

2026 International Summer Course on Environmental and
Ecological System Engineering

Part A: Environmental Accounting and Systems Thinking
(EAST)

Lecture 1: Energy and System Organization

Mark T. Brown
Dept. Environmental Engineering Sciences
Center for Environmental Policy
University of Florida





Welcome to the 2026 International Summer Course on Environmental and Ecological System Engineering. My name is Mark Brown from the Department of Environmental Engineering Sciences at the University of Florida, and I will be leading the first portion of this course on environmental accounting and systems thinking.

I would like to begin by saying how much I regret that I cannot be with you in person. Circumstances have prevented me from traveling to China this year, and I would have much preferred to develop these lectures with you face-to-face.

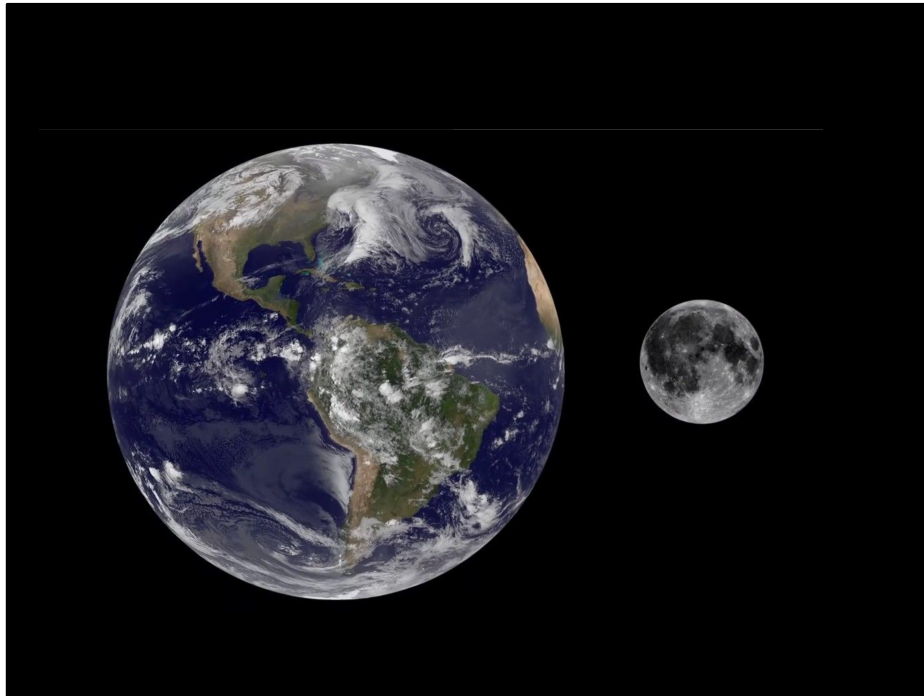
Although we will not meet in person, I hope these lectures will convey not only the ideas that we will explore together, but also some of the excitement and enthusiasm that I have developed for this field over many years of research and teaching. I have intentionally left time at the end of each lecture for discussion with your instructors because this material is best learned by asking questions, challenging ideas, and exploring concepts together.

With that in mind, let us begin by stepping back from the technical methods that we will develop later in the course. Before we discuss emergy, environmental accounting, or systems analysis, I would like us to consider a much broader question: Why do the natural and human systems around us become organized in the remarkable ways that they do?

Throughout this course we will examine systems that, at first glance, appear completely unrelated. We will study ecosystems and economies, rivers and cities, biological processes and human decision-making. Traditionally these subjects are taught as separate disciplines, each with its own concepts, methods, and vocabulary. Our goal will be quite different. We will look for the fundamental principles that unite them.

This opening lecture is intended to provide that perspective. Rather than introducing analytical methods, it asks a series of fundamental questions about organization, transformation, energy, and work. Those ideas will become the foundation upon which the remainder of the course is built.

Many of the ideas we will explore throughout this course were developed by the American ecologist H. T. Odum, who recognized that the same fundamental principles could be used to understand ecosystems, human societies, and their interactions.



Let us begin with something that is both familiar and remarkable.

The Earth and the Moon orbit the same Sun and formed from the same solar system approximately 4.5 billion years ago. Yet today they could hardly be more different. One is covered by oceans, forests, and an extraordinary diversity of life. The other is a world of rock, dust, and impact craters.

Planetary science provides convincing explanations for these differences. The Earth's greater mass allows it to retain an atmosphere, while the Moon's weaker gravity cannot. The Earth's magnetic field shields that atmosphere from the solar wind, and its distance from the Sun permits liquid water to exist over much of the planet's surface. Together these conditions created an environment capable of supporting life.

These explanations represent some of the great achievements of planetary science. However, they are not the questions that concern us in this course.

Our investigation begins after these conditions already exist. Suppose we have a planet that receives a continual supply of available energy and possesses the physical conditions necessary to support life. Why do organized systems emerge? Why do oceans circulate? Why do forests develop? Why do rivers organize into branching networks? Why do ecosystems, cities, and economies become increasingly complex?

Those are the questions that will guide the lectures that follow.

The Organized Planet



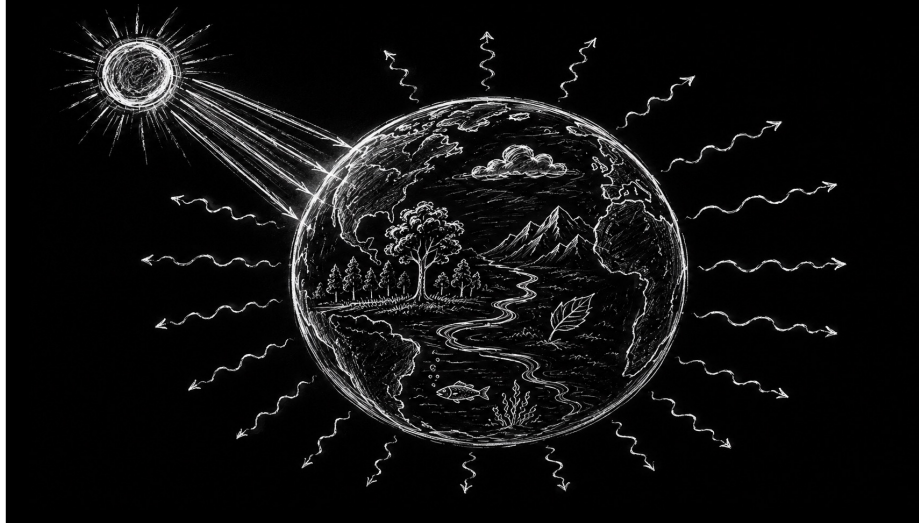
The remarkable feature of Earth is not simply that it possesses an atmosphere, liquid water, or life. Many planets have unusual and fascinating physical characteristics. What makes the Earth truly exceptional is the extraordinary degree of organization that exists throughout the planet.

Wherever we look we encounter organized systems. Water flows through rivers and drainage networks. Nutrients circulate through ecosystems. Living organisms build and maintain highly ordered tissues. Cities construct transportation, communication, and utility networks. Economies coordinate the activities of billions of people over vast distances. At first glance these systems appear to have very little in common. They belong to different scientific disciplines, operate at different scales, and involve completely different processes.

The central premise of this course is that these apparent differences are, in many ways, superficial. Beneath them lies a common set of organizing principles. Each of these systems requires continual inputs of energy and materials. Each transforms resources, performs work, and maintains organized structure through continual change. It is these shared characteristics—not the obvious differences—that will become the focus of our study.

The scientific discipline devoted to understanding these common principles is known as ****Systems Ecology****. Rather than concentrating on one particular kind of system, Systems Ecology seeks to understand how energy, materials, and information interact to produce organization across the natural and human world. That systems perspective provides the intellectual foundation for everything that follows in this course.

Why Doesn't Earth Run Down?



One of the most familiar observations in science is that organized structures tend to deteriorate with time. Buildings weather. Metals corrode. Machines wear out. Even mountains are gradually eroded by wind, water, and ice. Left to themselves, highly organized structures become progressively less organized.

This tendency is so universal that it forms the basis of one of the fundamental principles of thermodynamics. In isolated systems, order gradually gives way to disorder. Energy becomes less available to perform useful work, and organized structures eventually break down.

Yet the Earth appears to do something quite extraordinary.

For more than four billion years it has remained an active, organized planet. The atmosphere continues to circulate. Oceans continue to move. Forests grow. Ecosystems develop and persist. Life has not merely survived—it has evolved into increasingly complex forms of organization.

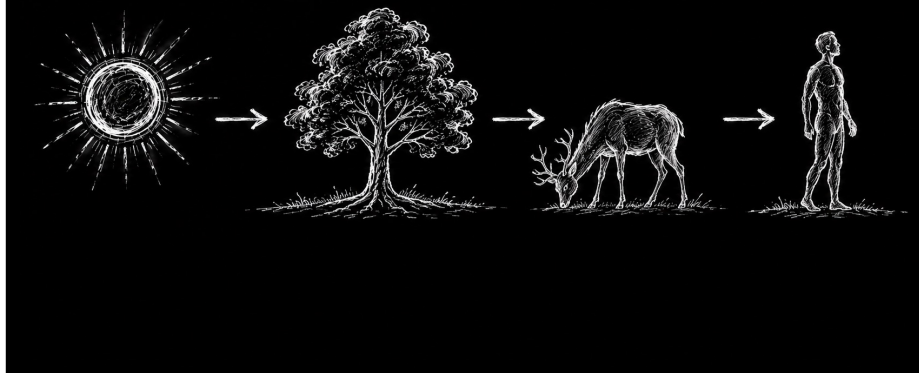
How can this be?

For many years I built small aquatic ecosystems in the laboratory. Each microcosm contained bottom sediments, water, aquatic plants, microorganisms, and small animals collected from nearby lakes. Once assembled, the systems were sealed. Nothing was added. No nutrients. No organisms. The only continual input was light, and controlled temperature.

At first I expected these miniature ecosystems to remain essentially unchanged. They did not. Neither did they collapse. Instead, they reorganized. Some species became more abundant. Others disappeared. Nutrient concentrations changed. The chemistry changed. The biological communities changed. Yet the systems remained alive and continued to function.

That experience taught me an important lesson. Living systems are not static. They persist because they continually reorganize themselves in response to changing conditions. Understanding how organized systems maintain themselves while constantly changing lies at the heart of Systems Ecology.

Living Systems



The answer begins with one of the most remarkable properties of life.

Among all the organized systems that we observe on Earth, living systems are unique. Rivers organize themselves. Hurricanes organize themselves. Even crystals develop highly ordered structures. But living systems possess an additional and extraordinary capability. They do not simply become organized—they actively maintain, repair, and reproduce that organization.

Every living organism is in a continual state of change. Cells divide. Proteins are synthesized and degraded. Molecules are replaced. In fact, many of the atoms that make up your body today were not part of your body just a few years ago. Yet despite this continual turnover, you remain the same individual. Your identity does not reside in particular atoms or molecules. It resides in the organization that those components continually create and maintain.

This observation illustrates one of the central ideas of Systems Ecology. Life is not best understood as a collection of objects. It is better understood as a dynamic network of processes. Matter continually enters and leaves the system, energy flows through it, and countless transformations occur every second. What persists is not the material itself, but the organization of that material.

This distinction is fundamental because it shifts our attention away from individual components and toward the processes that sustain them. Throughout this course we will repeatedly return to this perspective, because understanding organization rather than simply describing structure is one of the defining characteristics of Systems Ecology.

Organization in Ecosystems



Let us begin with one of the most familiar ecosystems on Earth—the forest.

To most people, a forest is simply a collection of trees. We notice the trunks, the leaves, the wildlife, and perhaps the beauty of the landscape. A systems ecologist, however, sees something much richer. A forest is not merely a collection of organisms; it is a highly organized system sustained by the continual movement and transformation of energy and materials.

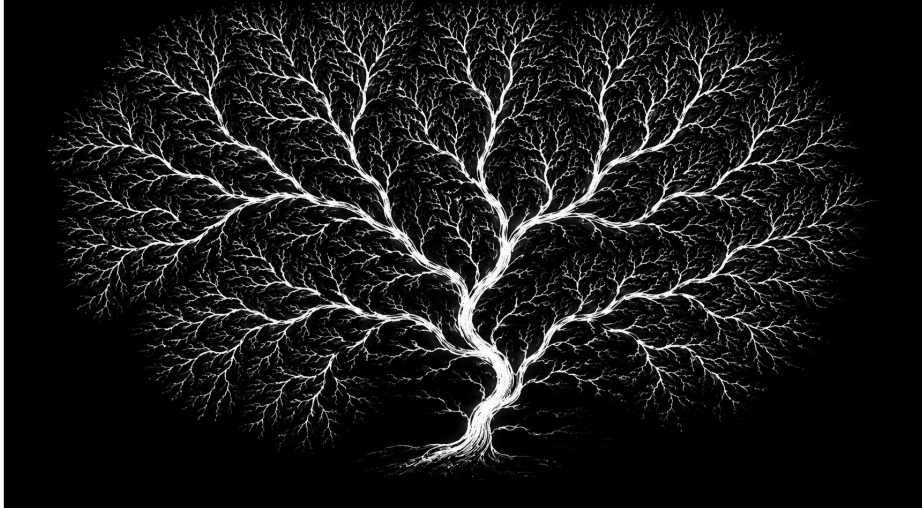
Every day, enormous quantities of sunlight enter the forest canopy. Only a very small fraction of that energy is captured through photosynthesis, yet that small fraction is sufficient to support an extraordinary web of life. It builds leaves, trunks, and roots. It supports fungi, insects, birds, mammals, and the countless microorganisms that inhabit the soil. Water moves continuously through the system, nutrients are recycled again and again, and the products of one organism become the resources for another.

Although the forest appears permanent, nothing within it remains exactly the same. Individual organisms are born, grow, reproduce, and die. Leaves fall. Trees decay. Nutrients return to the soil. New organisms take their place. The components are continually changing, yet the forest itself persists because its organization is continually renewed.

This change in perspective is one of the defining characteristics of Systems Ecology. Rather than seeing a forest as a collection of trees, we see it as a network of interacting processes. We follow the flow of energy, the cycling of materials, and the countless transformations that continually create and maintain the organization of the system. Traditional ecology often emphasizes the components of a system. Systems Ecology seeks to understand the relationships among those components and the processes that bind them together.

Many scientific disciplines begin by studying the individual components of a system. Systems Ecology complements that approach by emphasizing the relationships among those components and the processes that bind them together.

Self-Organization



The organization that we observed in a forest might appear to be a unique property of living systems. It is tempting to assume that organization requires life. Surprisingly, that is not the case.

Consider a river network.

Rivers are among the most familiar features of the Earth's surface, yet they display an extraordinary degree of organization. Small channels merge to form larger streams. Larger streams join to become rivers. The same branching pattern is repeated over and over again, from the smallest watershed to the largest river basin. Similar drainage networks develop on every continent, despite enormous differences in climate, geology, vegetation, and topography.

How does such a remarkably organized pattern arise?

No engineer designed these networks. There is no blueprint hidden beneath the landscape. Instead, the organization develops naturally as water flows downhill under the influence of gravity. As water moves, it erodes the soil, forming small channels. Those channels capture more water, increasing their erosive power. They deepen, widen, and connect with neighboring channels. Over time, a highly organized drainage network emerges without external direction or central control.

This phenomenon is known as ****self-organization****, and it is one of the central concepts of Systems Ecology. Order does not always require a designer. Under the right conditions, organization can emerge naturally from the interactions among the components of a system.

As we shall see throughout this course, rivers are not unique. The same principle appears repeatedly in physical, biological, ecological, and even human systems. Understanding how self-organization occurs is one of the first steps toward understanding how complex systems emerge, develop, and persist.

Energy Organizes Matter



The river illustrates that organization can emerge naturally from the interaction of relatively simple physical processes. Hurricanes demonstrate that the same principle operates on an even larger and more dynamic scale.

Most people think of a hurricane as a destructive storm. They remember the powerful winds, heavy rainfall, flooding, and damage left behind. A systems ecologist sees something quite different. A hurricane is one of the most remarkable examples of self-organization found anywhere in nature.

No one designed a hurricane. There is no central controller directing its development. What begins as a cluster of ordinary thunderstorms can, under the right conditions, organize into a highly structured system with a calm central eye, spiral rain bands, and powerful winds circulating around a common center. As this organization develops, the storm becomes increasingly effective at drawing warm, moist air inward near the ocean surface, lifting that air through the eyewall, releasing the latent heat stored in water vapor, and transporting the resulting energy outward through the upper atmosphere. In other words, the organization is not merely a pattern—it allows the hurricane to capture, transform, and redistribute energy far more effectively than an unorganized collection of thunderstorms. The storm behaves as a single, integrated system whose interacting components continually sustain and maintain its remarkable organization.

Where does this organization come from?

Ultimately, it comes from the Sun.

Not from the sunlight shining on the storm at that moment, but from solar energy that has been absorbed and stored by the tropical oceans over weeks and months. As warm ocean water evaporates, enormous quantities of available energy are stored as latent heat in water vapor. When that water vapor condenses into clouds and rain, the stored energy is released, driving the winds and maintaining the remarkable organization of the storm.

From a systems perspective, the hurricane is far more than an atmospheric disturbance. It is a highly organized heat engine that captures dispersed thermal energy, concentrates it into organized motion, and transports enormous quantities of heat from the tropics toward higher latitudes. Its structure exists because it performs that function efficiently.

This example illustrates another fundamental principle of Systems Ecology. Organization is not an end in itself. Organized systems develop because organization allows energy to be transformed and used more effectively. That idea will reappear throughout this course as we examine ecosystems, economies, and ultimately the concept of energy.

Organization at the Human Scale



If the principles we have discussed are truly fundamental, then they should not apply only to natural systems. They should also help us understand one of humanity's greatest achievements—the city.

Cities are among the most complex organized systems ever created. They contain millions of people, millions of buildings, transportation networks, communication systems, water supplies, wastewater treatment facilities, electrical grids, manufacturing centers, commercial districts, schools, hospitals, and governments. Each of these is an organized system in its own right. Together they interact to form an even larger system whose complexity far exceeds that of its individual components.

Yet there is another remarkable characteristic of cities. They do not appear randomly across the landscape. Throughout history, the world's great cities have developed where important flows naturally converge. Rivers. Natural harbors. Fertile valleys. Mineral resources. Transportation corridors. These locations concentrate the energy, materials, people, and information needed to support increasingly complex forms of organization.

Modern cities continue to evolve in much the same way. Highways, airports, electrical networks, and digital communications have changed the mechanisms by which resources are exchanged, but they have not changed the underlying principle. Cities develop where resources can be concentrated, transformed, and redistributed most effectively.

Like forests, rivers, and hurricanes, cities are self-organizing systems. They persist because they receive continual inputs of energy, materials, and information, and because their organization allows those resources to be transformed and distributed more effectively than would otherwise be possible.

This observation represents an important extension of Systems Ecology. The same principles that help us understand rivers and ecosystems also help us understand human settlements. Although the structures are different, the underlying processes are remarkably similar.

Organization Through Information



Our final example is perhaps the most abstract, but it is also one of the most important.

Unlike a forest, a river, or even a city, an economy has no obvious physical boundary. You cannot point to it on a map or observe it from an airplane. Yet every day we participate in it. We buy food, travel to work, communicate with one another, manufacture products, exchange services, and make countless decisions that collectively give rise to one of the most complex organized systems on Earth.

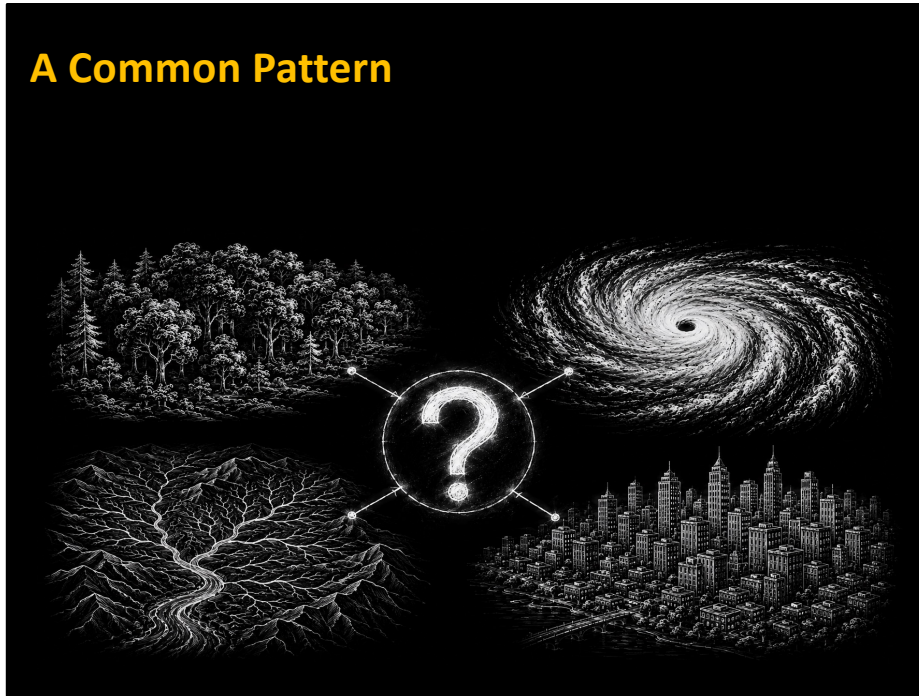
At first glance, an economy appears to be about money. Money is certainly important, but it is not the economy itself. Money is simply one means by which society coordinates the movement of resources. Beneath every financial transaction lies something much more fundamental: the transformation of energy, materials, labor, and information into goods and services that support human society.

Like every organized system we have examined today, an economy depends upon continual inputs. Food must be produced. Fuels must be extracted. Electricity must be generated. Materials must be transported. Information must be communicated. These countless transformations occur simultaneously and are coordinated through an extraordinary network of communication, markets, institutions, and human decision-making.

As societies become more complex, an increasing fraction of that organization is informational rather than physical. Decisions made in financial markets, government agencies, research laboratories, and communication networks influence the movement of materials and energy over enormous distances. Information becomes a mechanism for coordinating physical processes, but it never replaces them. Every product, every service, and every exchange ultimately depends upon continual flows of energy and materials.

From the perspective of Systems Ecology, an economy is therefore much more than a monetary system. It is a highly organized network of transformations that links the natural environment with human society. Understanding those transformations—and the energetic support required to sustain them—will become one of the central themes of this course.

A Common Pattern



Let us now step back and consider what we have observed.

We have examined a remarkably diverse collection of systems. Forests. Rivers. Hurricanes. Cities. Economies. At first glance these systems appear to have almost nothing in common. They belong to different scientific disciplines, operate at different spatial and temporal scales, and involve very different physical, biological, and social processes.

Yet when we examine them from a systems perspective, a very different picture begins to emerge.

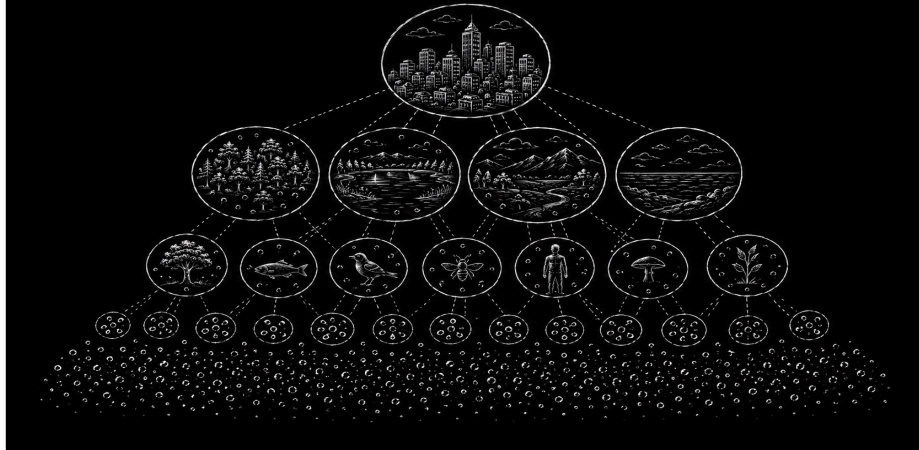
Every one of these systems requires continual inputs from its surrounding environment. Every one transforms energy and materials into new forms. Every one performs useful work. Every one develops and maintains organized structure through countless interacting processes. And every one persists because it continually reorganizes itself in response to changing conditions.

This is a profound observation because it suggests that organization itself may obey a common set of principles. Forests, rivers, hurricanes, cities, and economies are obviously different systems, yet they appear to be governed by remarkably similar processes.

That realization lies at the heart of Systems Ecology. Rather than studying each system in isolation, Systems Ecology seeks to identify the common principles that underlie all organized systems. Once we recognize those common patterns, we can begin developing a common scientific language capable of describing systems that, on the surface, appear completely unrelated.

The remainder of this lecture introduces several of those common principles. The remainder of this course develops the concepts and analytical tools needed to understand them in much greater depth.

Hierarchy



One of the most striking characteristics of organized systems is that they rarely exist at a single level. Instead, organization develops into a series of interconnected levels, each built upon the one below it.

Atoms combine to form molecules. Molecules become cells. Cells form tissues. Tissues become organisms. Organisms interact to form ecosystems. Human beings organize into families, communities, cities, economies, and nations. At every scale, smaller systems become components of increasingly larger systems.

This hierarchical organization is not accidental. Each level depends upon the levels below it for energy, materials, and support, while at the same time contributing new functions and new forms of organization to the levels above. The result is a nested structure in which every level is both a complete system in itself and a component of a larger system.

Hierarchy is one of the most fundamental organizing principles in Systems Ecology because it allows increasingly complex forms of organization to develop without losing their connection to the physical processes that sustain them. As organization increases, new properties emerge that cannot be understood simply by examining the individual components in isolation.

We have already seen this principle. A city is more than a collection of buildings. A forest is more than a collection of trees. An economy is more than a collection of individual transactions.

Throughout this course we will return to the concept of hierarchy many times. It provides one of the keys to understanding energy quality, transformity, emergy, and ultimately the organization of both natural and human systems.

Why Complexity?



Not all organized systems develop to the same degree. Some remain relatively simple throughout their existence, while others evolve into systems of extraordinary complexity. Understanding why this occurs is one of the central questions in Systems Ecology.

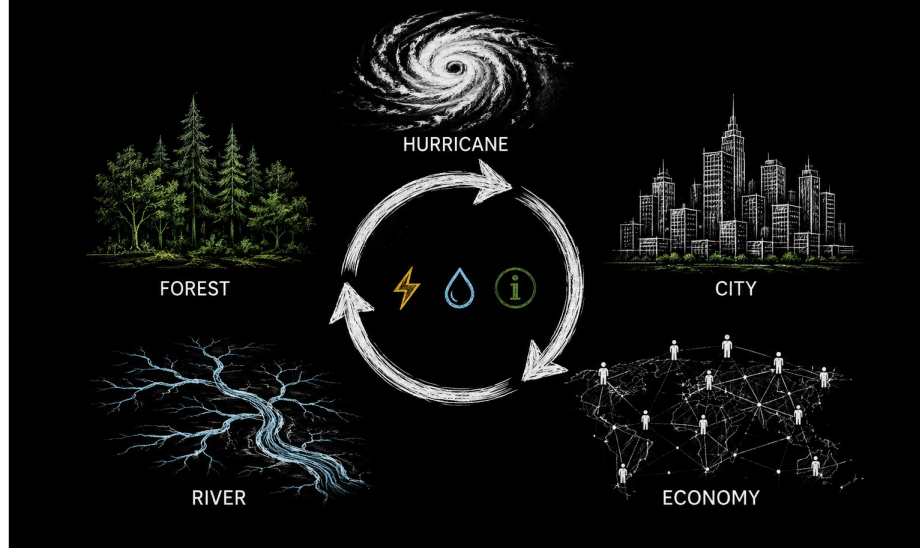
As organized systems develop, they often acquire new structures and new capabilities. They retain resources more effectively. They recycle materials more efficiently. They develop specialized components that perform different functions, and they establish increasingly intricate networks of interaction. The result is not simply greater complexity, but greater organization.

A mature forest provides a good example. Compared with a recently disturbed landscape, it contains more species, more interactions, more recycling pathways, and a far greater capacity to capture, store, and utilize available resources. Similarly, a modern city possesses transportation networks, communication systems, educational institutions, financial organizations, and countless other interacting components that allow it to perform functions impossible for a small village.

This increasing organization is not merely an accumulation of parts. It represents an increasing ability to capture, transform, distribute, and utilize available energy and materials. As organization increases, the capabilities of the system increase as well.

Throughout this course we will see that complexity is best understood not simply by counting components, but by understanding the relationships among those components and the functions they perform. Organization is valuable because it enables systems to accomplish more with the resources available to them.

What Drove Organization?



By this point, we can begin to recognize that the examples we have examined are not isolated phenomena. They are different expressions of the same underlying principles.

Hierarchy explains how organization develops across scales.

Increasing organization explains how systems become capable of performing increasingly sophisticated functions.

Yet these principles alone do not explain how organization is created or maintained.

To answer that question we must examine an even more fundamental idea.

Every organized system is continually transforming energy and materials.

Transformation is the universal process through which organization is built, maintained, and renewed.

It is this process of continual transformation that provides the bridge to the remainder of today's lecture.

The Transforming Universe



Having identified several common characteristics of organized systems, we can now ask a more fundamental question. What process is common to every organized system, whether it is a forest, a river, a hurricane, a city, or an economy?

The answer is transformation.

The universe is not a collection of static objects. It is a dynamic system in which matter, energy, and information are continually being transformed. Stars transform hydrogen into heavier elements. The Earth transforms solar radiation into winds, waves, rainfall, and biological production. Living organisms transform sunlight into biomass, food into movement, and information into action. Human societies transform natural resources into buildings, technologies, knowledge, and culture. Everywhere we look, one form becomes another.

Transformation is therefore not simply one process among many. It is one of the fundamental characteristics of the cosmos. Every organized system exists because it continually transforms available resources into new forms and new patterns of organization. The products of one transformation become the resources for the next, producing long chains of interconnected processes that link the geosphere, biosphere, and human economy into a single evolving system.

From the perspective of Systems Ecology, this observation changes the way we view the world. We no longer see forests, rivers, cities, or economies as collections of objects. Instead, we see networks of transformations connected by the continual movement of energy, materials, and information. Organization is not something that simply exists; it is something that is continually produced and continually renewed.

This conclusion brings us to another fundamental question. If transformation is the process by which organization develops, what makes transformation possible? To answer that question we must now turn our attention to energy.

Energy Drives Transformation



If transformation is the universal process through which organization develops, then an even more fundamental question immediately follows. What makes transformation possible?

The answer is energy.

Energy is often introduced in physics as the capacity to perform work. That definition is entirely correct, but from the perspective of Systems Ecology it represents only the beginning of the story. Energy is the driving force behind every transformation we have discussed throughout this lecture. Without a continual supply of available energy, transformations would cease, organization would gradually disappear, and every organized system would eventually decay.

Matter alone cannot create organization. The atoms that make up a forest are not fundamentally different from those that make up a desert. The atoms in a living organism are no different from those in the surrounding environment. What distinguishes an organized system is not the material from which it is built, but the continual flow of energy through that material. It is energy that drives movement, powers transformations, builds structure, and maintains organization.

This principle applies at every level of organization. Solar radiation drives atmospheric circulation, the hydrologic cycle, and photosynthesis. Chemical energy supports metabolism, growth, and reproduction. Fuels power transportation, manufacturing, and modern economies. Information systems themselves ultimately depend upon electrical energy generated from physical resources. Regardless of the system, organization can persist only so long as energy continues to flow through it.

This simple observation becomes one of the central themes of Systems Ecology. To understand any organized system, we must first understand the sources, pathways, and transformations of the energy that sustain it. That realization naturally leads to our next concept. If energy makes transformation possible, what does energy actually accomplish? The answer is work.

Work Creates Organization



We have now reached one of the most important concepts in this course. Before we can proceed further, we need to establish exactly what we mean by the word *work*.

In introductory physics, work is usually defined as the application of a force acting through a distance. That definition is entirely appropriate for mechanical systems, and it remains one of the cornerstones of classical mechanics. However, it is too restrictive for the broad range of physical, biological, ecological, and human systems that we wish to understand.

Throughout this course, we will adopt a more general systems definition. We will define *work* as a useful transformation of energy. Whenever energy is transformed work has been performed. The transformation produces a useful change in the organization or functioning of a system

This broader definition allows us to describe an extraordinary range of phenomena using a common conceptual framework. A river performs work by transporting sediments and reshaping the landscape. A forest performs work by transforming sunlight, carbon dioxide, and water into living biomass. Hurricanes perform work by transporting heat from tropical oceans toward higher latitudes. Cities perform work by transforming resources into buildings, transportation systems, and infrastructure. Economies perform work by transforming natural resources into goods, services, and information.

Viewed from this perspective, work is not simply motion or mechanical effort. Work is the fundamental process through which organization is created, maintained, and continually renewed. Every organized system that we have examined in this lecture exists because energy is continually being transformed into other forms of energy that are capable of driving more complex transformations.

This definition also provides a bridge to one of the central ideas of this course. If work creates and maintains organization, then every organized system embodies the cumulative results of countless energy transformations that have occurred over time. One of the primary objectives of energy analysis is to understand and quantify those transformations and the work they represent.

The Journey Ahead



Today we have taken the first step toward understanding the remarkable organization that surrounds us. We have seen that forests, rivers, hurricanes, cities, and economies are not simply collections of objects. They are organized systems sustained by continual flows of energy, materials, and information. Although they differ enormously in their structure and function, they share a surprising number of fundamental characteristics.

Recognizing these common characteristics is only the beginning. To understand organized systems scientifically, we need more than observations. We need a way to describe systems consistently, to follow the movement of energy and materials, to identify relationships among components, and to understand how organization develops across many different scales.

The next lecture begins that process. It introduces systems thinking and the Energy Systems Language developed by H. T. Odum. Together they provide a powerful conceptual framework for describing complex systems and understanding the interactions that sustain them.

As the course progresses, we will build upon that foundation. We will develop the concepts of energy quality, available energy, transformity, emergy, and environmental accounting. These ideas will allow us to examine ecosystems, economies, and the interactions between human society and the environment using a common scientific language.

By the end of this course, I hope you will find yourself looking at the world differently. Whether you are studying a forest, a river, a city, or an entire nation, I hope you will begin to recognize the common organizing principles that unite them and to appreciate the remarkable role that energy plays in shaping the natural and human world.

Understanding Organization



Throughout this course you will encounter many new concepts, methods, models, and analytical tools. Some will come from thermodynamics, others from ecology, engineering, economics, and environmental accounting. At times these subjects may appear quite different, and it may seem that we are moving in many different directions.

In reality, every lecture is directed toward the same objective.

We are trying to understand how organized systems emerge, develop, and persist.

Whether we are studying forests, rivers, hurricanes, cities, economies, or the biosphere itself, we are asking variations of the same fundamental scientific question. How does energy give rise to organization? How is that organization maintained? And how can we understand it within a common scientific framework?

I encourage you to keep these questions in mind throughout the course. If you do, the many concepts we will introduce—from systems thinking and the Energy Systems Language to transformity, energy, and environmental accounting—will gradually come together into a single, coherent understanding of the natural and human world.

I hope that, by the end of this course, you will not simply have learned a new analytical method. I hope you will have developed a new way of looking at the world—one that recognizes the common organizing principles shared by all complex systems, and the fundamental role of energy in creating, sustaining, and transforming them.

Thank you. I hope this course changes the way you look at the world.