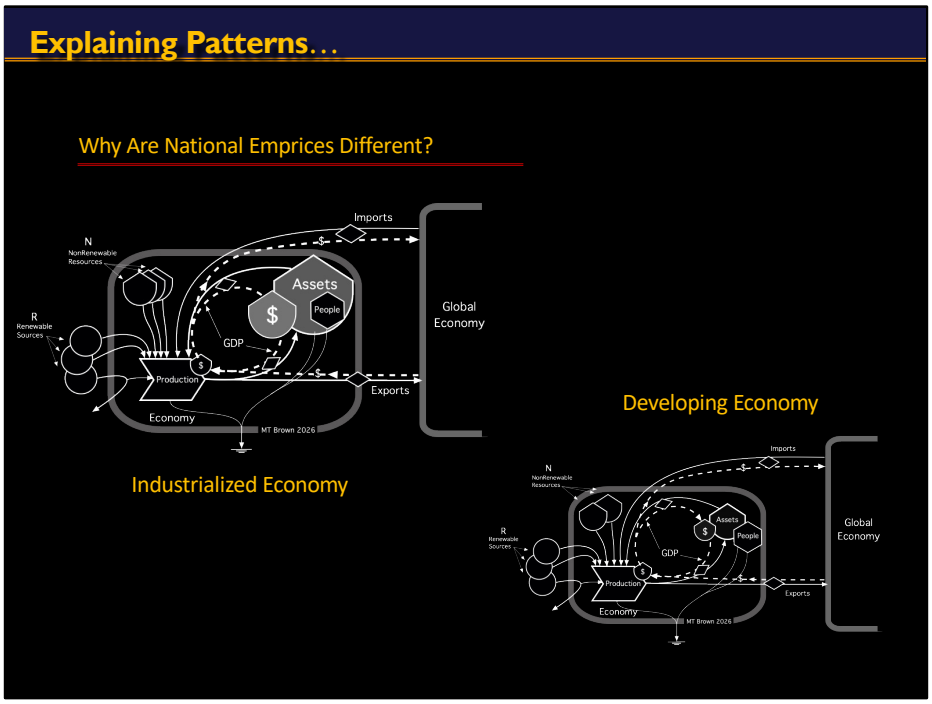
In many developing nations, however, the monetary economy is much smaller relative to the emergy required to sustain it.

Consequently, each unit of currency represents considerably more emergy.

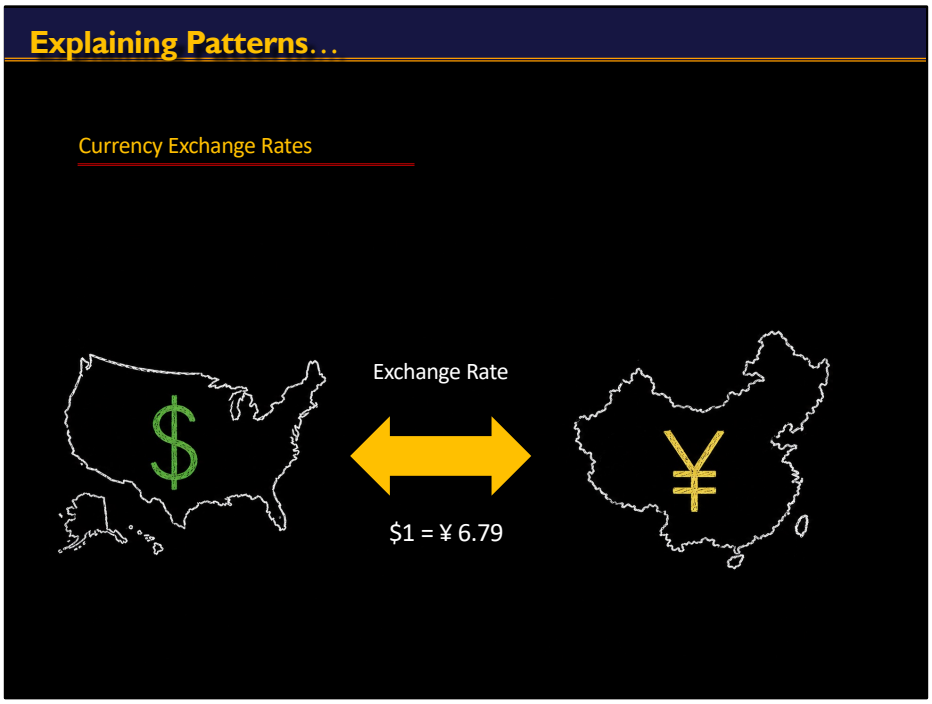
This distinction is extremely important because countries do not trade emergy directly—they trade goods and services using money.

If one dollar represents very different amounts of emergy in different countries, then equal monetary exchanges do not necessarily represent equal emergy exchanges.

This observation provides the foundation for understanding emergy purchasing power, unequal terms of trade, and ultimately the accumulation of international debt.



The answer becomes clearer if we think about the economy as an autocatalytic system.
At first glance, these two national systems appear very similar. Both receive renewable resources, imports, fuels, and minerals.
Both transform these inputs into goods, services, and economic activity.
The critical difference is found inside the economy itself.
Industrialized economies contain enormous accumulated storages of assets and money.
These storages represent the emergy invested over many decades or even centuries in infrastructure, factories, transportation systems, technology, institutions, education, and financial capital.
These accumulated assets reinforce one another in an autocatalytic process.
Existing capital supports additional production, investment, and innovation, which in turn creates still more capital. As the economy grows, it generates an increasingly large monetary economy and a correspondingly large GDP.
Developing economies typically contain much smaller accumulated storages.
Although they may utilize substantial emergy through agriculture, forestry, fisheries, or mineral production, they generate a much smaller monetary economy and GDP because the reinforcing capital structure is less developed.
As a result, each unit of currency represents a larger amount of emergy, producing a higher National Emprice.
National Emprice therefore reflects not simply the amount of emergy flowing through an economy, but the relationship between that emergy and the accumulated capital that has developed within the economic system.
This distinction becomes critically important once countries begin trading with one another.
If the same amount of money represents different amounts of emergy in different economies, then equal monetary exchanges do not necessarily represent equal emergy exchanges.
The next question is obvious. If national currencies represent different amounts of emergy, what happens when countries trade with one another?



Before countries can trade, they must first exchange currencies.

Every country has its own monetary system. The United States uses dollars, China uses yuan, Europe uses the euro, and Japan uses the yen.

Before an American company can purchase goods from China, or a Chinese company can purchase goods from the United States, one currency must be exchanged for another.

The **exchange rate** tells us how many units of one currency can be obtained for a unit of another.

Today, for example, one U.S. dollar exchanges for about 6.8 Chinese yuan.

Tomorrow that number may be slightly different, and next month it may change again.

Where does that number come from?

In most countries, exchange rates are determined primarily by international currency markets.

They are influenced by supply and demand, interest rates, inflation, trade balances, government policy, capital investment, and market expectations.

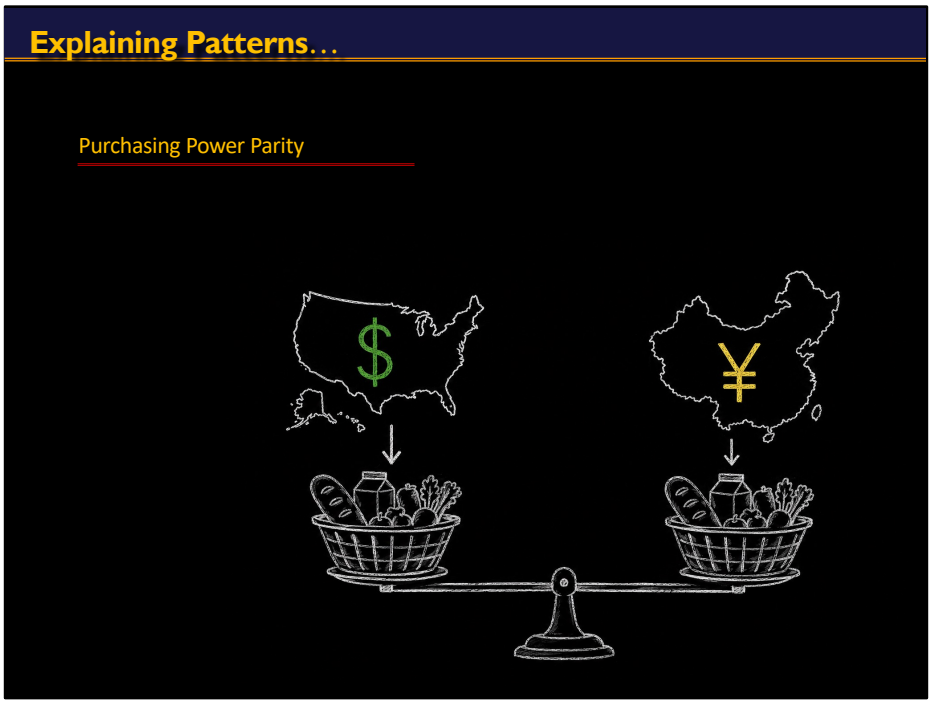
In other words, an exchange rate is a **market price** for one currency expressed in another currency.

Exchange rates are essential because they allow international trade to occur. But they also have an important limitation.

An exchange rate tells us how currencies trade against one another. It does **not** tell us how much real value those currencies can purchase.

A dollar exchanged for yuan may buy far more goods in one country than the same dollar would buy in another. Economists recognized this problem many years ago and developed the concept of **Purchasing Power Parity** to compare the real purchasing power of different currencies.

As we will see next, emergy analysis asks exactly the same question. Instead of evaluating a basket of goods using prices, we evaluate that same basket using emergy.



Imagine purchasing exactly the same basket of goods in two different countries.

The basket might contain food, clothing, transportation, housing, and other everyday necessities.

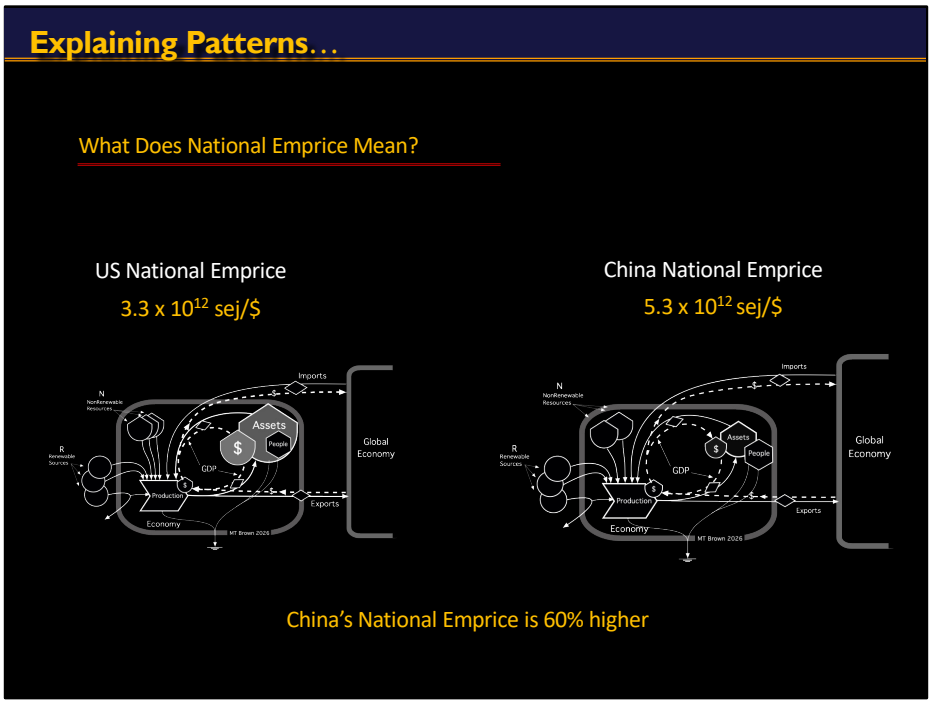
Even after converting currencies using the market exchange rate, the cost of that basket is often very different.

Purchasing Power Parity, or PPP, asks a simple question:

How much of each country's currency is required to purchase the same basket of goods and services?

Rather than comparing currencies directly, PPP compares what those currencies can actually buy.

This provides a much better measure of the real purchasing power of different currencies than exchange rates alone.



Conventional Purchasing Power Parity estimates the relative purchasing power of currencies by comparing the prices of a representative basket of goods.

Emergy Purchasing Power Parity begins with the National Emprice of each economy.

Because National Emprice expresses the average emergy represented by one unit of currency, it provides a direct measure of the average emergy purchasing power of that currency.

Emergy Purchasing Power Parity is based on the National Emprice of each economy..

The logic is similar: both ask what a unit of currency can command. But the emergy comparison is made from the whole national account, not from pricing a basket item by item.

Emergy analysis uses the same general idea of purchasing power but applies it at the scale of whole national economies.

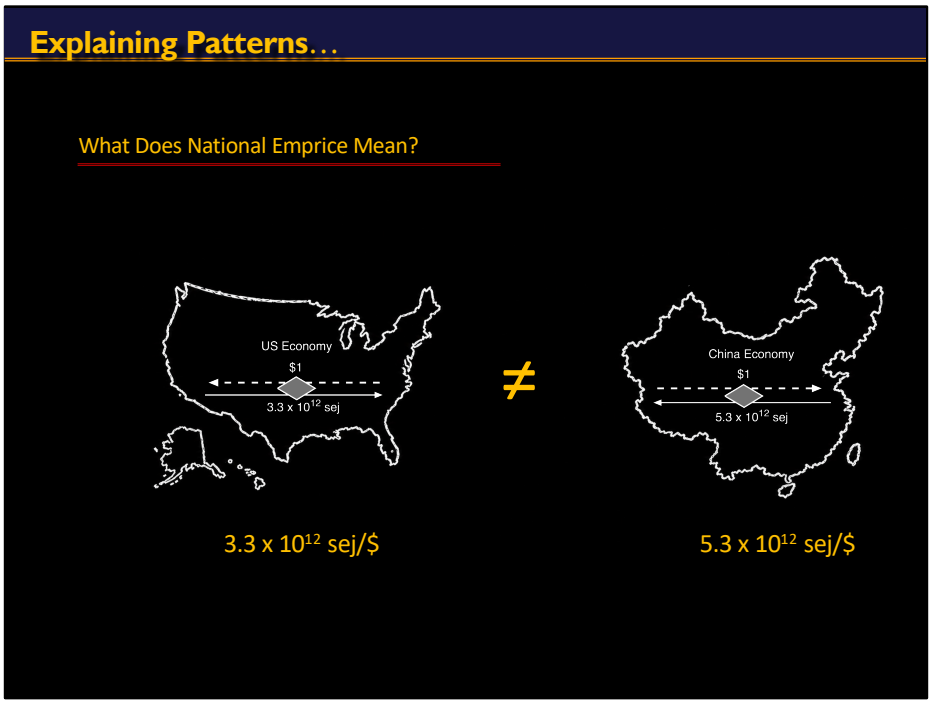
Instead of asking how much a selected basket of goods costs in each country, we ask how much emergy is represented by each unit of national currency.

That is what National Emprice gives us.

By comparing the National Emprices of two countries, we compare the average emergy purchasing power of their currencies.

On average, one dollar spent in China purchases goods and services embodying about 60% more emergy than one dollar spent in the United States..

What does that mean?....



The answer is that a dollar does not represent the same amount of emergy in every economy.

Here we compare the average purchasing power of one dollar in the United States with the purchasing power of one dollar in China.

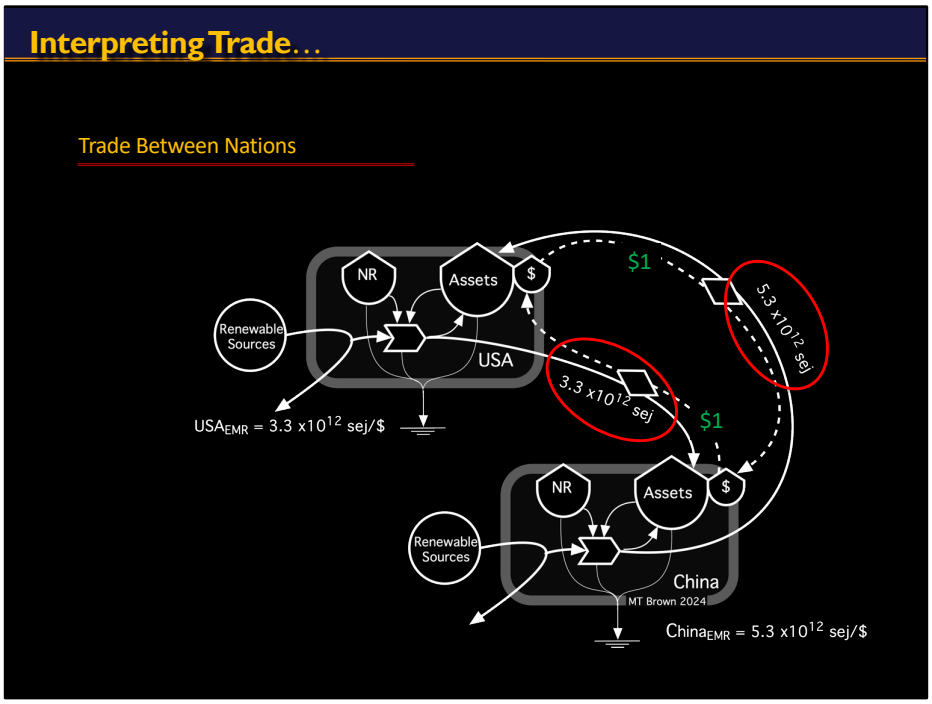
Because China's National Emprice is higher than that of the United States, one dollar spent in China purchases goods and services that, on average, embody more emergy than one dollar spent in the United States.

This does **not** mean that every individual product contains more emergy. Individual commodities vary widely depending on how they are produced and where they are produced.

Instead, this is a statistical property of the national economy as a whole.

National Emprice represents the **average** emergy corresponding to one unit of currency across all economic activity within that country.

Emergy Purchasing Power Parity therefore compares the average biophysical purchasing power of currencies rather than simply their market exchange rate.



We can now see why differences in National Emprice matter.

Imagine that one dollar's worth of goods is exported from the United States to China.

At the same time, one dollar's worth of goods is exported from China to the United States.

From the perspective of conventional economics, this appears to be an equal exchange.

One dollar has been exchanged for one dollar.
But emergy accounting reveals something different.

On average, one dollar's worth of goods exported from the United States embodies about **3.3×10^{12} solar emjoules**.

One dollar's worth of goods exported from China embodies about **5.3×10^{12} solar emjoules**.

The monetary exchange is equal, but the emergy exchange is not.

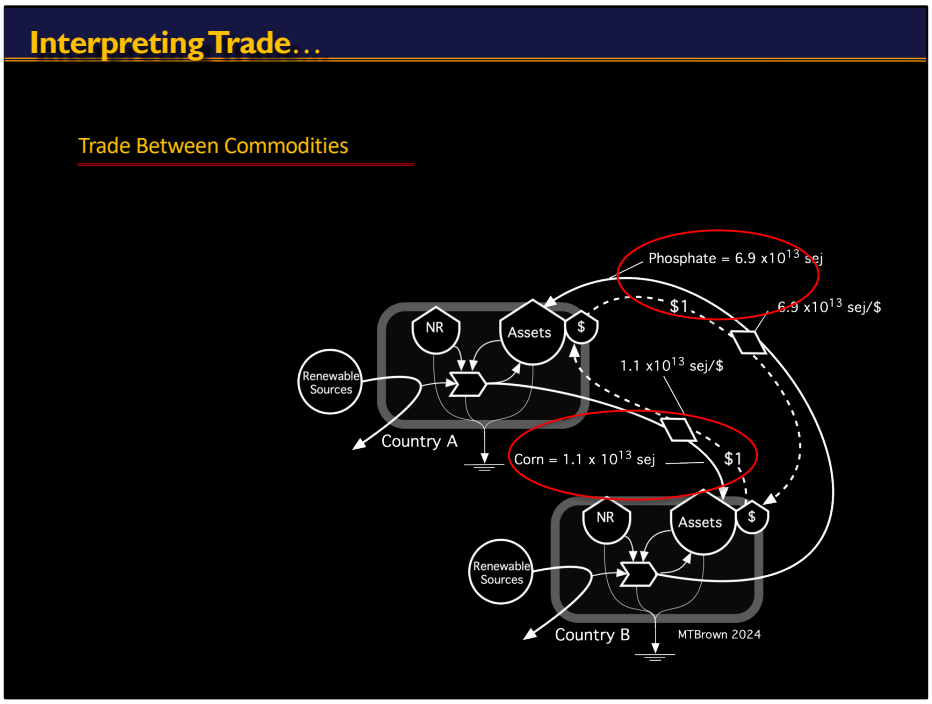
For every dollar of trade, the United States receives goods and services containing more emergy than it sends, while China exports more emergy than it receives in return.

This difference does not arise because either country is paying an unfair price.

It arises because the same unit of currency represents different average amounts of emergy in the two national economies.

Emergy Purchasing Power Parity therefore provides a biophysical perspective on international exchange.

It reveals transfers of embodied emergy that are invisible when trade is evaluated using money alone.



Does the same reasoning apply to individual products.?

The answer is yes.

Here we compare a simple exchange.

One country exports one dollar's worth of corn, while the other exports one dollar's worth of phosphate fertilizer.

The monetary exchange is perfectly balanced. Each country exports goods valued at one dollar.

But the emergy embodied in those two commodities is very different.

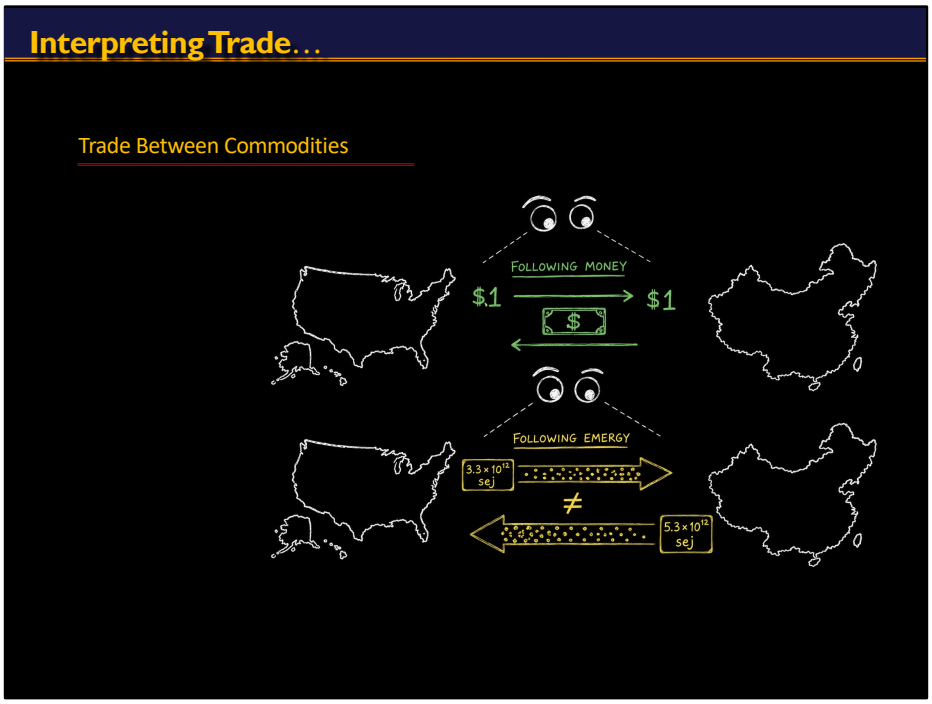
As we learned earlier, every commodity has its own emprice because each requires a different amount of emergy to produce each dollar of output.

As a result, the emergy transferred in the two directions is unequal, even though the monetary exchange is exactly equal.

This illustrates an important principle.
Unequal emergy exchange can occur at two different scales.

It can arise from differences in the average National Emprice of entire economies, and it can also arise because individual commodities have different emprices.

In practice, international trade reflects both effects simultaneously.



We have now reached one of the central conclusions of national emergy accounting.

Conventional economics evaluates international trade by following the movement of money. A country with a negative monetary balance of trade is generally viewed as losing wealth.

Emergy accounting follows the goods and services moving in the opposite direction.

Remember that money and emergy flow in opposite directions.

When two countries have different National Emprices, equal monetary transactions represent unequal transfers of emergy.

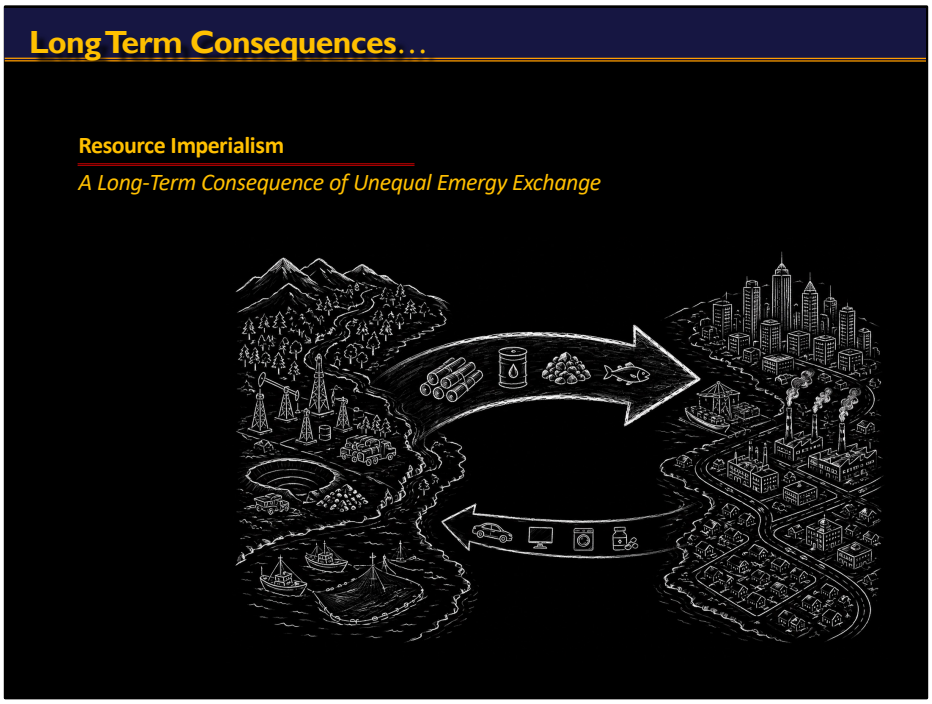
Countries with higher National Emprices export more emergy for each unit of currency than countries with lower National Emprices.

Consequently, when trade is balanced in monetary terms, it is not balanced in emergy terms.

The country with the higher National Emprice experiences a net export of emergy, while the country with the lower National Emprice experiences a net import of emergy.

This is not an occasional outcome or an accounting anomaly. It is the expected consequence of trading between economies whose National Emprices differ.

That raises an important question. What are the long-term consequences of persistent net transfers of emergy through international trade?



We have shown that differences in National Emprice produce systematic differences in the amount of emergy exchanged for each unit of currency..

In practice, many of the countries with the highest National Emprices are developing economies whose exports consist largely of primary resources—timber, agricultural products, fisheries, fuels, and mineral ores.

These commodities often embody large amounts of emergy while generating relatively modest monetary returns.

At the same time, many industrialized economies with lower National Emprices import these resource-intensive commodities and export manufactured goods, technology, and services.

The result is a persistent net transfer of embodied emergy toward the industrialized economy, even when the monetary value of trade appears balanced.

The combination of these two patterns reinforces the unequal transfer of emergy through international trade.

When this process continues year after year, decade after decade, industrial economies continually accumulate the embodied work of nature from other regions while expanding their own industrial and financial capital.

Resource-producing economies, meanwhile, continually export a portion of the emergy embodied in their forests, fisheries, soils, fuels, and mineral resources.

It is this long-term, self-reinforcing transfer of embodied emergy through international trade that I refer to as Resource Imperialism.

Like many systems we have studied, Resource Imperialism is autocatalytic. Industrial economies accumulate the capital that further strengthens their industrial base, while resource-producing economies continually export part of the emergy needed to build their own..

Global Applications…

International Debt: Another Application

Country	**Years to Repay** (Official Exchange Rate)	**Years to Repay** (Emergy Based Exchange Rate)
Mali	17.9	4.4
Niger	21.7	5.2
Burkina Faso	30.4	2

The implications of National Emprice extend beyond international trade.

Consider international debt.

Today, debt is evaluated entirely using conventional exchange rates.

The amount owed, the annual repayments, and the time required to repay are all calculated using monetary exchange rates.

Emergy accounting asks a different question.

What if currencies were compared using their National Emprices instead of their market exchange rates?

When we applied this approach to several West African countries, the results were remarkable.

Using emergy-based exchange rates, the estimated time required to repay existing national debts decreased by factors ranging from approximately 4 to 15.

The reason is straightforward.

Conventional exchange rates undervalue the embodied emergy represented by the currencies of these economies.

When repayment is evaluated on a biophysical basis, those countries are contributing much more real value than conventional monetary accounting recognizes.

Whether emergy-based exchange rates should influence international lending policy is ultimately a question for policy makers.

The important point for us is that emergy accounting provides a completely different perspective from which these questions can be examined.

Throughout this lecture we have moved beyond evaluating individual nations to understanding how nations interact as parts of a larger global system.

The National Emergy Accounting Database makes this possible.

Instead of studying one country at a time, we can compare nearly every economy on Earth using a common biophysical accounting framework.

That allows us to ask entirely new scientific questions.

Why do some countries have high National Emprices while others do not?

How do renewable resources influence national development?

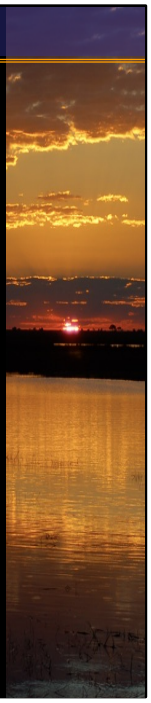
How does trade redistribute emergy among nations?

How do these patterns change through time?

These are no longer questions of individual case studies. They become questions about the organization and evolution of the global economy itself.

Emergy accounting provides a way to study that global system from the perspective of energy, resources, and the work required to sustain human civilization.

Thank You…



Thank You for Your Attention

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