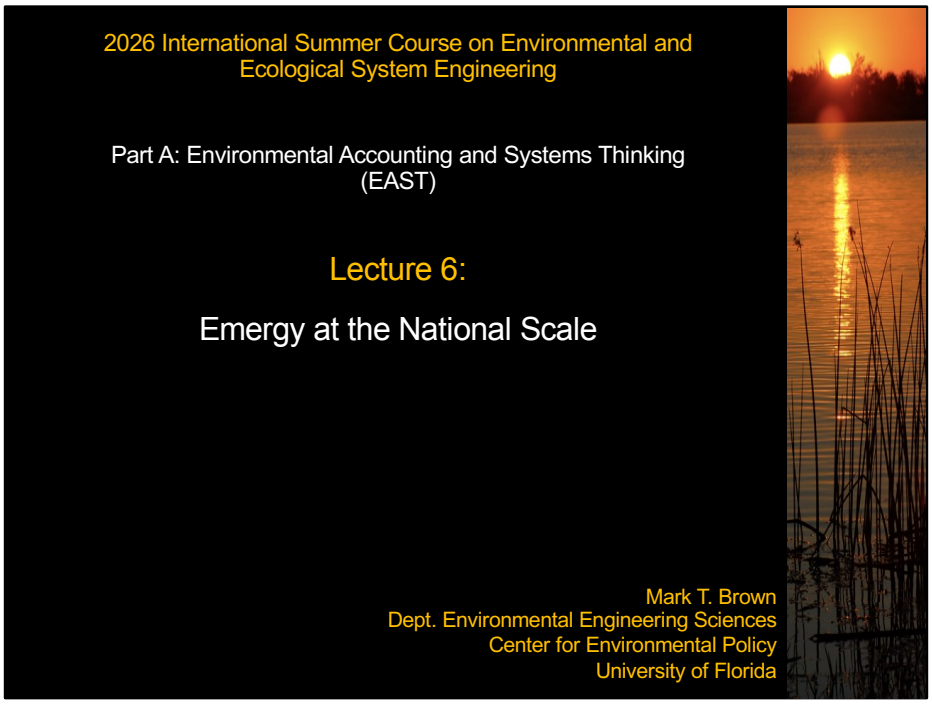


In this lecture we explore the relations between resources and national economies from a biophysical perspective

BIOPHYSICAL = biophysical refers to the physical realities of the natural world

—specifically the flows of energy, matter, and ecosystem services that sustain economic activity.

It contrasts with traditional economics, which often views the economy purely in terms of *money and financial transactions*

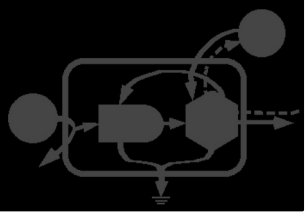
Organization…

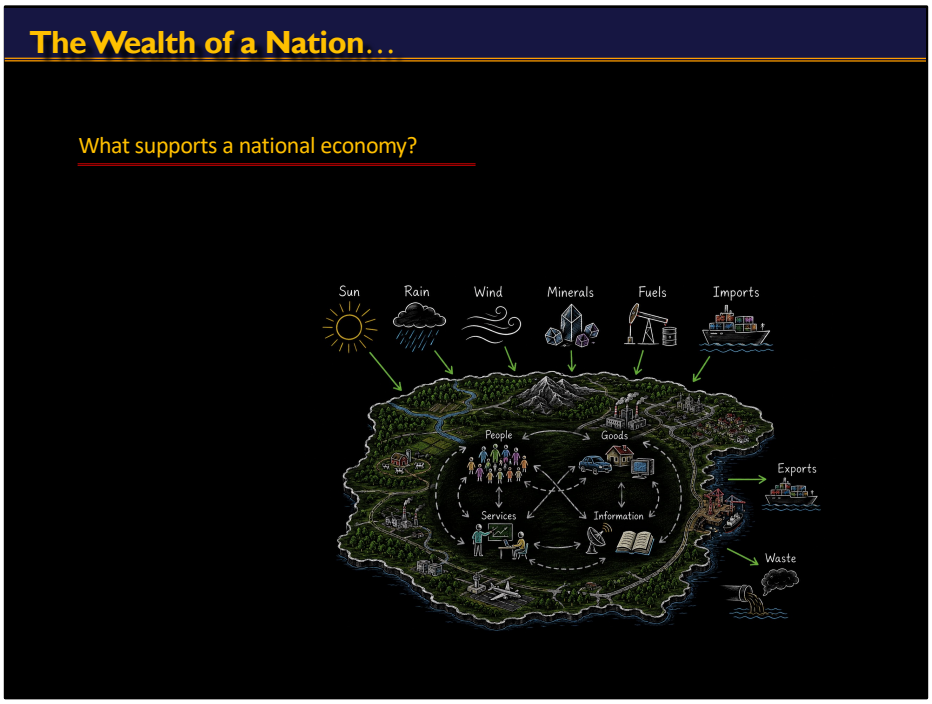
The Wealth of Nations

Accounting for the Wealth of Nations

National Emergy Indicators.

Pathways to National Sustainability





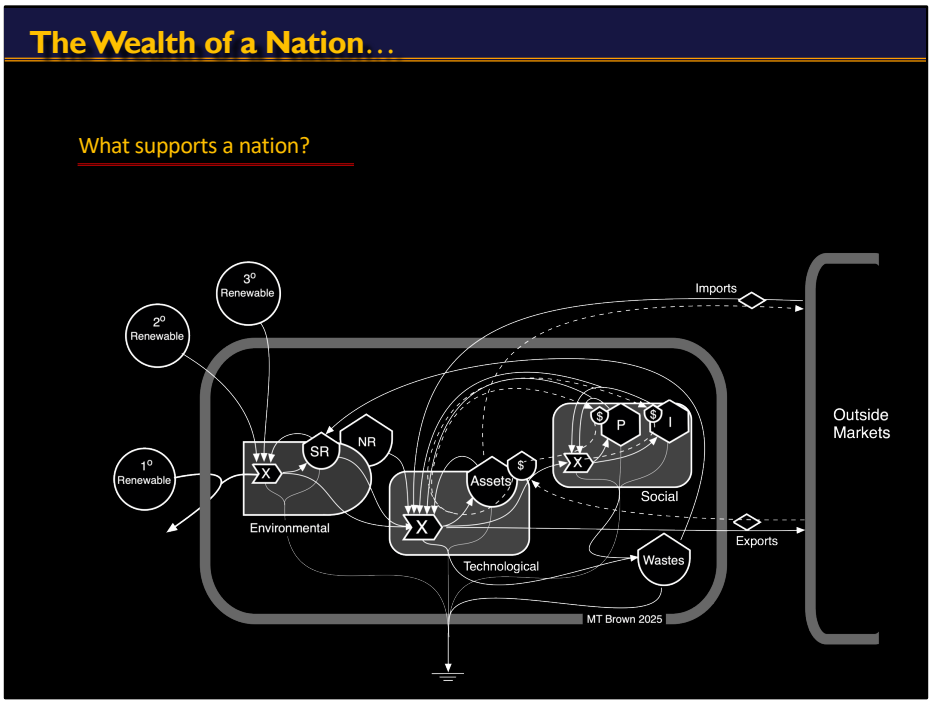
Economists begin with GDP.

Emergy begins one level deeper.

Before an economy can produce anything, it must first be supported by environmental resources.

National emergy accounting asks a simple question:

What are all of the inputs required to sustain an entire national economy?"



At the end of the previous lecture we briefly talked about National Emprice

And suggested that it was computed by dividing the total emergy driving an economy by the economy;s GDP

Now we're going to look deeper at the emergy basis of national economies.

From an emergy perspective, a nation is much more than a collection of businesses or a measure of GDP.

It is a large, integrated system composed of the environment, technology, and society, all interacting continuously.

On the left, renewable energies support forests, agriculture, water resources, mineral formation, and all of the natural capital upon which the economy depends.

That natural capital is transformed by technology into buildings, machines, transportation systems, and other physical assets. Physical capital,

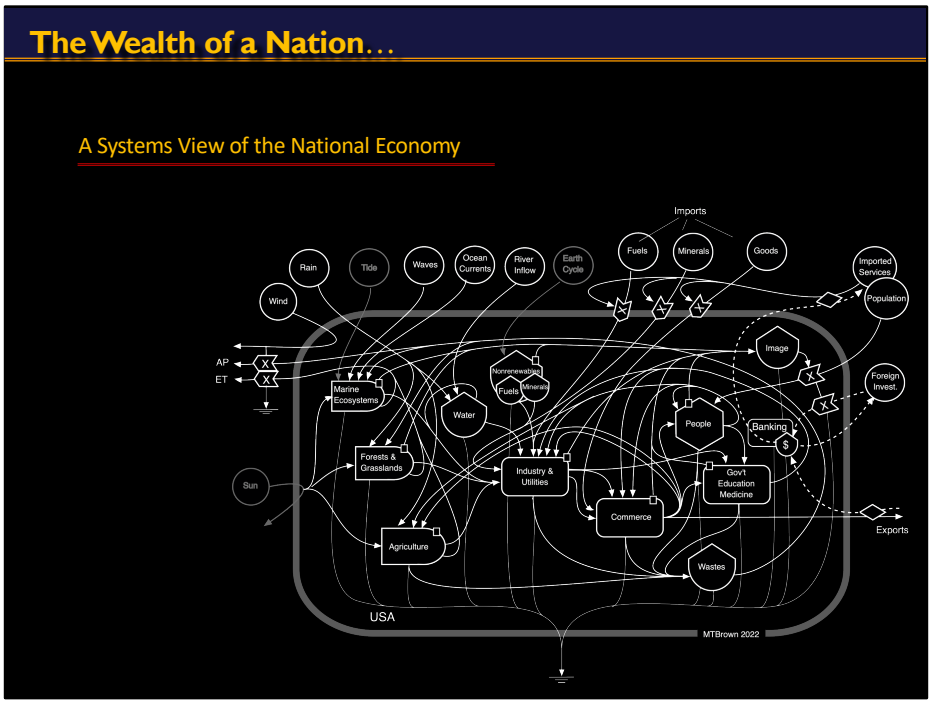
These, in turn, support people, institutions, education, commerce, and the exchange of information that make up society. What might be called social capital

Notice that all three forms of capital are connected. Natural capital supports physical capital. Physical capital supports human activity. Human knowledge and institutions influence how natural resources are managed and how technology develops.

The entire nation also exchanges goods and services with the outside world through imports and exports, while wastes are returned to the environment.

This figure provides a conceptual map of the system we will evaluate.

In the next slide, we replace this simplified picture with a full systems diagram that traces the major emergy flows supporting a modern national economy



A complete systems model of the United States.

Don't worry about every symbol or every pathway. Look at the overall organization.

Along the top are the major external inputs that support the nation.

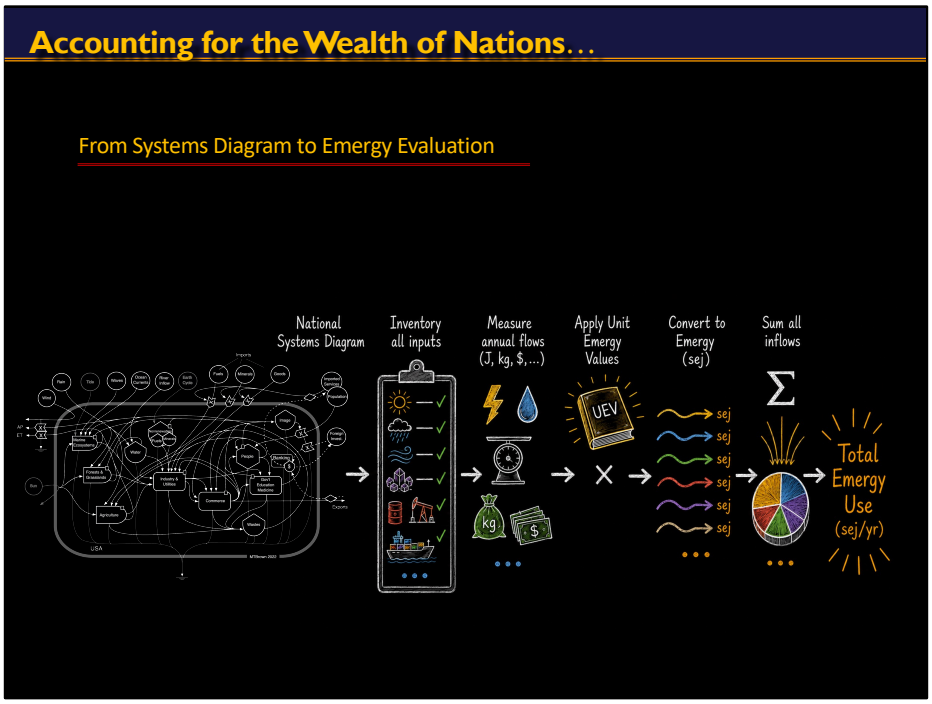
Within the national boundary, these resources support a network of interconnected sectors.

Notice that nothing operates independently. Every sector depends on the others through continuous exchanges of energy, materials, goods, services, and information. The economy is not a linear chain of production—it is an interacting network of feedbacks.

Finally, the nation exchanges resources with the rest of the world through imports and exports, while degraded energy leaves the system as heat and wastes return to the environment.

This diagram serves as the blueprint for national emergy accounting.

Our task throughout the rest of this lecture is simply to measure the emergy flowing along these pathways and determine how much environmental support is required to sustain an entire national economy.



An emergy evaluation always begins with a systems diagram.

The systems diagram identifies every important input supporting the nation.

Once those inputs have been identified, each one is measured in its natural physical units. Energy is measured in joules, materials in kilograms, and services in dollars.

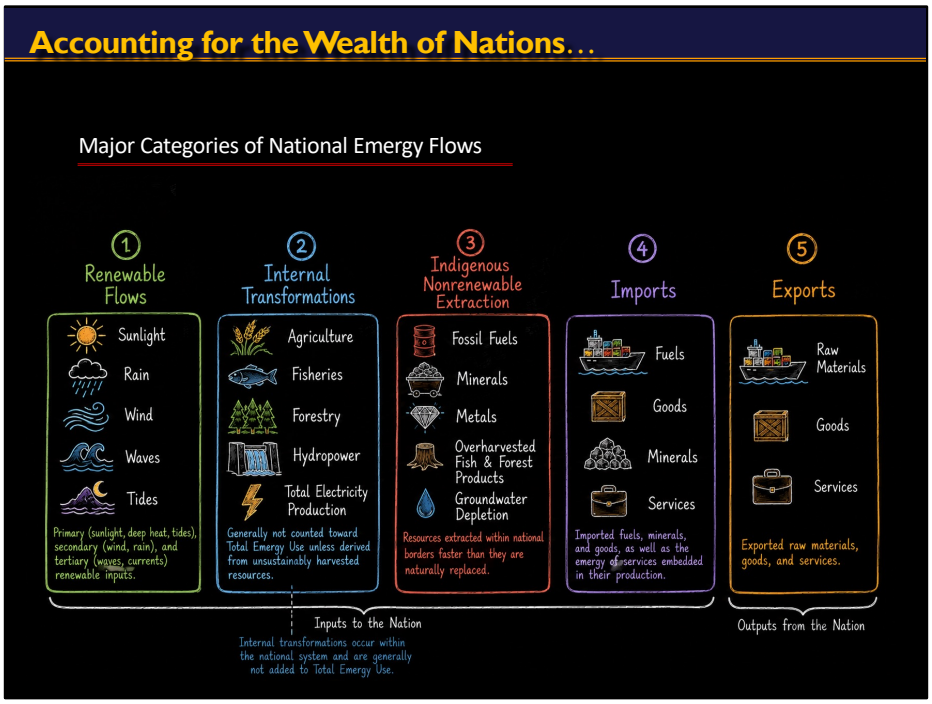
Next, each flow is multiplied by its appropriate Unit Emergy Value. This converts every input into a common unit—solar emjoules.

Now something remarkable happens. Resources that cannot normally be compared—sunlight, rainfall, minerals, fuels, imported goods, labor, and services—are all expressed in exactly the same units.

Because every flow has been converted to solar emjoules, they can now be added together.

The result is the **Total Emergy Use** of the nation: the total environmental support required each year to sustain that economy.

Although a national economy is enormously complex, the accounting procedure is exactly the same one we used earlier to evaluate a single product. The only difference is the scale. Instead of accounting for dozens of flows supporting one product, we now account for hundreds of flows supporting an entire nation."



Although a national emergy evaluation may contain hundreds of individual line items, nearly all of them fall into five major categories.

The first category is renewable flows.

The second category is internal transformations. These include agricultural production, forestry, fisheries, hydropower, and electricity generation. These are important parts of the national economy, but they are generally **not** counted toward Total Emergy Use because they are transformations of resources that have already been accounted for. The exception occurs when these products are obtained by depleting natural capital, such as overharvested forests, fisheries, or groundwater. In those cases, the emergy is counted as nonrenewable extraction.

The third category is **indigenous nonrenewable extraction**. These are resources taken from within the nation's own territory faster than they are naturally replaced. They include fossil fuels, minerals, metals, and other forms of natural capital depletion.

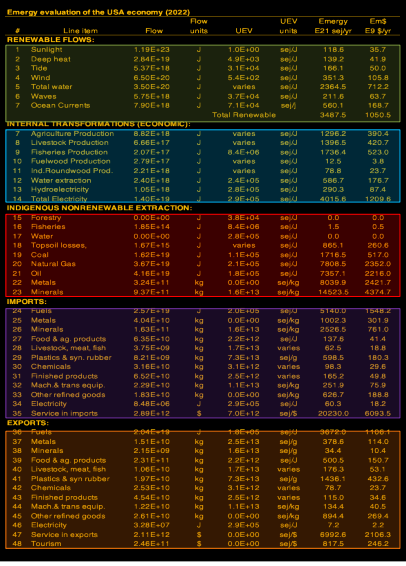
The fourth category is imports. Nations receive fuels, minerals, manufactured goods, and services from other countries. Each imported product carries with it the emergy required for its production and therefore contributes to the environmental support of the national economy.

Finally, there are exports. These include raw materials, manufactured goods, and services sold to other nations. Exports represent emergy leaving the national economy and becoming part of the support of economies elsewhere.

These five categories provide the organizational framework for every national emergy evaluation."

Accounting for the Wealth of Nations…

Emergy Evaluation Table

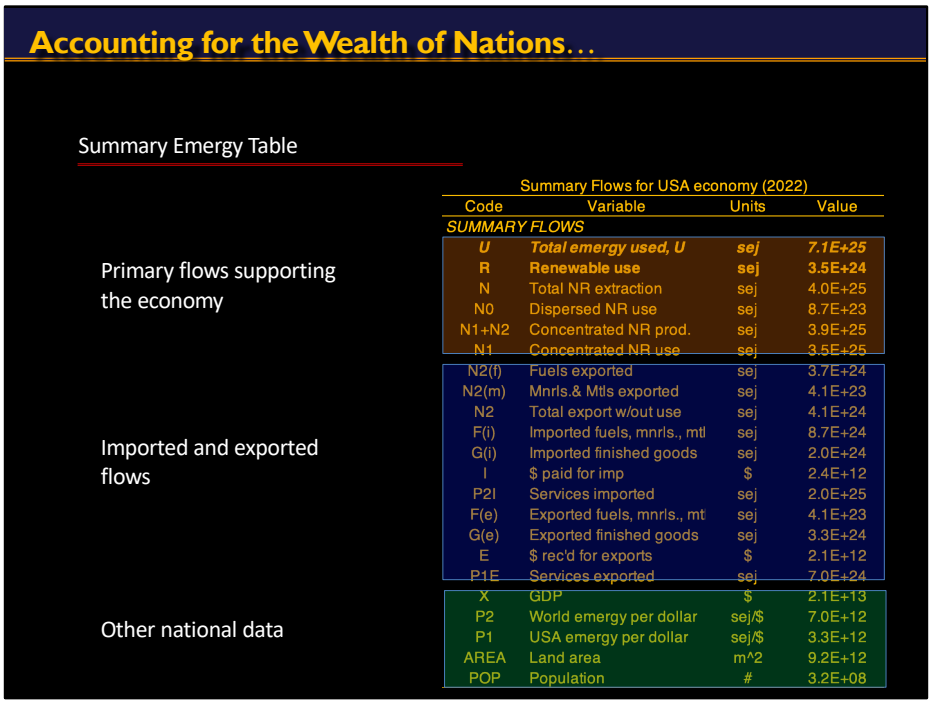


Emergy evaluation of the USA economy (2022)

#	Line Item	Flow	Flow units	UEV	UEV units	Emergy E21 sej/yr	Em$ E9 $/yr
RENEWABLE FLOWS:							
1	Sunlight	1.19E+23	J	1.0E+00	sej/J	118.6	35.7
2	Deep heat	2.84E+19	J	4.9E+03	sej/J	139.2	41.9
3	Tide	5.37E+18	J	3.1E+04	sej/J	166.1	50.0
4	Wind	6.50E+20	J	5.4E+02	sej/J	351.3	105.8
5	Total water	3.50E+20	J	varies	sej/J	2364.5	712.2
6	Waves	5.75E+18	J	3.7E+04	sej/J	211.8	63.7
7	Ocean Currents	7.90E+18	J	7.1E+04	sej/J	560.1	168.7
				Total Renewable		3487.5	1050.5
INTERNAL TRANSFORMATIONS (ECONOMIC):							
7	Agriculture Production	8.82E+18	J	varies	sej/J	1296.2	390.4
8	Livestock Production	6.66E+17	J	varies	sej/J	1396.5	420.7
9	Fisheries Production	2.07E+17	J	8.4E+06	sej/J	1736.4	523.0
10	Fuelwood Production	2.79E+17	J	varies	sej/J	12.5	3.8
11	Ind.Roundwood Prod.	2.21E+18	J	varies	sej/J	78.8	23.7
12	Water extraction	2.40E+18	J	2.4E+05	sej/J	586.7	176.7
13	Hydroelectricity	1.05E+18	J	2.8E+05	sej/J	290.3	87.4
14	Total Electricity	1.40E+18	J	2.9E+05	sej/J	4015.6	1209.8
INDIGENOUS NONRENEWABLE EXTRACTION:							
15	Forestry	0.00E+00	J	3.8E+04	sej/J	0.0	0.0
16	Fisheries	1.85E+14	J	8.4E+06	sej/J	1.5	0.5
17	Water	0.00E+00	J	2.9E+05	sej/J	0.0	0.0
18	Topsoil losses,	1.67E+15	J	varies	sej/J	865.1	260.6
19	Coal	1.62E+19	J	1.1E+05	sej/J	1716.5	517.0
20	Natural Gas	3.67E+19	J	2.1E+05	sej/J	7808.5	2352.0
21	Oil	4.16E+19	J	1.8E+05	sej/J	7357.1	2216.0
22	Metals	3.24E+11	kg	0.0E+00	sej/kg	8039.9	2421.7
23	Minerals	9.37E+11	kg	1.6E+13	sej/kg	14523.5	4374.7
IMPORTS:							
24	Fuels	2.57E+19	J	2.0E+05	sej/J	5140.0	1548.2
25	Metals	4.04E+10	kg	0.0E+00	sej/kg	1002.3	301.9
26	Minerals	1.63E+11	kg	1.6E+13	sej/kg	2526.5	761.0
27	Food & ag. products	6.35E+10	kg	2.2E+12	sej/J	137.6	41.4
28	Livestock, meat, fish	3.75E+09	kg	1.7E+13	varies	62.5	18.8
29	Plastics & syn. rubber	8.21E+09	kg	7.3E+13	sej/g	598.5	180.3
30	Chemicals	3.16E+10	kg	3.1E+12	varies	98.3	29.6
31	Finished products	6.50E+10	kg	2.5E+12	varies	165.2	49.8
32	Mach.& trans equip.	2.29E+10	kg	1.1E+13	sej/kg	251.9	75.9
33	Other refined goods	1.83E+10	kg	0.0E+00	sej/kg	626.7	188.8
34	Electricity	8.48E+08	J	2.9E+05	sej/J	60.3	18.2
35	Service in imports	2.89E+12	$	7.0E+12	sej/$	20230.0	6093.5
EXPORTS:							
36	Fuels	2.04E+19	J	1.8E+05	sej/J	3672.0	1106.1
37	Metals	1.51E+10	kg	2.5E+13	sej/g	378.6	114.0
38	Minerals	2.15E+09	kg	1.6E+13	sej/g	34.4	10.4
39	Food & ag. products	2.31E+11	kg	2.2E+12	sej/J	500.5	150.7
40	Livestock, meat, fish	1.06E+10	kg	1.7E+13	varies	176.3	53.1
41	Plastics & syn rubber	1.97E+10	kg	7.3E+13	sej/g	1436.1	432.6
42	Chemicals	2.53E+10	kg	3.1E+12	varies	78.7	23.7
43	Finished products	4.54E+10	kg	2.5E+12	varies	115.0	34.6
44	Mach.& trans equip.	1.22E+10	kg	1.1E+13	sej/kg	134.4	40.5
45	Other refined goods	2.61E+10	kg	0.0E+00	sej/kg	894.4	269.4
46	Electricity	3.28E+07	J	2.9E+05	sej/J	7.2	2.2
47	Service in exports	2.11E+12	$	0.0E+00	sej/$	6992.6	2106.3
48	Tourism	2.46E+11	$	0.0E+00	sej/$	817.5	246.2

This is what a national emergy evaluation actually looks like.

Although there are nearly fifty accounting entries, notice that every line belongs to one of the five categories we discussed on the previous slide



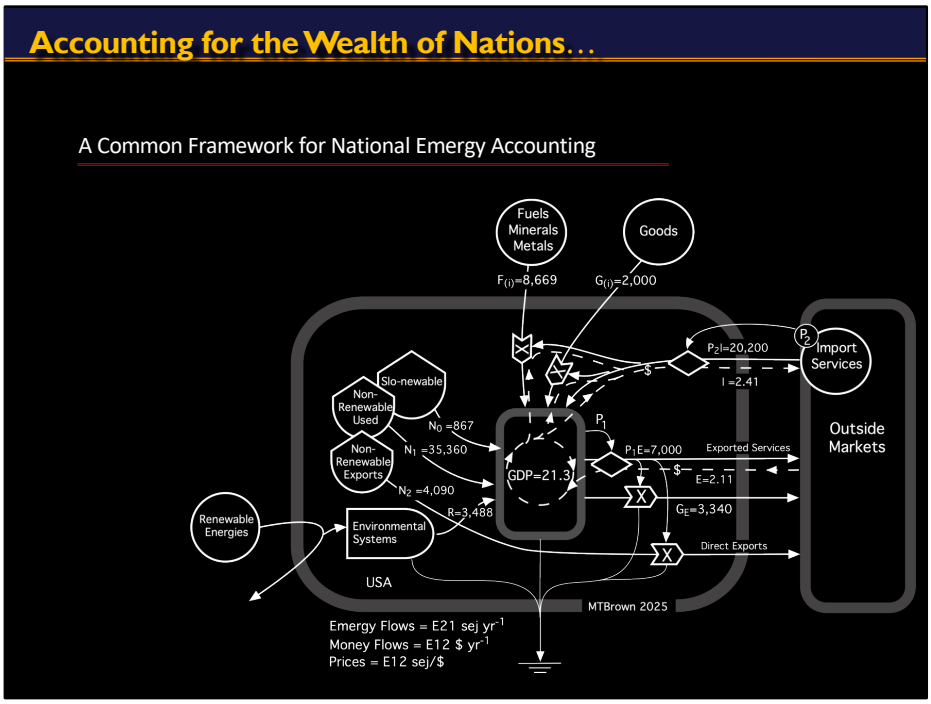
Although the complete emergy evaluation may contain dozens of individual accounting entries, those results are ultimately condensed into a standard summary table.

This summary reports the key quantities needed to describe and compare national economies. Every emergy evaluation is encouraged to use the same set of variables and symbols so that results from different nations can be compared directly.

The first group summarizes the Primary emergy flows supporting the economy, including total emergy use, renewable resources, indigenous nonrenewable extraction, imports, and exports.

The second group summarizes Imports and Exports

The remaining entries describe other characteristics of the nation, such as Gross Domestic Product, the national emprice, land area, and population.



The summary table gives us a standardized list of variables.

This diagram shows how those variables are connected within the national economy.

Renewable resources enter from the environment,

nonrenewable resources are extracted from natural capital,

imported goods and services enter from international markets, and exports leave the nation.

Money flows in the opposite direction to emergy, just as we observed in individual market transactions.

Together, the summary table and the summary diagram provide a common framework for reporting national emergy evaluations. Because every country can be represented using the same variables and the same diagram, meaningful comparisons become possible."

Accounting for the Wealth of Nations…

National Emergy Indicators

Emergy Indices for the USA Economy (2022)

Variable	Units	Calculation	Value
Total emergy used, U	sej	*R+N0+N1+F(i)+G(i)+P2I*	7.1E+25
Renewable emergy flow	sej	R	3.5E+24
Flow from indigenous nonrenew resei	sej	N	4.0E+25
Flow of imported emergy	sej	F(i) + G(i) + P2I	3.1E+25
Total exported emergy	sej	F(e) + G(e) + P1E	1.1E+25
Imports minus exports	sej	[F(i) + G(i) + P2I] - [F(e) + G(e) + P1E.]	2.0E+25
Imports to Exports	-	[F(i) + G(i) + P2I] / [F(e) + G(e) + P1E.]	2.9
Imports to Exports (excl. services)	-	[F(i) + G(i)] / [F(e) + G(e)]	2.8
Use per capita	sej/capita	U/pop	2.2E+17
Emergy Money Ratio	sej/$	U/GDP	3.3E+12
Fraction used, locally renewable	none	R/U	4.9%
Renewable percapita	sej/capita	R/pop	1.1E+16
NonRenew/capita	sej/capita	N/pop	4.0E+16
Fraction of use imported	none	[F(i) + G(i) + P2I] / U	43.8%
Areal Empower Intensity	sej/m^2	U / (area m^2)	7.7E+12
Environmental Loading Ratio (ELR)	-	[(N1+N0) +(F(i) + G(i) + P2I)}/R	19.2
Emergy Yield Ratio (EYR)	-	U / [F(i) + G(i) + P2I}	2.3
Environmental Sustainability Index		EYR/ELR	0.12

Finally, we combine the many flows and variables into a set of Indices shown in this table.

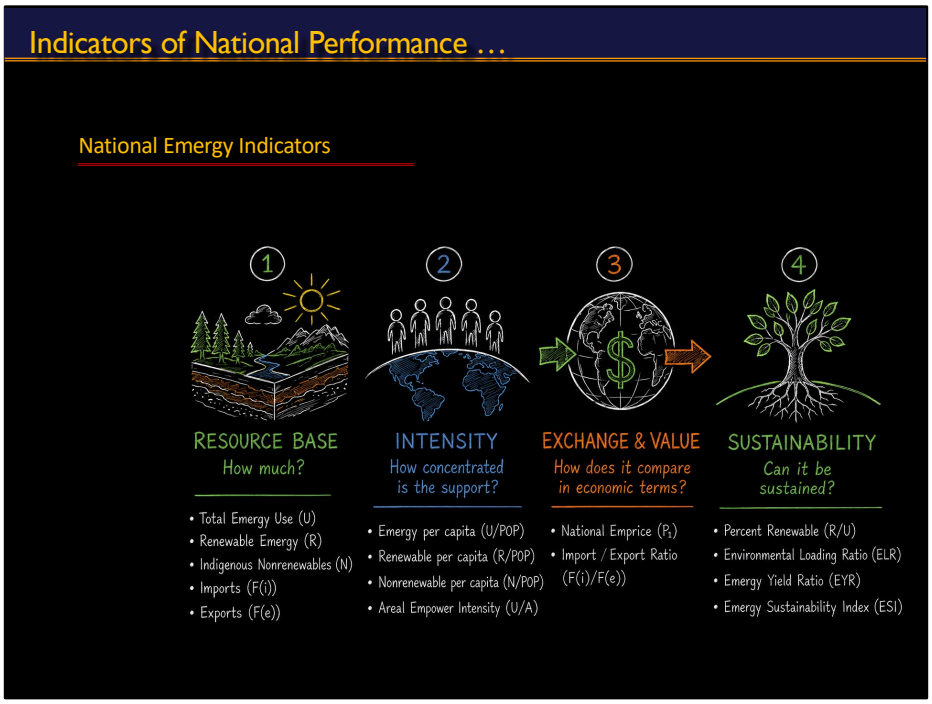
It to is a standard table so that comparison with other countries is facilitated

Every one of these quantities can be calculated from the national emergy account.

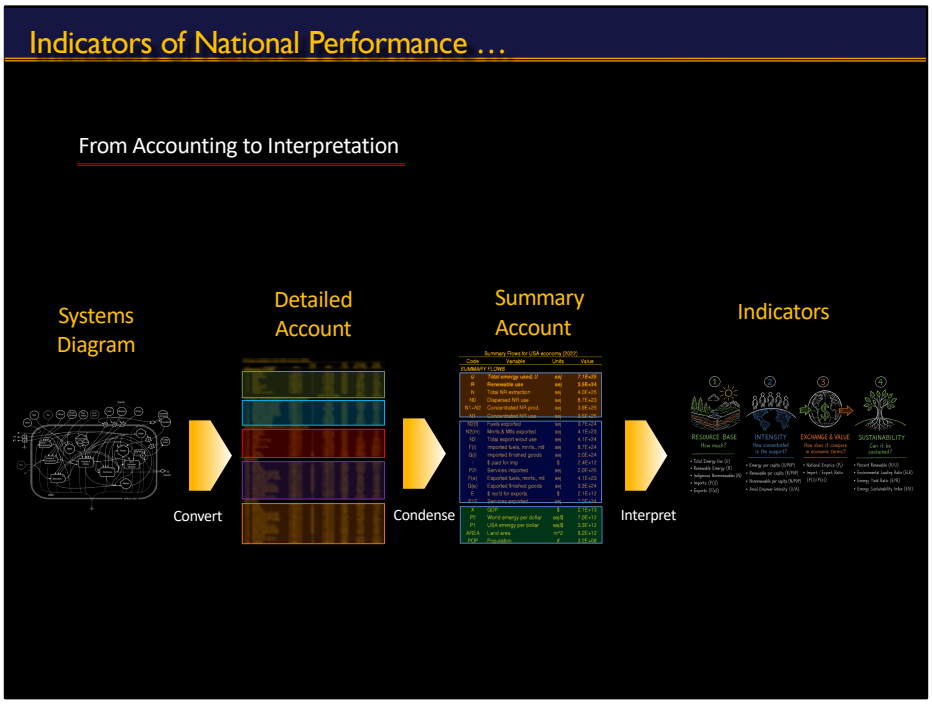
Some simply describe the size and structure of the economy,

while others evaluate its dependence on natural resources and its long-term sustainability.

We'll next explore what these indicators tell us.



There are four main categories of indices that help to judge national performance.



We have now completed the national emergy account.

Before moving on, let's review what we have accomplished.

We began with a systems diagram that identified every important flow supporting the nation.

Next, we measured each of those flows and converted them into a common unit of solar emergy.

The result was the detailed emergy evaluation table.

We condensed the flows into a standard summary table that groups the major categories of emergy support.

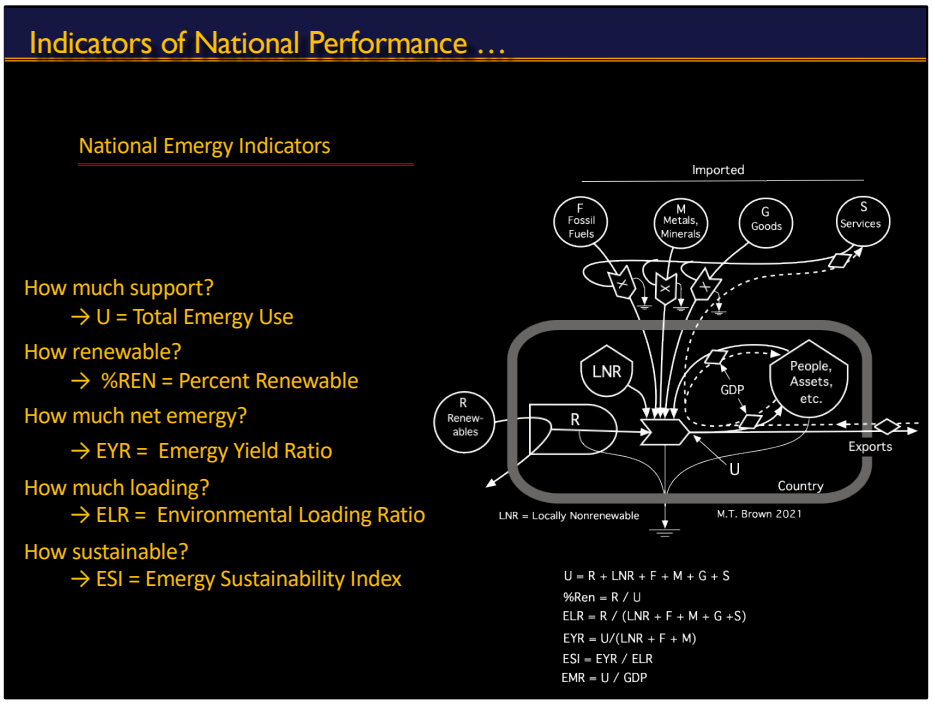
Finally, we combine the summary variables in different ways to create indicators that answer specific questions about the national economy.

In other words, each step simplifies the previous one while preserving its essential information.

We move from detailed accounting toward interpretation.

from this point forward…. We are no longer asking how to calculate the account

we are asking what the account tells us about a nation.

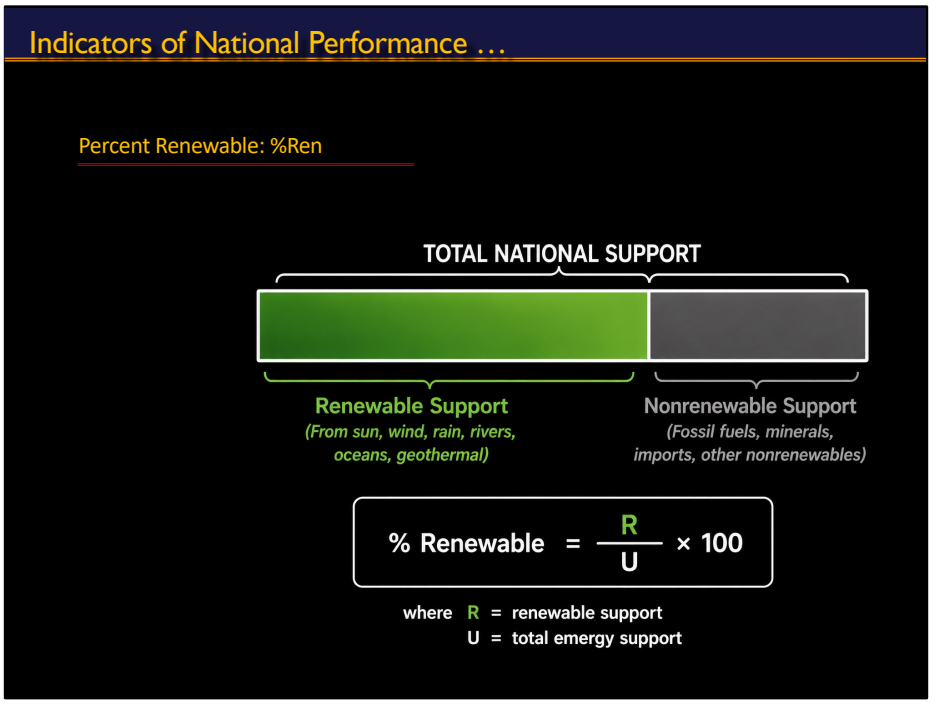


The next question is simple: **What do these numbers tell us?**

The equations shown here are not additional accounting.

They are simply different ways of interpreting the national emergy account.

Together, they transform a list of accounting values into measures that help us understand and compare national economies.



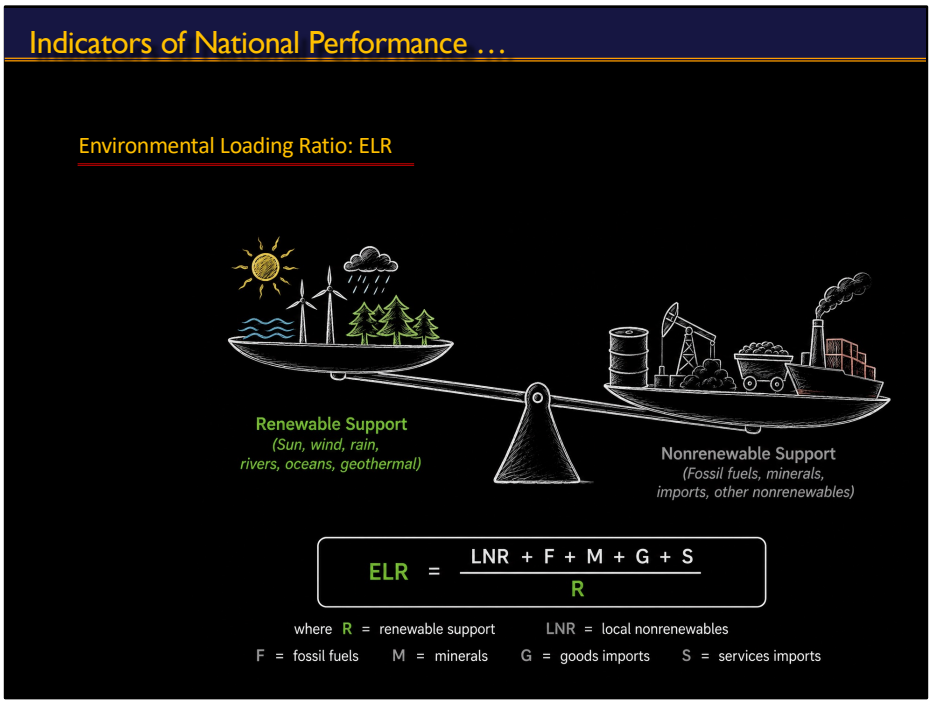
One of the simplest and most useful indicators is **Percent Renewable**.

It measures the fraction of a nation's total emergy support that comes from annual renewable environmental resources.

Most industrial economies rely heavily on fossil fuels, minerals, and imported resources. As a result, their Percent Renewable is often surprisingly small.

A higher Percent Renewable generally indicates that a nation's economy depends more on annually renewed environmental resources and less on the depletion of natural capital.

Because renewable resources are replenished each year, this indicator provides one of the simplest measures of the long-term sustainability of a national economy.



Percent Renewable tells us how much of a nation's support comes from renewable resources.

Environmental Loading Ratio asks a different question.

What is the Impact of the Economy on the Environment?

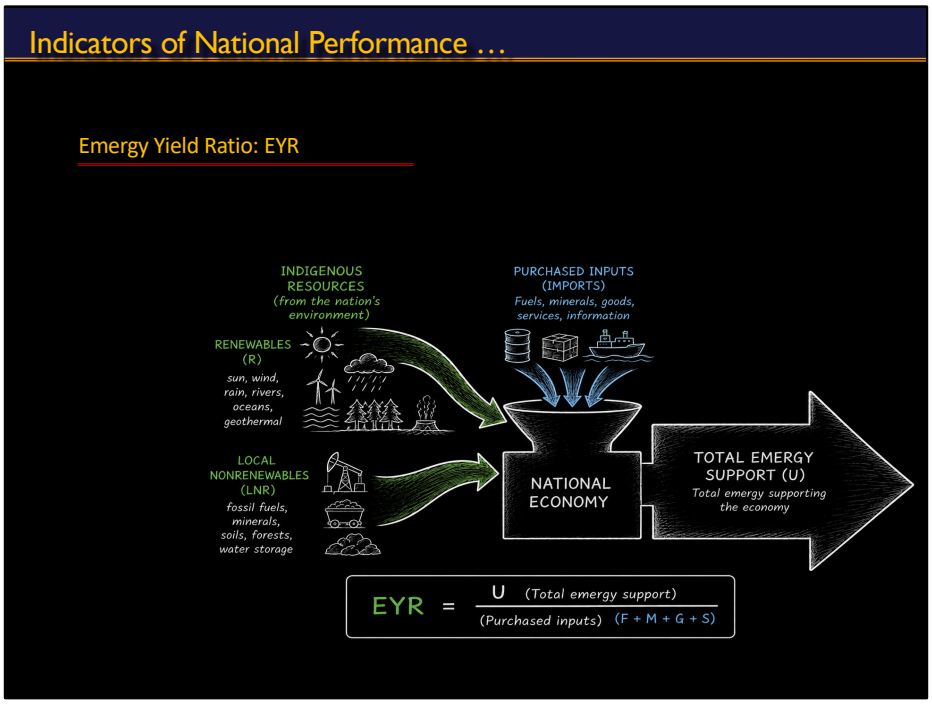
It measures how heavily the economy depends on nonrenewable resources and imported inputs relative to its renewable environmental support.

When most of the support comes from renewable resources, the loading ratio is low.

As dependence on fossil fuels, minerals, and imported resources increases, the loading ratio becomes larger.

A high Environmental Loading Ratio indicates that the economy places greater pressure on renewable environmental systems and depends increasingly on resources that are depleted or obtained from elsewhere.

For this reason, ELR is often interpreted as a measure of environmental stress or environmental loading.



Emergy Yield asks a different question.

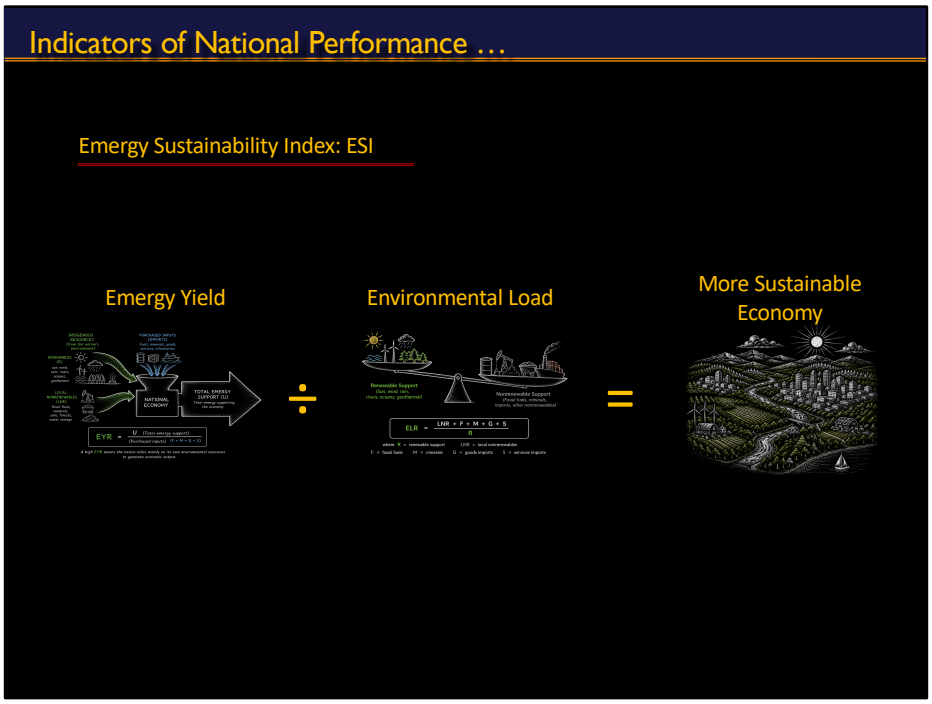
how much total emergy supports the national economy compared with the purchased resources entering from outside the country.

The Emergy Yield Ratio compares the total emergy supporting the economy with purchased inputs (Imports).

A nation with a high Emergy Yield Ratio relies primarily on its own environmental resources.

Conversely, a nation with a low Emergy Yield Ratio depends much more heavily on purchased resources from outside its borders.

Neither Emergy Yield nor Environmental Loading alone tells the whole story. The next indicator combines both.



The **Emergy Sustainability Index**, or **ESI**, combines the EYR and the ELR into a single measure.

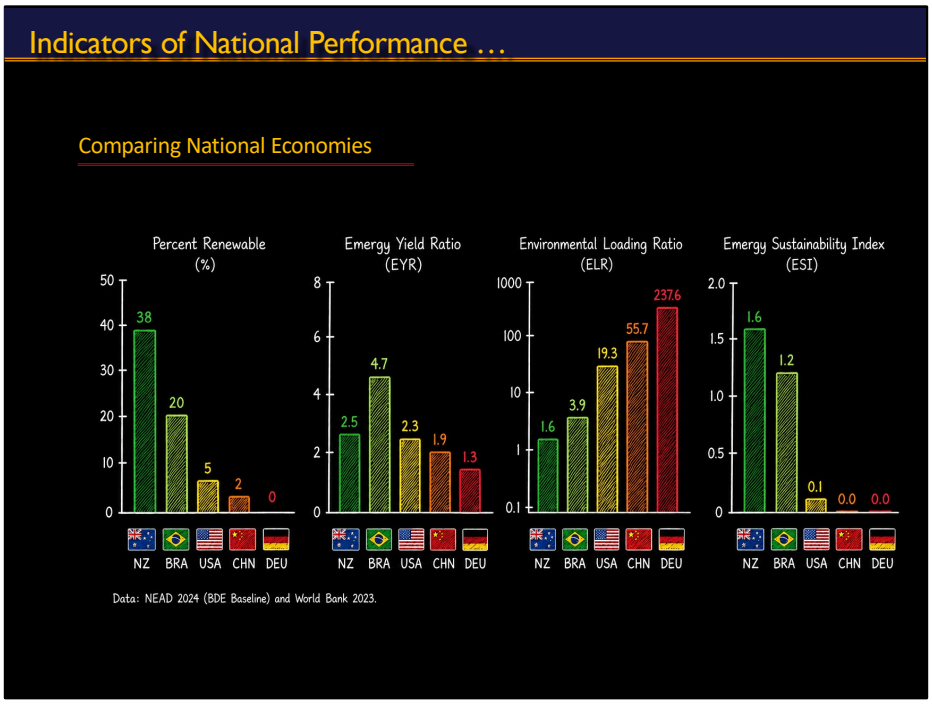
It is simply the Emergy Yield Ratio divided by the Environmental Loading Ratio.

A higher ESI indicates that a nation generates substantial emergy from its own resource base while maintaining relatively low environmental loading.

A lower ESI indicates either heavy dependence on nonrenewable support and a limited contribution from domestic resources…., or both.

The Emergy Sustainability Index does not predict the future.
Rather, it provides a way to compare the biophysical performance of different national economies using a common framework.

In other words, economies with high ESI make effective use of their own environmental resources without placing excessive pressure on them.



We can now compare countries using the same accounting framework.

Notice that countries differ greatly in their renewable support, emergy yield, environmental loading, and sustainability.

These differences reflect variations in natural resource endowment, population, climate, geography, and patterns of economic development.

In general highly industrialized nations have low %renewable, relatively low EYRs, High environmental loads and extremely low ESIs

Three principles guide the evaluation of national sustainability from an emergy perspective. A country is more likely to be sustainable when:

- it maintains sufficient emergy use per capita to sustain quality of life,
- a larger share of its total emergy inputs comes from renewable sources,
- it maximizes emergy yield. while
- minimizing its environmental load.

Several emergy-based metrics help assess these principles, including per capita emergy use, percent renewable, the Environmental Loading Ratio (ELR), the Emergy Yield Ratio (EYR.

National Sustainability…

UN Human Development Index

UN Human Development Index

Country	HDI Category
Belize	High
Bolivia	High
Fiji	High
Gabon	High
Guyana	High
Mauritius	High
Mongolia	High
Namibia	Medium
Argentina	Very High
Iceland	Very High
New Caledonia	Very High
The Bahamas	Very High

Although these countries differ greatly in geography and economic development, they share one important characteristic.

Each has access to abundant renewable resources relative to the demands placed upon them.

Some are small island nations surrounded by highly productive marine ecosystems.

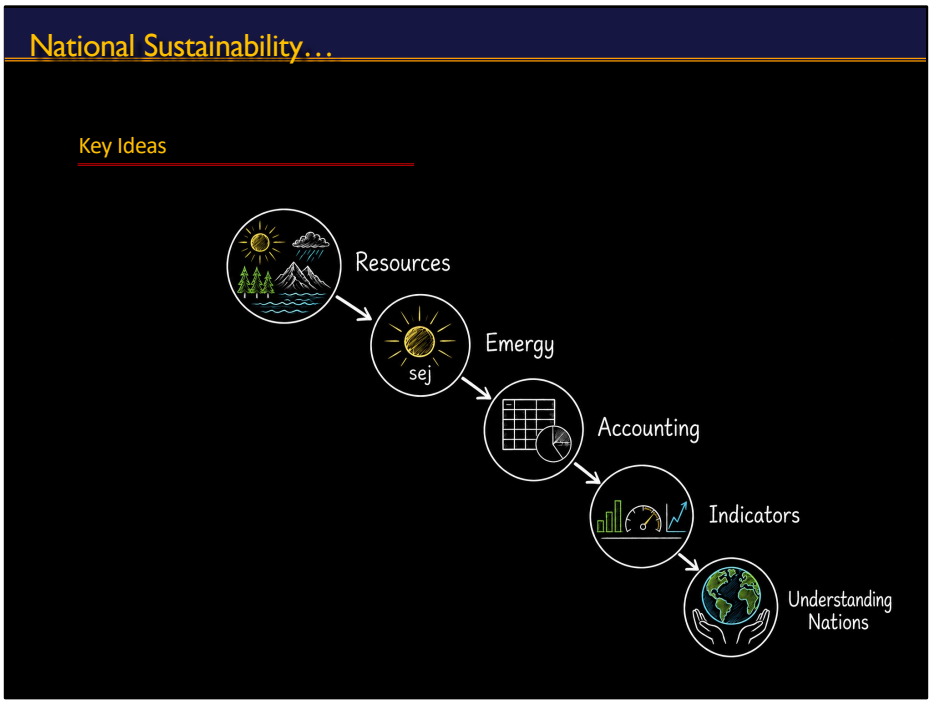
Others are large countries with abundant forests, rivers, or rangelands supporting relatively small populations.

Iceland represents yet another pathway, relying heavily on renewable hydroelectric and geothermal energy.

These examples illustrate an important principle.

There is no single route to national sustainability.

Different nations achieve favorable emergy profiles through different combinations of geography, renewable resources, population density, and patterns of resource use.



Throughout this lecture we have followed a single idea from beginning to end.

Nations are supported by environmental resources.

Emergy provides a common measure of those resources.

National accounting organizes that information into a standard framework.

Indicators transform the accounting into measures that describe the structure and performance of national economies.

Together, these tools allow us to compare countries on the basis of their biophysical support rather than economic output alone.

In the next lecture, we will apply this framework to national emergy accounts from around the world and examine the global patterns they reveal.

Thank You…

Thank You for Your Attention

感谢您的聆听