If wishes were horses, Courts can give us all the *Shakti* we desire:

In reality how much energy can we have?

Sagar Dhara[1]

Two problems plague us today—environmental deterioration and economic inequity. Both have been caused by our overdrawing energy from nature and distributing it inequitable. Consequently, we face three tipping points—climate change, rapid deterioration of life support systems and peak oil, each having the potential of collapsing human society. To comprehend where we went astray, we must travel back 10,000 years to understand the history of the energetics of human society. This article explores the history of energy surplus—its creation and distribution, and attempts to answer the question of how much energy can each one of us have if we were to stay within earth's capacity to provide energy sustainably and were it distributed equitably.

Till I recently read the AP High Court order in Forum for Better Hyderabad Vs AP Government and Entertainment and Amusement Developers Pvt Ltd (Order in WP 7848 of 2003 passed on 20.7.2004), I was under the impression that humans could only degrade the environment. I stood corrected by the order, which quotes the developer's affidavit, ***"Waterfalls are being created to enhance natural features".*** The Forum filed a public interest litigation in the AP High Court praying that further encroachment and spoilage of the Hussain Sagar Lake and its environs be stopped as they apprehended this to happen because of the developer's plans to construct an entertainment park, *Jalavihar*, on the lake's banks. The Court ruled in the developer's favour; without explaining the meaning of *enhancing nature*, therefore tacitly agreeing with him. I wonder if the Court or anyone else can enlighten me on how Jalavihar or anyone can pull this trick off. And if it can be done, we would have solved our energy overshoot problem, if not the energy inequity one.

If wishes were horses, the AP High Court would wave its magic wand again and enhance nature's energy yield manifold to satisfy all our desires. And that would reduce pain from at least one of the two primary energy issues cause—energy collapse in the near future and energy inequity. And William Camden (1551-1623) would feel proud that his proverb, '*If wishes were horses, beggars could ride*', which broadly means it is more useful to act than to merely wish, has been given a modern twist. This could be one solution.

To arrive at more realistic solutions requires us to understand energetics of human society, or energy flows in human society. Why is it important to do that? Because, we are on the brink of a global civilazational collapse and anyone of three tipping points that stare us in the face could push over the cliff into a deep abyss and it will take us a long time to recover from that fall.

Tipping points

We face three tipping points today, each with the potential to collapse human society. The first is peak oil which has the potential of triggering a deep global recession in the near future. Alternative energy sources—nuclear and green—show bleak prospect of becoming viable replacements. The second is global warming, which is predicted to drastically impact the environment, human health and livelihoods. Humans have wonked the carbon cycle to such an extent that it won't get fixed for a long time to come. And the last is the recent rapid deterioration of the life support systems—land, water, air and biodiversity—the environment provides, as a consequence of its overuse.

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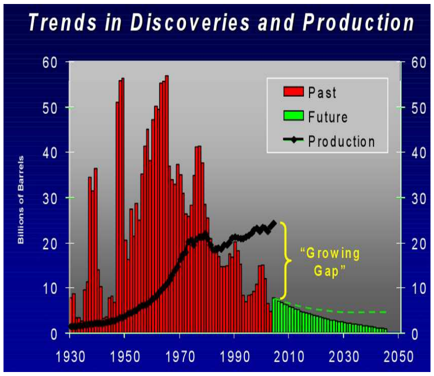
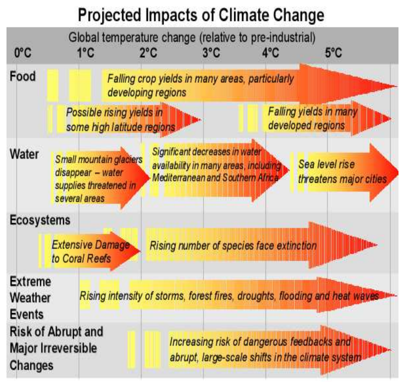
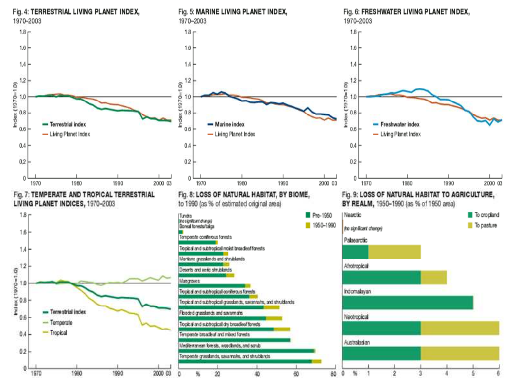
[1]The author belongs to the most rapacious predator tribe that ever stalked the earth—humans, and to a net destructive discipline—engineering, that has to take more than a fair share of the responsibility for bringing earth and human society to tipping points. You can write to him at: *sagdhara@gmail.com*

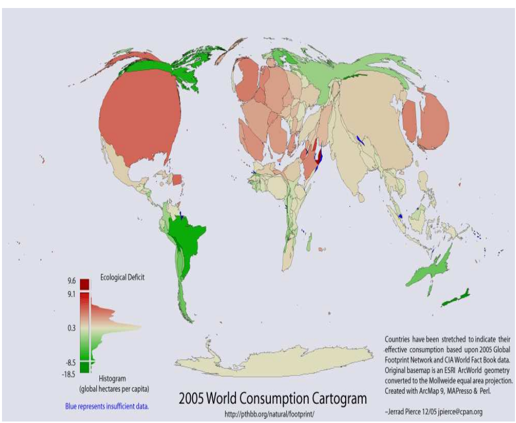
We now require 1.5 earths to satisfy our current consumption rates, and by 2015 if our consumption pattern persists, we will require two earths. We are consuming the earth's natural capital endowment rather than living off its "interest".

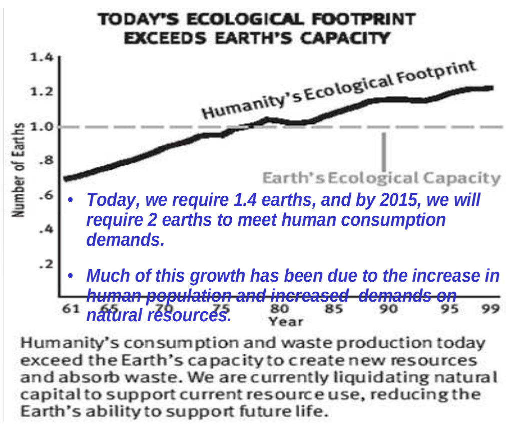






3 tipping points—Peak oil, Climate change, Rapid deterioration of environmental life support systems





Year	Percent income		
	Richest 25%	***Middle 50%***	***Poorest 25%***
1860	58%	30%	12%
1913	69%	25%	6%
1960	72%	25%	3%
	Richest 20%	***Middle 60%***	***Poorest 20%***
2000	74%	24%	2%

Inequity: A continuous ***widening inequity***—income, asset holding and energy consumption—has caused greater global instability and conflict.

Impacts: The likely impacts of the three tipping points are predicted to be very wide ranging:

- **Rise in mortality and morbidity** due to lack of work and consequent decrease in nutritional intake, spread of vector-borne diseases due to temperature rise, extreme weather events such as storms, floods, drought, and increased lawlessness;
- The **creation of environmental exiles** due to sea rise, drought, glacial lake outbursts, floods that will occur at increased frequency due to glacial melt, and extreme weather events;

- **Loss of food and water security and increase in hunger** due to temperature rise, precipitation and soil moisture changes, desertification, acidification of oceans and water bodies, and decrease in eco-system services as a consequence of degraded environment;
- **Loss of forests and biodiversity** due to energy price hikes, temperature and precipitation changes, increased incidence of forest fires, conversion of forests to other uses, and decrease in eco-system services as a consequence of degraded environment;
- **Loss of employment and work opportunities** due to energy price hikes and consequent disruption of the global economy;
- **Disruption of the global social and political order and consequently increased lawlessness** due to disruption of the global economy;
- **Increase in global conflict due to growing inequity.**

Each of these tipping points has the potential to radically alter human society as we know it today, and sadly we do not quite know how.

Energy

What is energy? The Greeks identified it with movement. *Shakti* the Sanskrit term for energy means *to able*. Much has been written on what is energy. But it is the Nobel Laureate Richard Feynman who sums it up succinctly by stating, "we have no knowledge of what energy is…. there are formulas for calculating some numerical quantities… it is an abstract thing and it does not tell us the mechanism or the reason for various formulas." So, we don't quite know what energy is.

However, we know what energy can do. It helps transform things from one state of being to another, eg, turns water into steam, causes lightening, powers natures cycles—hydrological, carbon, etc, grows a plant into a tree, transports humans over distances, and performs a myriad of other physical, chemical, geological and biological transformations. Shakti is understood to be the primordial cosmic energy that pervades the universe and is responsible for creation and change, even liberation.

Natural and social history is the fascinating story of the twists and turns that energy conversion has taken in the last 4.6 billion years of earth's existence. There are four primary energy sources available on earth—solar, geothermal, planetary and nuclear energies. The first three sources have shaped nature, and along with the fourth source, though only in the last half century, have shaped human society.

Solar energy, the most important energy source, has the largest flux, 173 W/m^2 at the earth's surface. It powers earth's climate—atmospheric circulation, hydrological cycle, and sustains life, primarily through photosynthesis and contributing to habitat maintenance of different species. At 90 mW/m^2, geothermal energy's flux is three orders of magnitude less than that of solar energy. It powers the re-creation of continents and oceans, causes earthquakes, volcanic eruptions, and tsunamis. Planetary energy caused by gravitational energy has a flux that is one-tenth that of geothermal energy and causes tides. Terrestrial nuclear energy is available almost entirely due to human intervention, and its impact on nature and society is almost entirely due human use of it.

There are several secondary energy sources that humans use. Until 500 years ago, biomass animate energy (humans and animals) were the two principle energy sources humans used. Biomass and animate energy are secondary energy sources derived from solar energy. Likewise wind that powered sailboats for centuries is derived from solar energy, and flowing water that powers watermills is derived from planetary energy.

Energy, whether from a primary or secondary source, comes in many forms, the most common forms being: kinetic, chemical, electro-magnetic, electrical, nuclear, magnetic, gravitation. Each of these energy forms is convertible into thermal energy, and some or all of the other energy forms.

Examples of energy conversion

Energy converter	**Energy conversion** From	**Energy conversion** To
Plants	Sunlight (Electro-magnetic)	Biomass (Chemical)
Humans	Food (Chemical)	Body tissue (Chemical, heat), Work (Kinetic)
Automobiles	Gasoline (Chemical)	Locomotion (Kinetic)
Motors	Electricity (Electrical)	Motion (Kinetic)

Energy converters are used to effect energy conversion. Some energy is lost in energy conversion.

Energy resources include five factors. The first is energy sources, eg, solar, animate, wind, fossil fuels (the last three being derivatives of solar energy), nuclear, etc. The second is energy conversion, which includes energy converters and energy conversion processes (draught animals, motors, power plants). The third is energy conveyance, which includes devices and processes (wheels, sails, power transmission lines, heat exchange by convection). The fourth is energy storage, including devices and processes (biomass, batteries). And the fifth is knowledge of energy availability and extraction, energy conversion, energy conveyance and energy use.

Changes in these factors are effected either by shifts in materials, eg, the replacement of stone implements by metallic ones or biomass and animate energy by fossil fuels, or by increasing the efficiency of energy converter and conveyance devices and processes, eg, the dramatic improvement in computer technology in the last quarter century. Such changes have affected the course of history very profoundly, eg, human migration patterns, shifts in production modes, eg, from hunter gatherer to primitive agriculture to traditional agriculture to industrial societies, discovery and conquest of new territories, wars, advances in communications, medicine, life sciences, information technology, space exploration.

A sixth factor which is not considered to be an energy resource but one which has influenced the course of history is the environment that provides the canvas for energy conversion.

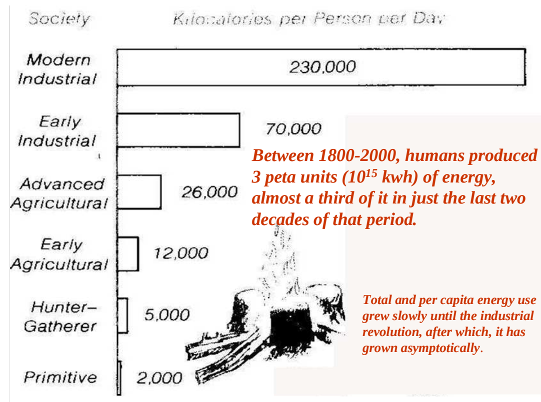
Humans combine all the five factors of energy resources in themselves. They are a secondary energy source, by converting food into heat and locomotion, they act as an energy converter, they use their hands and feet as tools to convey energy and they also create knowledge of energy use. Domesticated animals combine three of these factors—they are a secondary energy source, are an energy converter and are also energy storage devices. Sometimes, they also act as an energy conveyor, ie, a tool. Unlike humans, they lack the capability to create knowledge.

The application of energy resources to raw materials transforms them to products and services for human consumption. For example, a rig is used to pump oil out of an oil well, after which it is transported in pipelines to tanker ships, processed in a refinery and either used as a fuel, eg, gasoline, or further processed to make plastics, fertilizers and a host of other products. The entire process requires the use of energy sources—oil, electricity, energy converters—power plant, motors, pumps, energy conveyers—electrical wires used for electro-magnetic control of equipment and pipes with fluids used for pneumatic control of equipment, and knowledge of engineering the extracting, refining and manufacturing of petroleum and petrochemical products. Oil, the raw material, is thus transformed into products.

Energy used to make a product or service is known as embodied embodied energy. It is the total commerial energy—fossil fuel, animate, biomass, etc—required to produce a good or service, market it and dispose it after its life is over. Products have different embodied energies, eg, aluminum has about ten times the embodied energy as steel. Embodied energy is important to understand the energetics of human society.

All living beings are energy seekers, users and converters. Living beings other than humans take only as much as energy from nature as is required for survival and reproduction. Throughout history humans have improved their knowledge of energy extraction and conversion and have drawn increasing amounts of energy. An increasing fraction of this energy was surplus, ie, it exceeded the energy required for metabolism.

It is this surplus that propelled societies from one stage to the next, eg, from hunter-gatherer to primitive agriculture to traditional agriculture, etc.   As surplus grew so did society's appetite for it. Had energy surplus entitlements been distributed equitably or owned socially, class society would not have arisen, nor would the energy withdrawals have exceeded earth's capacity. However, social structures since slavery were fashioned to give inequitable energy surplus entitlements to a priveleged minority. The history of the creation of energy surpluses and their expropriation is central to understanding human development.

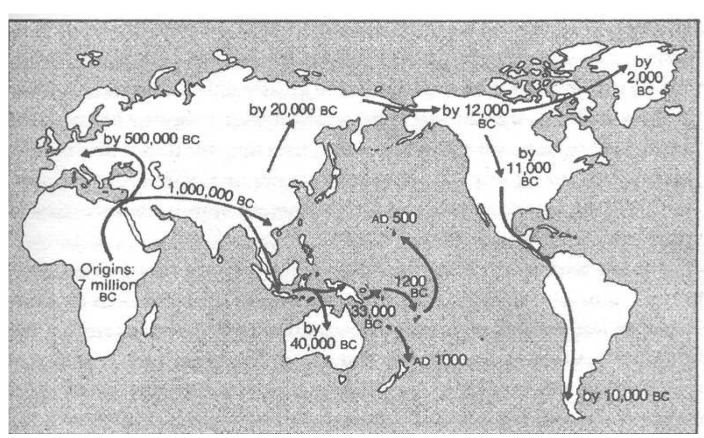


In this article, the classification of ages is by the major energy source used by humans during that period. The major human activity considered for discussion is one that provided the maximum energy surplus. For example, industrial society also did agriculture, but it was industry that provided a majority of the energy surplus.

Anthropo-energy age

The anthropo-energy age is when the main source of energy used by humans was their body. Hunting and gathering was the main activity by which humans obtained energy (food).

Through most of the Paleolithic and Mesolithic ages (1.8 Mya-10Kya)[2], gathering edible plants, fruits and nuts, scavenging and hunting were the principle means for proto-humans and their successor, *Homo sapiens*, to obtain food. To help them do this they fashioned crude tools from stone and bone—spears were used 40 Kya, bows and arrows, 25 Kya, fishing hooks, 12 Kya and fishing nets, 8 Kya, and learned to use fire to cook food, keep warm and keep wild ani-



[2] Mya-million years ago, Kya-Thousand years ago

mals at bay. The two most important energy sources were human energy and biomass and the two main energy converters were humans and a fireplace.

The spread of proto-humans and humans was towards areas that yielded more energy (food), eg, coastal areas and river valleys vegetation and game were plentiful. Proto-humans migrated from Africa to Eurasia about a million years ago, then to Europe 0.5 Mya.

Environmental barriers delayed the colonization of Australia and the Americas. It required mastery of watercraft to cross the 100 km sea channels between Asia and Australia, and this was done 40 Kya, for the sea channel to be crossed. The frosty wind-swept Siberia had to be crossed to reach Alaska, and the warmer lands beyond in America. That was possible only after humans learned to stitch warm clothing, which happened 14 Kya. By 12 Kya, Antarctica was the only continent that remained un-colonized by humans.

The fraction of human edible phytomass—fruits, nuts, tubers, certain leaves, etc—in natural ecosystem is small (other animals, eg, cattle, can digest lignin and cellulose which humans cannot). Likewise, game, even if plentiful requires considerable effort to catch or trap, particularly as some of it is arboreal. Hunters often had to follow migrating herds or move after exhausting available resources at one place. Consequently hunter-gatherers required large expansive areas to obtain the food they required, and this kept their population densities to 1-2 persons/km^2, or even lower.

Human activity creating maximum energy surplus during this age	**Chronology**		**Energy source**	**Energy conversion (converters/ processes)**	**Energy conveyance (devices/ processes)**	**Energy storage**	**Knowledge**	**Environmental factors**
	Age	**Period**						
Hunting-gathering	Paleolithic-Mesolithic ages	1.8 Mya-10 Kya	Human	Human (Chemical→thermal/ kinetic)	Hunting/cutting tools, boats	Humans	Tool making	Proto-humans and humans migrated towards areas that had high usable energy yields and low environmental barriers to get there, eg, deserts, seas, tundra, etc.
			Biomass	Fireplace (Chemical →thermal)	Flint stone	Biomass	Lighting & using fires	

Gathering food involved everyone in a band, barring the very young, old and infirm. Hunter-gatherer societies were nomadic people with virtually no hierarchy, but or private ownership of energy resources. Some have called them the *noble savages* and *primitive communists*. Hunter-gatherer societies exist to this day in remote parts of the world, eg, Andaman Islands, Borneo, the Amazon, the Arctic Circle, etc.

The per capita energy availability for hunter-gatherers is range between 7.5-12.5 GJ/a[3]. Energy surplus[4] of hunter-gatherer societies in arid regions was as low as 5 times the expended energy, and as high as 30 if tubers were harvested, the average for all regions being 10-20. This surplus energy was adequate for making tools, organize bands and for some leisure, but inadequate for division of labour and specialization to devel-

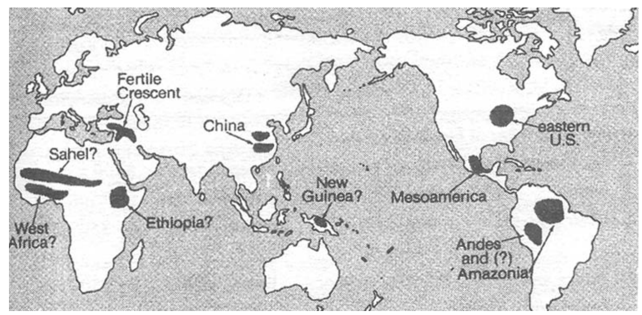
[3] GJ/a—Giga (10^9) Joules per annum
[4] Energy surplus can be defined in many ways. In this article, it is defined as the energy return on energy invested in an activity.

op. Without this energy surplus, hunter-gatherers would not have made the leap to the next social stage, ie, primitive agriculture in the Neolithic age.

Bio-energy age

Bio-energies consist of animate (human and animal) energy sources and biomass. In this age, besides using human-power, domesticated animals were used as a prime mover.

Agriculture began to be developed and it gradually replaced hunting-gathering as the prime activity that created the maximum energy surplus in the Neolithic age; and remained so for a very long time—10-0.5 Kya. Agriculture can be divided into several stages—primitive agriculture and pastoralism of the Neolithic age, traditional agriculture from the Iron age up to modern times and modern agriculture. Throughout its history, agriculture has provided food, fodder and fibre for human and animal needs.



Primitive agriculture: The energy surplus created by hunter-gatherers provided the springboard for human society to move towards agriculture. Primitive agriculture initially appeared independently in at least five places. The Fertile Crescent in the Middle East, in what is today part of Syria, Turkey, Iraq and Iran saw the domestication of founder crops of wheat, barley, peas, lentils, and flax from wild grasses around 10 Kya; followed by millet, rice, soybean, beans in China, ~9 Kya; corn, beans and squash in Mesoamerica, ~5 Kya; potato and manioc in the Andes and Amazon, ~5 Kya; and sunflower in Eastern America, ~4.5 Kya.

Paleo-botanists believe that the Sahel, West Africa, Ethiopia and New Guinea may also have been sites where plant domestication occurred independently. Once founder crops spread to other areas, the domestication of local crops occurred as early as 9 Kya in the Indus Valley (sesame, eggplant), 8 Kya in Egypt (fig, chufa), 8-5 Kya in Europe (oats, poppy).

Domestication of animals happened almost at the same time as domestication of plants and at the same sites as the founder crops. And this helped humans make the shift to agriculture faster. Goats and sheep were domesticated in the Fertile Crescent, pigs and silkworms in China, turkey in Mesoamerica, llama and guinea pig in the Andes and Amazon, humped cattle in the Indus Valley, donkey and cat in Egypt, guinea fowl in the Sahel, and horse in the Ukraine. Reindeer, camel and yak were domesticated a little later in Northern Europe, Arabia, Himalayas and the Tibetan Plateau, respectively. The dog was domesticated much earlier as a guard and hunting animal. Domestic animals provided milk, meat, farm manure, draught power for farming and transport, hides and wool for clothing and other utilities. In some places elephants, monkeys, bears, eagles, and cheetahs were tamed and trained but never domesticated.

This period also saw the development of simple wooden ploughs and other agricultural implements, harnesses for draught animals, wheeled vehicles (Fertile Crescent, 5 Kya) for transporting agricultural produce and smooth roads (Rome, 2 Kya), and square sailed ships (Egypt, 4.5 Kya). These inventions helped societies shift to agriculture.

There was nothing automatic in the shift from hunting-gathering to agriculture. Many societies did not make the transition to agriculture. Inuits have remained nomadic hunters and fishermen to this day as their rangelands were too cold to grow crops.

Human activity creating maximum surplus energy	**Chronology**		**Energy sources**	**Energy conversion (energy converters/ conversion processes)**	**Energy conveyance (devices/ processes)**	**Energy storage**	**Knowledge**	**Environmental factors**
	Age	**Period**						
Primitive agriculture & pastoralism	Neolithic age	10-4 Kya	Solar, animate energy	Domesticated plants (Solar/animate→chemical)	Rudimentary wooden ploughs & agricultural implements	Biomass	Plant domestication, agricultural practices	Many plants and animals domesticated in Eurasia, and fewer in Mesoamerica and Africa, none in Australia because of specific environmental endowments of these continents. Environmental diversity of the Fertile Crescent helped plant and animal domestication.
			Biomass	Domestic animals (Chemical→thermal/ kinetic)	Animal harness	Biomass	Animal husbandry, selective breeding	
			Animate energy	Humans/ draught animals (Chemical→kinetic)	Wheeled vehicles, roads	Humans, draught animals	Trade, road making	
			Wind		Sails	No storage	Trade, sail making & use	

On occasion, the shift from hunting-gathering to agriculture even reversed itself. The Maori who colonized the Chatham Islands (South-west of New Zealand) 3 Kya as farmers found that the tropical crops they brought with them did not grow in the cold climate of the island. They had to either leave Chatham Island or revert to fishing, hunting and gathering. They chose to do the latter, which left them with insufficient food surpluses to support non-hunting professions such as craft specialists, bureaucrats, armies and chiefs.

The transition also took considerable time. Many societies continued to hunt and gather while doing some farming. Their farming tools and techniques were rudimentary and did not immediately give them food surpluses that exceeded yields that hunting and gathering gave them. Some hunter-gatherers become nomadic pastoralists, but did no farming. Continuing to hunt and gather while experimenting with primitive agriculture also insured against possible crop failure.

For the last 10,000 years, the Bakhtiari nomads, who derive their name from the legendary Mongol herdsman, Bakhtyr, have driven their sheep and goats through the cold semi-Arid steppe forests of the Zagros Mountains that lie along the Western border of present-day Iran. They survive on the milk, meat and skin their herds provided, and occasionally trade skins for other necessities with outsiders they occasionally meet.

Primitive agriculture took many forms; the best known ones practiced in many parts of the world were the slash and burn technique and shifting agriculture. Land was cleared off its original vegetation so that it could be cultivated. After some time, it was abandoned so that the original vegetation grew again and restored its fertility.

The increase in usable energy density on farmlands triggered the shift to agriculture. By domesticating crops and animals, a hectare of farm land yielded 90% usable biomass, a huge jump from just 0.1% for hunting-gathering. A hectare of land could now feed many more farmers than hunter-gatherers, besides ensuring better food security. Population densities during primitive agriculture increased 30-40 fold over the anthropo-energy age.

The per capita energy consumption of primitive agriculturalists ranged 18-24 GJ/a. Energy returns for shifting agriculture may range 11-15 fold for small grain, 20-40 fold for root crops and good corn yields, and 70 fold for legumes in rich farmlands. These surpluses helped primitive agriculture move on to the next stage of development, ie, traditional agriculture that was more settled and permanent.

While primitive agricultural societies inherited the largely egalitarian structure of hunter-gatherer societies, surplus food and larger populations triggered the beginning of the division of labour and a settled way of life in villages. Bands became tribes and tribes required some minimal administration to maintain intra and inter-tribal order and harmony. Initially elders performed this job, but in due course Chiefs—whether appointed by selection or hereditary, soon took over this task. Soon the trappings of a bureaucracy made its appearance and converted voluntary contributions that people made to the Chief for his services into compulsory tax or forced tribute that was used for the upkeep of the bureaucracy. It also helped build the Chief's personal wealth.

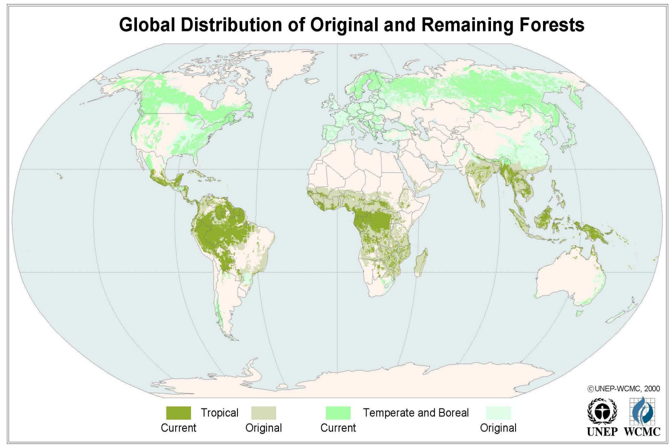
Food surplus meant that everyone in the tribe did no longer be a farmer and some could become herders, carpenters, blacksmiths, traders, etc. Division of labour, including that between genders, began with food surplus. Men did more of the agriculture and hunting-gathering and women did more of the child rearing and food preparation.

Why did the first agricultural revolution occur in Eurasia and not on any other continent? Diamond argues that, Eurasia had the largest and the most diverse landmass, hence a larger genetic pool of flora and fauna. There was a greater probability of finding plants and animals that were domesticable in Eurasia than in Africa, Australia and the Americas, and this allowed the Mesopotamians, Chinese and other Eurasians to transit from hunter-gatherers to primitive farmers earlier. Second, Eurasia's large breadth facilitated diffusion the domesticated plants, animals and other technologies quickly as there are fewer environmental barriers—climatic, geo-morphological—along latitudes. Because of their geographical orientation, diffusion of ideas and technologies in Africa and the Americas had to happen along longitudes, which offer greater environmental barriers for plant diffusion as climate and geo-morphology changes more rapidly along longitudes. Third, the early invention of writing in Eurasia helped in the diffusion of ideas and technologies and forge ahead of Africa, Australia and the Americas. All three factors helped in allowing surplus energy to be created earlier in Eurasia.

Traditional agriculture: Traditional settled agriculture spans a very long period of time from the Iron age (4 Kya) through the Middle ages and up to modern times. It includes many types of agricultural systems—hydro-agricultural civilizations of the Nile, Mesopotamia and Indus valleys, the Inca agrarian system of mountain terraces, European agriculture of the Middle Ages, and wet rice growing in Asia.

Crops and agricultural methods diffused from the places where they first took root to other places which had similar agro-climatic conditions. Imported crops and the agricultural methods were modified to suit local conditions.

All agricultural systems in this period shared the same secondary energy sources—biomass and animate energy. The primary source is solar energy, which is used in photosynthesis to convert Carbon dioxide into biomass. Since traditional agriculture uses no fossil fuels, it is a completely renewable activity that adds no Carbon dioxide to the atmosphere, except from permanent land use change from forest to agriculture.



Traditional agriculture progressed very gradually by extending the cropped area and through farm intensification. The former was done by converting forests and grasslands or planting hardy crops on unutilized marginal lands. In the last 8 Kya, 40 million km^2, or half the original forest area of the world has been clearfelled to make way for agriculture. Farm intensification was done by gradually improving the efficiency of energy conversion and conveyance technologies to deliver greater output on the same land. Improvements that occurred in other fields, eg, better connectivity between places, helped indirectly in raising surpluses.

One of the important methods that helped increase farm intensification was by replacing human labour with animal power. Animals were first introduced to do ploughing as that required the maximum energy input. Oxen and water buffaloes were better suited for ploughing the wet clayey paddy soils of South and East Asia. Horses were better suited for ploughing European soils, though were more expensive to maintain than cattle. Draught animal harnesses were first used in China 2 Kya; their design being improved to increase traction efficiency and also fit draught animals of different sizes better.

Irrigation was another important method to do farm intensification. It was first used in the Fertile Crescent, Egypt, China, the Indus Valley and Mesoamerica. The simplest irrigation system that was used was the counterpoise system, where a single labourer lifted water from a water source at a lower level with a bucket slung at one end of a lever counterpoised with a weight at the other end. Hand or foot operated paddle wheels, waterladders, Archimedean screws, waterwheels with buckets, and run-of-the river watermills were subsequent devices that delivered considerably more water than the counterpoise and were used in India, China, Vietnam, Korea, Japan, Egypt, etc.

In several civilizations, elaborate irrigation canals were built. Ancient Egypt developed a system of winter cultivation based on receding Nile floodwaters. China constructed extensive irrigation systems, the best known one being Dujiangyan which dates back to over 2 Kya. Upland Mayans built rock-walled terraced fields and downland they built an extensive network of canals to irrigate their lands.

Improved fertilization was a third device used for increasing farm intensification. The replacement of depleted soil nitrogen, phosphorus, potassium and micro-nutrients was done by plowing back crop residue and farm and animal waste into the soil. In some places legumes were grown by rotation on the same land. Inorganic fertilizers began to be used in the Twentieth Century.

Gradual improvements in farm implements also helped farm intensification. Primitive ploughs were first used in the Fertile Crescent ~6 Kya. They were made of wood and used to make small furrows in light soils. Over time, they became metal tipped or were made from iron and could be used to plough heavier soils, particularly when yoked to draught animals. The introduction of mouldboards that turn the soil to one side and upturn cut weeds was a further improvement that allowed tilling to be done in one operation. The first seed drills were used in the Fertile Crescent as far back as 3 Kya and minimized seed waste that was high in manual broadcasting of seeds. Harvesting, threshing and winnowing tools were also improved over time. Animals gradually replaced human energy for threshing and winnowing operations and increased the amount of output that could be obtained with minimal human effort.

The first independent written scripts that we definitely know of happened in Mesopotamia 5 Kya, followed by Mexico 2.5 Kya. Early scripts also appeared in China, Egypt, the Indus Valley, Phoenicia, Easter Island and other places. Written scripts were a major advance that helped in knowledge diffusion and accounting, which helped the spread of agricultural practices and trade of agricultural produce.

Human activity creating maximum surplus energy	**Chronology**		**Energy sources**	**Energy conversion (energy converters/ conversion processes)**	**Energy conveyance (devices/ processes)**	**Energy storage**	**Knowledge**	**Environmental factors**
	Age	**Period**						
Traditional agriculture	Iron age-Middle ages	4-0.5 Kya	Planetary (gravity)/ animate	Irrigation canals/ lifts (Potential→Kinetic, Chemical→Potential)	Irrigation canals/ locks, lifts	Water storage in reservoirs	Irrigation	Agriculture flourished initially in lands that could yield high energy returns, eg, river valleys. Pastoralism took root on more marginal lands whose energy yields were lower and that could not support agriculture so well.
			Charcoal, biomass	Foundry (Chemical→thermal)	Agricultural implements, eg, iron harrows, seed drills	Charcoal	Metallurgy & tool making	
			Animate	Crop/ animal residues (Chemical→chemical)	Animate	Biomass	Irrigation, ploughing, fertilization	
							Cropping cycles	
							Writing	

Shifts in energy conversion and conveyance, ie, agricultural tools, irrigation, fertilization and cropping pattern was slow throughout the time when traditional agriculture was practiced. In the 3.500 years when traditional farming was done, farm output increased rather slowly, and consequently so did human population.

The per capita energy consumption when traditional agriculture produced the majority of energy surpluses was of the order of 30-50 GJ per annum. Net energy returns for wheat crops was about 20 fold for the Roman Empire, 40 fold during Medieval Period and over 150 fold at the beginning of the Nineteenth century.

In time, society and its administration became more complex. Chiefdoms combined to form kingdoms, and kingdoms, if they became sufficiently big, became empires. Kings appointed chiefs for various provinces and made them responsible for collecting taxes, maintaining law and order and contributing manpower and money for wars that were waged against other kingdoms.

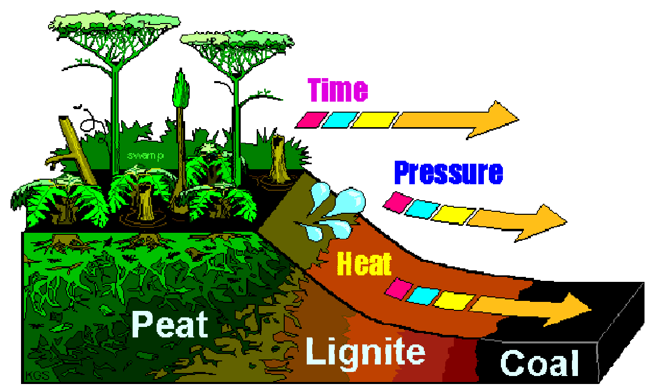
Greater food surplus also meant that a higher percent of the population no longer needed to work as farmers and could pursue other vocations. During the long period when traditional agriculture was the primary energy surplus producing activity, a vast range of new craft and administrative vocations were created—craftsmen, traders, intellectuals, bureaucrats, soldiers—and this division played a major role in the Middle Ages in moving society to the fossil fuel age.

Fossil fuel age

In the year 1306, nobles and clergymen from all over England came to London to participate in the newly established parliament. There they protested the acrid stench of burning coal they were greeted with. King Edward I banned the use of coal, but lacked the means to enforce it. Were it enforced, the world today may have been a different. By the late Sixteenth century, Britain had a rising population and dwindling forests and needed a new fuel to power their foundries, so they learnt to tolerate the stench of burning coal.

In the Fossil fuel age, humans began to use fossil fuels—coal, oil, natural gas—as their primary energy source. The widespread use of coal in Sixteenth century Britain heralded the shift from the Bio-energy to the Fossil fuel age. Fossil fuels are ancient plants and animals transformed by nature.

Coal was largely formed during the Carboniferous age (360-300 Mya). Peat, formed from dead vegetation, changes to lignite and coal due to anaerobic reaction, compaction and heat. The gaseous products (methane being one) are typically expelled from the deposit to make it carbon-rich. The stages of this trend proceed from plant debris through peat, lignite, sub-bituminous coal, bituminous coal, anthracite coal, to graphite (a pure carbon mineral). Oil and natural gas were formed in a manner quite similar to that of coal, except that they were formed largely from sea plants and animals.



The last 500 years—the fossil fuel age—consists of pre-industrial societies till the beginning of the industrial revolution in the Eighteenth Century, and industrial society since then.

Pre-industrial society: The pre-industrial period of the Fossil fuel age can be dated from the time coal began to be used widely in Britain, ie, 500 years ago, till the beginning of the industrial revolution, ie, 300 years ago. Though coal was increasingly used in the pre-industrial period, animate energy and biomass remained the primary energy sources. Wind (sailing ships, windmills) and water (watermills) power were increasingly used in during this period in China, India, Middle East, Japan, and Europe. Though wind energy contributed far less than other energies sources did during this period, its importance was because sail ships were used for trade (exchange of energy surpluses) and for discovering and colonizing new lands (new energy sources).

During this period, energy conveyance devices became more efficient and changed the manner in which energy surpluses were created. Windlasses, capstans, treadwheels and gearwheels assisted in doing a host of mechanical jobs more efficiently, eg, lifting water and heavy weights. Improvement in energy conveyance tools set the tone for the shift to fossil fuels, which is one of the principal defining characteristics of industrial society.

Agriculture remained the activity that generated the largest surplus energy, thus contributing significantly to the shift from the bio-energy age to the Fossil fuel age.

Industrial society: The last 250 years saw a shift in the primary energy from animate, biomass wind and water energies to fossil fuels. The former energy sources are an almost immediate transformation of solar energy into usable energy for humans via photosynthesis, wind and water flows. Fossil fuels delayed the transformation of solar energy into usable energy by several thousand to million years.

Fossil fuels have a very high energy density (coal—22-32 MJ/kg, oil—42-46 MJ/kg, natural gas—50-52 MJ /kg), and are easy to transport and store, which other energy sources (water at 100 m head 0.001 MJ/kg) lacked these advantages. This allowed larger energy throughputs to flow through the economy, and consequently generated larger surplus energy. A spate of new energy conversion and conveyance processes and technologies aided this process.

Samuel Crompton's spinning mule, patented in 1769, not only revolutionized cotton mills in Britain, but also set into motion the industrial revolution. Soon after, James Watt's steam engine was used to pump water out of coal mines, allowing mines shafts to be extended deeper underground. The steam engine was subsequently used for other applications in the newer industries. The iron industry saw major changes when coke replaced charcoal and cupolas began to be used. This allowed larger quantities of iron to be produced cheaply, and providing further impetus to the industrial revolution through the manufacture of more steam engines, the building of railways and later, the manufacture of automobiles.

By the late-Eighteenth century, the industrial production of sulphuric acid and calcium carbonate laid the foundation for the chemical industry. By the middle of the Nineteenth century, watch making gave birth to industrial machine tools. The three mother machines—lathes, shapers and drilling machines were made around the same time. Without them the manufacturing industry would never have happened and manufacturing processes would never have jumped out from cottage industries to mechanization, and later automation.

The number of new inventions and innovations in the industrial revolution period are far too many to recount in this short article. But it is worth mentioning some notable ones. In 1820, London streets were lit by gas obtained from coal gasification. Consequently, social life flourished, factories ran at night. Other innovations followed thick and fast—paper and glass making, Portland cement, inland waterways that moved bulk goods, better roads, railways, etc.

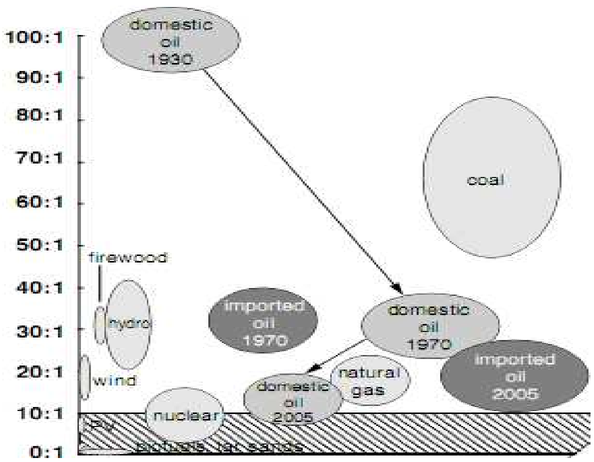
The Indonesians knew of fuel properties of oil they found seeping through the earth long before the first commercial oil wells were dug in Pennsylvania in the 1860s, after which refined oil became a replacement for depleting whale oil used for lighting. Since then there have been a flood of inventions—automobiles, aeroplanes, inorganic fertilizers, diesel pumps, etc—that use of petroleum products. Oil has become indispensible for meeting our daily needs. And so, global politics in the last 150 years has revolved around oil.

While Michael Faraday demonstrated electro-magnetic induction in 1831, it took Thomas Alva Edison to translate the science of electricity into a technology that revolutionized the world in the Twentieth century. The high vacuum light bulb that Edison demonstrated in 1879 was supplemented by the eclectic motor and transformer to achieve this. Electronics was a post World War II phenomenon that further extended the achievements of electricity.

Natural gas began to be used commercially only in the Twentieth century. Robert Bunsen invented a burner that could burn natural gas safely in 1885. But it took another few decades for gas pipelines to be built from gas fields to consumers.

Fossil fuels—coal, oil, gas—contribute over 85% of the world's primary commercial energy requirements. Most modern energy converters and conveyers use fossil fuels or electricity, which is largely a product of fossil fuels. The quantum of energy use and the energy surplus in the Fossil fuel age is unprecedented in the human history. At 12,000 million ToE per annum, global energy consumption today is many orders of magnitude higher than it was during the Bio-energy era.

Till the advent of industrial society, biomass (energy density 13-15 MJ/Kg) and stored water (5 KJ/Kg) were the only major means of storing energy for later use. Industrial society's major energy source is fossil fuels, nature's invention for storing high density energy (20-50 MJ/Kg). Industrial society has invented other storage devices—batteries, flywheels, super-capacitors, molten salts, etc. But none of these devices comes anywhere close to the energy densities that nature has created. The mostly widely used energy storage device, a battery, has an energy storage density of 100-600 KJ/Kg, which is a capacity 2 order of magnitudes less than biomass or fossil fuels.



Surplus energy in the fossil fuel age is generated because the EROEI (energy return on energy invested) of fossil fuels, ie, for every joule invested to extract and process fossil fuels, the return 10-70 (sometimes >70) joules. The surplus energy available by using fossil fuels is enormous.

Energy efficiency and energy surplus

A surplus implies that the output exceeds the input. In all the three major ages—anthropo-energy, bio-energy and fossil fuel ages, energy surpluses were created. The law of energy conservation implies that efficiency of any energy conversion process has to be less than one, ie, that energy output is less than the energy input. How can the seeming contradiction between laws of nature that imply that output energy be less than the input in any energy conversion process, and our observations regarding population growth and rising wealth, implying energy output is greater than input, ie, creation of surplus, be explained?

This riddle can only be solved if we can find some unaccounted energy input that explains the seeming contradiction. That unaccounted energy is solar energy. It is provided free of energy cost by nature in energy conversion processes that have played a central role in powering nature and the development of human society.

Humans are basically solar farmers. As hunter-gatherers, they lived off wild roots, herbs, shrubs and game that solar energy created. As farmers, they grew crops powered by solar energy, and fractionally by animate energy and biomass, both being secondary energy forms created by solar energy. In the Fossil fuel age, goods and services are produced using fossil fuels, which are again products of solar energy.

In each of these ages, an energy balance would look like this:

Hunting-gathering: The primary energy input used by humans is human energy, and output is food. Solar energy used in photosynthesis by vegetation is the energy that nature provides free of energy cost. Biomass energy used for heating and cooking is relatively small, hence can be neglected in the energy balance equation.

Energy input = Human energy[5] expended to gather food + ***Solar energy for plant photosynthesis***

Energy output = Energy content of food

Energy input exceeds energy output if solar energy is included, but energy output will exceed input if it is excluded. Nature provided solar energy free of energy cost as no human energy was expended to obtain it. Therefore, if solar energy is included, energy conversion efficiency (η) of hunting-gathering is less than one (<1), and the laws of nature are adhered to. If solar energy is excluded, net energy output obtained by humans exceeds the input humans have expended, hence there is formation of energy surplus that was used for gathering more food than was required for immediate consumption by the hunter-gatherers, making tools useful for obtaining food and for other activities. It is this surplus energy that powered human development into the next age.

Agriculture: The primary energy inputs for agriculture are animate energy and biomass. Wind and water are secondary energy were used for goods, services, infrastructure, eg, farm tools, roads, etc that form inputs for agriculture (these inputs are in the form of embodied energy and must be accounted for over the agricultural produce that they are used over their lifetime). The primary energy output is in food, and a minor secondary output is embodied energy in fibre and other produce from agriculture and animal husbandry. The energy throughput for producing goods, services and infrastructure is relatively small.

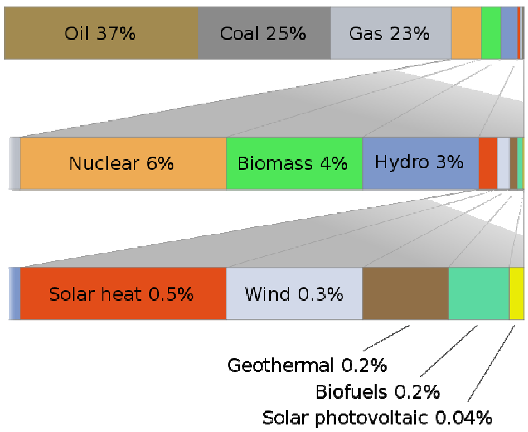
Energy input for agriculture = Human & animal energy[5] expended for agriculture + Biomass energy used in agriculture + Embodied energy of goods, services, infrastructure + ***Solar energy required for growing crops***

Energy input for goods/services = Animate & biomass energy expended for producing goods/services + Embodied energy of goods, services, infrastructure + ***Solar/ wind/ water energy required for producing goods/ services***

Energy output for agriculture = Energy content of food & fodder + Embodied energy of fibre & other produce from agriculture & animal husbandry

Energy output for goods/services/infrastructure = Embodied energy of produced goods/ services/ infrastructure

[5] This includes energy required for human and animal metabolism and upkeep



Global energy use by sector	%
Industry	48
Transport	27
Residential (household consumption)	15
Services	7
Agriculture	3

The above input/ output equations can be summarized as follows:

Energy input = ∑ (Animate energy + Biomass energy + Embodied energy inputs + ***Solar energy inputs for agriculture/ goods/ services/ infrastructure***)

Energy output = ∑ (Energy content of biomass output + Embodied energy of goods/ services/ infrastructure produced)

If the solar energy is included, the input energy will exceed the output energy, and $\eta<1$ for energy conversion and the law of conservation of energy would hold. However, if it is excluded as nature provides it free of energy cost, energy surplus is created, which powered human development into the next age.

Industrialism: Though biomass and animate energy continue to be used more in South nations and by the poor, fossil fuels have become the primary energy source for creating surplus in industrial society, contributing 85% of the commercial energy demand (neglecting animate energy and solar energy used in photosynthesis). Secondary energy sources such as wind, water, planetary (dams for generating power), electricity and nuclear energy are also used, though their combined contribution is barely 15% of the total global energy consumption.

For the first time in history, a very large fraction of the global energy throughput is used to produce goods and services other than those required for basic human necessities (food, clothing, housing), and are consumed disproportionately by North nations and the rich (in North and South nations). Agriculture consumes only ~3% of the total global energy consumption.

Energy output is primarily in the form of embodied energy in goods, services and infrastructure. A small fraction of the output is in the form of embodied energy in agricultural produce. Unlike in Bio-energy age, embodied energy of agricultural produce may exceed the energy content of agricultural produce by a significant amount in North nations as an enormous amount of energy is expended in packaging, storage and transport of agricultural products.

Energy input for goods/services/infrastructure = Energy input for extracting and processing fossil fuels + Energy inputs for producing other energy sources + Embodied energy of goods & services used for producing goods, services, infrastructure + ***Excess energy in fossil fuels and other energy sources***

Energy input for agriculture = Animate energy expended for agriculture + Biomass energy used in agriculture + Energy input for extracting and processing fossil fuels in agriculture + Energy inputs for producing other energy sources used in agriculture + Embodied energy of goods & services, infrastructure + ***Solar energy required for growing crops + Excess energy in fossil fuels and other energy sources***

Where, ***Excess energy in fossil fuels*** = Energy content of fossil fuels – Energy input for extracting and processing fossil fuels;

And, ***Excess energy in other energy sources*** = Energy realized from other energy sources – Energy inputs for producing other energy sources.

Energy output for goods/services/infrastructure = Embodied energy of produced goods/ services/ infra-structure

Energy output for agriculture = Embodied energy content of food & fodder + Embodied energy of fibre & other produce from agriculture & animal husbandry

The above input/ output equations can be summarized as follows:

Energy input = ∑ (Animate energy + Biomass energy + Energy for producing fossil fuels and other energy sources + Excess energy in fossil fuels and other energy sources + Embodied energy inputs + ***Solar energy inputs for agriculture/ goods/ services/ infrastructure***)

Energy output = ∑ Embodied energy of goods/ services/ infrastructure/ agricultural produce produced

The energy input and output of agriculture in industrial society is small compared to that of the other sectors. As a first approximation of the energy balance equation, input and output energies for agriculture may be neglected.

The energy cost for extracting and processing fossil fuels is only a small fraction of the of the energy content of fossil fuels, of the order of ~2-5% and sometimes 10%, of the energy content of fossil fuels. The balance energy is available as energy free of cost. This free energy contributes to energy surpluses in industrial society. Energy output exceeds energy input because solar energy has made fossil fuels free of energy cost to humans. As in earlier societies, energy efficiency <1, and the laws of nature are followed. But net energy output exceeds the input, hence energy surplus is formed.

An increasing energy surplus does not necessarily imply an increase in energy efficiency. Energy surplus can be increased by increasing energy throughput as happened in industrial society. This process could well happen with decreasing energy efficiencies, eg, a kilocalorie of edible food in the US requires many kilocalories to produce, store, package and market it. The embodied energy content of such food is many times greater than the energy content of the food.

Appropriation of energy surplus by energy-haves

Whatever be the energy surplus in a society, with the exception of hunter-gatherer societies, why was it not distributed equally or equitably in other societies?

Through private ownership of energy resources: During the anthropo and bio-energy ages, two forms of class society—slavery and feudalism (and their variants) dominated. During the fossil fuel age, capitalism dominates the world. Energy surpluses created in class societies were distributed inequitably, the lion's share being appropriated by energy-haves—slave owners, feudal lords and the bourgeoisie. In all class societies, the energy-haves invested less energy than the returns they got, the surplus being the energy solar energy provides free of energy cost to humans.

Surplus energy is obtained when a) solar energy free of energy cost is used by humans in photosynthesis to make vegetation usable by humans as food, fibre, fodder (and indirectly animals usable by humans); and by way of wind power and fossil fuels, b) planetary energy is tapped by humans by way of water power, c) energy is generated in nuclear reactions. In all these cases, input energy investment by humans to tap these energy sources must be less than the energy yields.

If a person (including legal persons like a company, tribe or a nation) or a group of persons establishes ownership over energy resources (energy sources, energy conversion and conveyance and knowledge of them) than such persons are able to own the surplus energy generated by virtue of their ownership of energy resources. They invest less energy in acquiring energy resources than the energy they reap by using them to create embodied energy. The difference between input and output, ie, surplus energy, can be claimed and appropriated by owners of the energy resources.

However, surplus energy has actually been created by nature. So, what right does a few persons who claim ownership over energy resources have to appropriate surplus energy? None, whatsoever. Surplus energy should belong to nature. The manner in which surplus energy is appropriated in all types of class society has the same underlying method. Surplus energy is released from the energy source by a class of energy-havenots, yet this surplus energy is not shared equitably by all humans, leave alone with other species.

In slave society, the slave owner provides the slave with a certain amount of energy in the form of food, housing and other wherewithal to take care of his and his family's survival. The grain that he produced by farming his owner's field and other services he performs are appropriated by the slave-owner as he owns the slave. The energy output of the slave in the form of energy in the crop and embodied energy in services exceeds the energy input into the slave, the difference being appropriated by the slave owner.

In feudalism, a serf provides energy inputs into land in the form of animate energy and embodied energy (tools). The farm output is shared with the feudal lord, who provides no energy inputs. Land is a secondary energy converter as it grows crops (which are energy converters), hence by virtue of owning the energy converter (land), the feudal lord is able to appropriate surplus energy for which he has provided no energy inputs.

In capitalism, the capitalist owns not only the energy source (fossil fuels), but also energy converters, energy conveyers and knowledge of them. Because the EROEI for fossil fuels ranges 10-70, the capitalist is able to get a much higher return than his investment.

Private ownership of energy resources is the cause for energy surpluses being appropriated by a class of energy-haves throughout the history of class society from antiquity till date. The process of accumulating surplus energy is the same in all class society, ie, energy and embodied energy input are less than the output, the excess being appropriated by the class of energy-haves. Fossil fuels have increased energy inequity significantly.

It is the labour of the energy-havenots that realizes energy from energy resources. Slaves do farming and it is their labour that realizes the energy and surplus available in crops. Serfs perform the same tasks as slaves, except that they are not owned by anyone. Workers in capitalism operate energy converters and conveyers and transform raw materials into finished products using fossil fuels. If any human has a first claim on surplus energy, it should be slaves, serfs and workers. Yet, because nature has created that energy and all that the energy-havenots have done is realized it, they may only have entitlement to the surplus energy, something that nature too has. Nature's entitlement could well be in the form of having such share of solar energy that will not disturb nature, or not removing fossil fuels from their mine/ wells. This is a discussion that requires another paper, so we will leave this thread of thought for now.

As land was the easiest global common from which energy could be harvesting, it was the first one to be privatized. That happened during antiquity. Water is more difficult to harvest energy from, hence was privatized more recently. Harvesting energy from air is the most difficult. The process of privatization of the atmosphere has just begun with the Kyoto protocol, not to harvest energy, but for dumping wastes. The Kyoto Protocol has created dumping rights for the developed nations, which in any case have the highest per capita greenhouse gas emissions.

Through conquest of other societies: Read any history textbook and it invariably extols the virtues of conquerors like Alexander, Akbar and others. Essentially, they were able to gain ownership of energy surpluses of another kingdom through conquest. This was the other way by which energy surpluses were appropriated. Again, the manner in which this was done in the various periods of history makes for fascinating reading. But in this brief article, only a few examples will be cited to indicate how energy appropriation was done through conquest.

During the Eleventh and Twelfth Centuries, the invention of the harness and the stirrup allowed the Mongol cavalry to use both hands freely to shoot arrows while riding a horse. This gave them great tactical advantage over armies of more advanced kingdoms in Iraq, Iran and India, which were vanquished. The surpluses created by these kingdoms were appropriated by the Mongols.

In 1532, Spanish marauder Francisco Pizarro captured the Inca emperor, Atahuallpa, but defeating his 80,000-strong army with just 168 Spanish horse-mounted soldiers armed with cannons, muskets, steel spears and swords, and wearing chainmail armour. Superior knowledge of metallurgy in Europe and the use of horses gave the Spaniards a great advantage and allowed them to extract the largest ransom ever extracted till then—gold that filled a room 22 x 8 x 17 feet.

After the Portuguese mariner Vasco de Gama landed in Calicut in 1498, the local ruler quickly realized the risk that Europeans may pose to his shipping lanes to trade with East Africa and the Arab countries. China, India and the Arabs had ships that were as good as or better than European ships. But European ships had a stern post rudder that gave them grater maneuverability, a mix of different type of sails on their three masts that gave them greater speed, and strongly built hulls that made them capable of withstanding more punishment. In the sea battles that followed soon after the Europeans landed in India, they were able to outmaneuver Indian ships and outgun them as the Indians had not yet mastered the use of ship-mounted cannons despite possessing them. The Europeans soon extracted tribute from the Indians and the Arabs for using sea lanes that they controlled. The Chinese withdrew their fleet from Indian waters half a century before the Europeans reached India. Had that not happened, their ships that were three times larger than European ones would have been more difficult for the European to penetrate India.

In the last three centuries, colonial powers such as the British, Dutch, and French were able to extract huge energy surpluses in the form of raw materials, and through cheap energy cost production facilities in off-shore factories. The British Empire thrived because it was able harvest energy resources from its vast colonies in both the old and the new worlds.

Energy inequity

Energy consumption today across regions is highly skewed. A South Asian consumes an average of 0.5 ton of oil equivalent[6] (Toe), an Indian 0.4 ToE, a European, 4 Toe, and an American, 8 Toe. The per capita global average is 1.8 ToE per year.

Energy consumption is an addiction, quite similar to smoking. It grabs and seduces people and makes them addicts, and is even more difficult to quit than smoking. Once a person or a nation consumes a certain amount of energy, it is very difficult to reduce that consumption level, and energy inequity persists, and often increases.

Stealing energy from nature and humans

Throughout the history of class society, the class energy-haves have stolen energy both from nature as well as from other humans who can best be termed as energy-have-nots. Eight thousand years ago, forests covered two thirds world's landmass, ie, 80 million km^2. Today, it is half that area, constituting one third the world's land area and this is to the detriment of plant and animal life. This has diverted 0.8 YJ (Yota {10^{24}} joules) of incident solar radiation per annum from nature, a 1000th of which is converted into net primary energy in forest biomass. The energy we expended to remove 40 million km^2 of forest is approximately 8 ZJ (Zeta {10^{21}} joules), and the net primary energy lost in biomass creation every year on those deforested lands is equal to the energy that are contained in 16 million nuclear bombs of the size of the bomb dropped on Hiroshima (50 Tera {10^{12}) joules), and the energy used by humans to cut those forests was ten times as many bombs (average embodied energy is 5 MJ/kg, average mass density of forests is 400 T/ha).

Per capita primary energy consumption

Region	ToE/yr
Central Africa	0.34
Northern Africa	0.69
Southern Africa	1.18
Australia-New Zealand	5.56
Central Asia	3.43
NW Pacific + East Asia	1.28
South Asia	0.49
SE Asia	0.73
Central Europe	1.81
Eastern Europe	3.49
Western Europe	3.86
Caribbean	1.11
Meso America	1.29
South America	1.13
North America	8.08
Arabian Peninsula	3.62
Mashriq	1.23

Energy-have classes have stolen enormous quantities of energy from nature and denied energy-have-nots their due share of energy, thereby exercising control and authority over the latter. The roots of the present environmental crisis (climate change, rapid environmental deterioration and peak oil) and human inequity are the same. They are because of private ownership of energy resources by the energy-haves, something that they have no moral right to claim. The toll has been huge—environmental injury (dealt with in another article) and violence against humans.

In the 20th century alone three types of human conflicts—interstate, colonial and civil wars consumed as many as 100 million human lives. The energy cost of the war machine is still not well understood. Suffice to say that about a tenth of our global energy consumption today, ie, 50 EJ (Exa {10^{18}} joules), or the equivalent energy yield of one million Hiroshima size atom bombs, is expended to keep the global war machine up and running. Between the various nuclear weapons states, they possess atom bombs that together can

[6] 1 Toe = 42 GJ

release about the same amount of energy and that have the potential to wipe out several hundred million people.

The remedy for all this is not very well understood and will probably not happen without the pain of collapse of human society as we know it.

Value and capital

The value of a good or service is proportional to the amount of embodied energy that has gone into making it. The price of a good or service is the fluctuation of its exchange value in the market. The medium used in the market used for representing the amount of embodied energy in a product or service, ie, value, is money.

Energy, when produced, cannot be consumed completely by the producer. The excess energy cannot always be stored conveniently for later use. For example, a farmer producing grain cannot consume all that he produced. Nor can he keep the grain for years together for it will be depleted by rodents and also rot with time. So, he sells what he does not require for immediate use for money. A part of the income is used for purchasing necessities for the household. The balance is left over is used to make an investment in extracting more energy by increasing or improving energy resources, ie, energy sources, energy converters/processes, energy conveyers/processes and knowledge of energy conversion and conveyance. Such an investment is called capital.

Since the origin of capital is in nature, ie, energy surplus, and is transformed by human intervention by the labour of energy-havenots, it can be said that 'natural capital' has been transformed into capital by human labour.

Limits to growth

Natural capital is limited, and we have begun to realize that only in the last half century ever since the first *Club of Rome* report was published. Peak oil manifests energy overdraw from nature. Earth's capacity to absorb our wastes is also limited, and this too is beginning to seep into public consciousness only in the last 25 years, ever since global warming has been taken note of.

Nature and economics

Economic theory earlier assumed that nature had an unlimited capacity for producing natural capital and an unlimited capacity for absorbing our wastes, and that it was possible for the economy to be in a growth mode forever. Economists are now grappling to come to terms with the realization that our world is limited.

In a closed system, eg, the universe, the total amount of energy is constant, but its distribution is uneven. Energy conversion always seeks to even energy distribution. The Second law of thermodynamics states that entropy, or a measure of the degree of disorder, always increases. Fossil fuels are highly ordered low-entropy forms of energy. By burning them, their energy is dissipated and entropy increases. Nature's project on earth to create increasingly complex forms of life increases order, hence creates negative entropy (negentropy). This does not violate the Second law as the earth is an open system. If order or entropy increases in one part of a the universe, it does not mean that disorder is not increasing in the universe.

However, economics is body of knowledge that helps humans to extract the maximum possible amount of energy from nature. And expending this energy causes entropy to increase. It almost appears that the projects that nature and humans are pursuing on earth are in collision. And economics has aided the human project to increasing entropy while ignoring nature's project to decrease it.

How much energy can we have?

The other solution can be worked out if we were to assume that we will have to live within the limits of what nature will allow us to do without hurting her, which implies that we will have to shift to a *"Risk minimization for all"* outlook from our current *"Gain maximization for a few outlook."* This begs the question ***"how much energy can we have?"*** While there are no well worked out answers, I am going to suggest a tentative one.

Excluding solar energy used for photosynthesis, 85% of the world's primary energy is supplied by fossil fuels. Forty six percent of the 8.9 Giga (10^9) ton of CO_2 as carbon (GtC) being currently released to the atmosphere, is not sequestered back to earth. Because of low EROEI of green and nuclear energies, they are not a viable replacement for fossil fuels in the near future. The only viable solution for beating climate change is to power down global energy consumption to a little less than half of our current consumption, ie, to 5,000 million ToE. If we were to assume the same primary energy source mix as prevalent today, and accept equal energy entitlements for everyone in the world, the energy available for each person is 31.5 GJ /year or 0.75 ToE/year. That is approximately the same energy consumption level as during the middle of traditional agricultural period (which was 40 GJ/y per capita).

What can a family of 4 persons consume assuming all CO2 emissions are sequestered and global energy equity?

Consumption item	GJ/yr
Food @2200 Kcal/person/day	13.5
Transport by bus @50 km/person/workday	13.0
3 Fans + 6 fluorescent bulbs @10 hrs/day	5.0
1 Fridge[7]	9.0
1 TV	8.0
1 Geyser working @1 hr/day for 150 days	1.5
1 Stove + 1 music system + 1 microwave	10.0
Housing—concrete 100 m^2 carpet area	16.5
4 mobiles phones	2.4
4 tables + 8 chairs + sofa set + 1 double bed + 2 single beds + 4 cupboards	7.0
Clothes & other minor personal belongings	4.0
Misl, incl for public infrastructure	36.1
∑Consumption-4 persons (@31.5 GJ) = 126 GJ = 3 ToE	

How far will 31.5 GJ go? Assuming a family of four persons, the question becomes what we can have for the family with an energy expenditure of 126 GJ/year, including embodied energy consumption. Using embodied energy tables, the family can expend energy on the items indicated in the table.

While this may look like the energy consumption of an average middle class family, this does not account for energy consumption on infrastructure and services that a government provides.

Energy consumption can increase further provided Carbon emissions per GJ of energy consumed reduce. This can happen either if the Cuba example of increasing organic farming and reducing energy consumption is followed or green energies substitute fossil fuels to some extent. However, these solutions do not detract from the main ones we are proposing, ie, powering down and energy equity.

At a per capita consumption of 31.5 GJ/yr, an Indian can double her energy consumption from current levels, but an average American must reduce hers by 90% and an average European by 80%. The moot question to ask is how can this be done?

[7] For fridge, TV, geyser, music system, energy includes embodied energy of consumer durable for 1 year + power required to run the durables

Conclusions

Whether peak oil has just happened or will happen shortly is no longer that important. There is general agreement that it is imminent. Energy prices will rise, and with them so will prices of all goods and services that are made from commercial energy sources. A global economic crisis followed by an economic collapse poses a clear and present danger. Such civilizational collapses have occurred due to energy overshoots in the past. They remained local as regional economies were not integrated the way the world's economy is globalized today.

The two twin problems that bedevil the world—energy overdraw and energy inequity—must be addressed urgently. Energy resources cannot be allowed to remain in private hands of individuals, states or nations (implying that international borders should be abolished), so that energy surpluses may be appropriated by them. They must be held in public trust for nature as a whole (including for humans) and on the basis of equity. The roadmap to there is still fuzzy and will take time to be worked out.

In the interim, development should be redefined. It must now mean, not creating additional energy generating capacities, but powering down and moving towards global energy equity. Countries like India have the technologies to power down. It is time for funding agencies like the World Bank and a host of North nation government and non-government funding agencies to setup shop in the North nations make it their primary object to transfer low energy consumption-high efficiency technologies there from South nations. It is also time for everyone to realize that they should reduce their energy and carbon footprints.

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