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Global Sustainability Summer School

Summary of Lectures by

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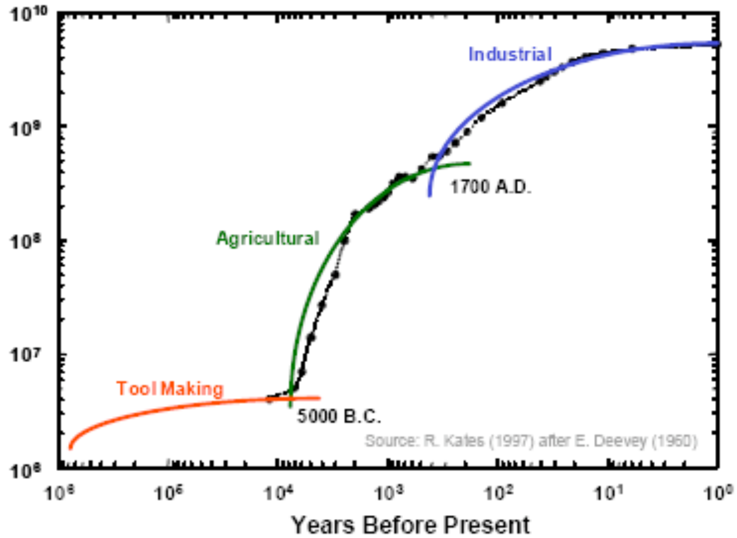
The three lectures delivered by Professor Nakicenovic centered on energy: the historical perspective of technology, the dynamics of the technology and the future perspectives.

1. History of Technology, an Energy Perspective
Technological change is a cumulative process. Its history can be mapped through a series of transformational phases and crises. Similar cycles of structural change patterns through time and economic development are evidence of the allocation of scarce resources. In the last twenty thousand years, however, a steady climate has contributed to the ability to develop a portfolio of technological systems.

Today's technological systems are based on evolutionary changes that were invoked at the dawn of human civilization with harnessing fire for the development of tools. Over human evolution, population and energy services per capita have increased enormously. Dozens of millions of people in hunter-gatherer societies gave way to one billion people at the onset of the industrial revolution. From an energy perspective, the path of this growth corresponds to three periods (Source: Sieferle, 1986):

1. Tool making: the primeval energy system of hunter and gatherer societies based on solar energy flows in the nature
2. Agriculture: the renewable energy system of the rational (pre-industrial) agricultural societies
3. Industrial: the fossil energy system of the industrial societies with vigorous qualitative and quantitative increase of energy services. Clear substitution of animal and human power with fossil energy.

Growth in human population was characterized by changes in energy sources as shown in the figure below.



(Source: Kates and Deevey)

Hunter-gather societies relied on solar energy flows and small stocks of embodied energy from nature but had very little resilience beyond ecosystem-dependent robustness. The primeval hunter-gatherer tribes and communities were fundamentally transformed by the Neolithic revolution that established agriculture, bronze and later iron tools, and thereby led to the emergence of early civilizations.

Four salient energy developments occurred in the transition from the hunter-gatherer to the agricultural societies: planned use of solar energy in agriculture and food production, use of animal muscle power, the emergence of slavery, the use of wind in sailing ships.

The basic technologies in use at the time were:

1. Wedge (practical application of the inclined plane), i.e. to cut wood
2. Inclined plane (power*distance = constant; transfer of power), i.e. to pull heavy loads
3. Screw (after Archimedes) or "winded inclined plane," i.e. to pump water
4. Lever (rudder, crane), i.e. used in the Saduf water pump
5. Wheel (transport rolls)

The societies relied on solar energy for agriculture and food processing. Most mechanical work was provided by human (often slave) and animal muscle power. In combination with muscle power, basic technologies facilitated technological development. Combining human muscle power with wheels and axis increased output. A grain mill operated by slaves was essentially the same as the wind and water mills that later grew to be widespread. More modern systems of pulleys and chains were eventually used to harness horse power to produce butter using a milk centrifuge.

Wind power was harnessed since antiquity for mills but grew in significance in the middle ages. Sailing ships became the main form of transport for goods and people serving as an essential technology for early world powers. Wind energy allowed early sailing nations to capitalize on the varying worth of tools and goods in different places. For example, the Venetian republic controlled much of the Mediterranean. Stationary use of wind power started in the 17th century. In the Netherlands, for example, wind power was used to pump water to dry lands.

Water power became significant during the medieval times. Its dominant use was for grain mills, water pumping and other forms of mechanical energy. Technological improvements were significant; undershot (water flows under wheel) was 30% efficient and new overshot technology (water flows over wheel) was up to 75% efficient. In the 18th century, turbines began to replace wheels, and within 100 years, turbines were pervasive. Monks played an essential role for the diffusion of water power technologies. Steam technology was also invented in pre-industrial time in agricultural societies (i.e. for a steam door opener) but was considered an attraction rather than a source of work.

The first energy crisis that occurred was the lack of fuelwood. The "peak of wood" started early in the Mediterranean region where woods was used for fuel and building boats. During medieval times, forests were common property but later became private property, reducing fuelwood availability for most. Household stoves were not capable of adapting to other fuel sources. Multiple uses of wood, such as industry use of charcoal for ore smelting, drove demand higher than supply.

The fuel crisis was the instigator for coal use, marking the beginning of the industrial revolution and a fundamental shift in the technological base. Human and animal work was substituted for machines, and fossil energy sources substituted for wood. Technological change allowed for the use of new and more abundant resources (Source: David Landes: *The Unbound Prometheus*, 1969).

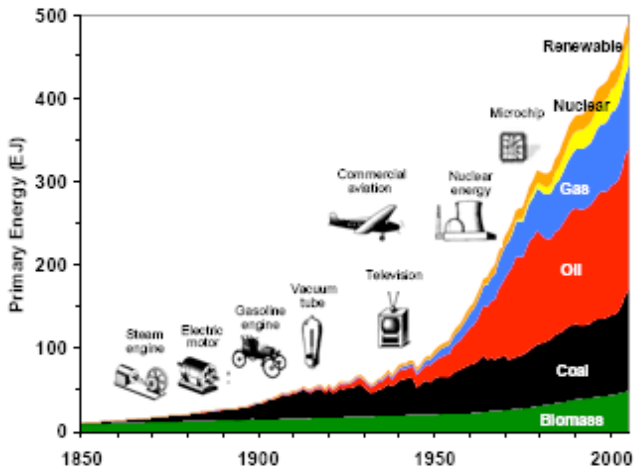
The last 200 years were an explosive period in human development. Technological innovation and diffusion allowed for liberation from physical toil, increased affluence, growth in settlement in urbanized areas, and the abolishment of slavery. The industrial revolution brought a 6 fold increase in population, a 100 fold increase in economic output, a 30 fold increase in energy, a 20 fold increase in CO2 emissions, and a 1000 fold increase in mobility.

The path of technological development was clear. Steam technology, for example, looks similar in many ways to the water pump. The true revolution for industry was the development of the steam engine (iterations by Papin, Newcomen, Watt) and drastic increase in its efficiency. Prior to this (1730), steam engines were only about 3% efficient, the same as a horse's conversion of hay to energy. After Watt's 30 year patent on steam engine technology expired, the diffusion and efficiency of steam engines grew exponentially.

The next energy crisis was coal production in Great Britain. Growth in production collapsed in 1920. During that period, Stanley Jevons became popular for the "The Coal Question," following his work pointing out the alarmingly urgent scarcity of coal and its potential to hamper the development of the engine. The crisis was discussed widely in society reminiscent of today's "peak oil" concept. "Jevon's paradox" was the idea that efficiency gains were outgrown by increases in the use of coal as total coal consumption grows exponentially.

Society survived the coal production crisis through the commercialization of oil and natural gas. Oil became 'black gold' following the scarcity of whale oil and a series of innovations. Natural gas was known since the 17th century and in use in China then. Drilling for gas and oil however, only began in the 18th century. Animal skin and pipelines were for transport.

World primary energy source path of growth and change are shown in the figure below:



Growth in energy technologies and knowledge unleashed a huge revolution characterized by growth in population, production, consumption, and use of natural resources. Transitions to each new energy cycle were driven by moments of scarcity and crises. It is possible that another significant transition is ahead of us constituting the fourth transformation to the post-industrial society. The question, however, is whether the fossil energy era can facilitate a transition to renewable energy. There are many candidates for energy technologies, but climate change is unlike other traditional drivers of technological change.

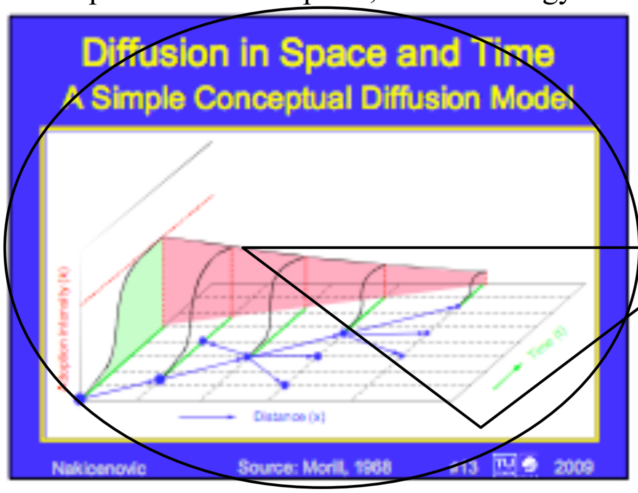
2. Dynamics of Technology

Changes in technology usage come in two general flavors: cumulative improvements to a base technology, or sudden, jarring transition to an entirely new technology. This is illustrated by the relatively steady decline in the price per distance traveled in the late 1700's, when travel was by stagecoach. With the introduction of railways the price for travel dropped by 75% over only a few years. Much of the narrative of technology could be said to have this same basic pattern: a series of wholesale replacements stitched together by more or less continuous marginal improvements in the prevailing technology.

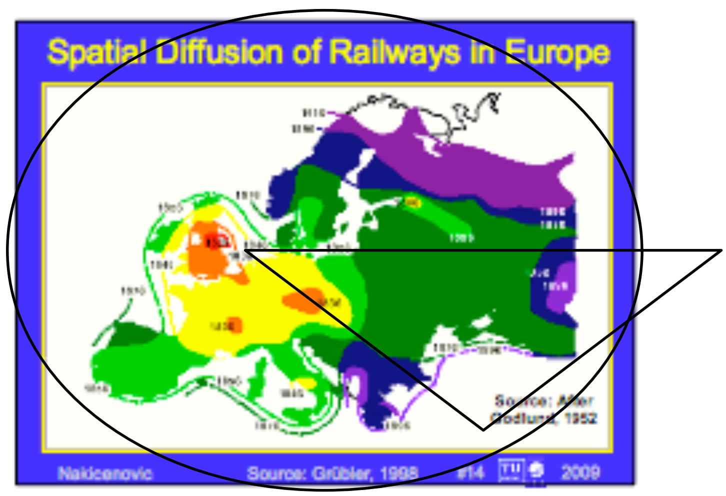
Synchrony of Adoption

A strange byproduct of the dynamics of technology diffusion as they play out both over time as well as over a geographical area is the tendency for adoption to "sync" up.

At the point of first adoption, the technology is unproven; the kinks to implementation have not been yet worked out. This results in a slow simmer towards the real embracement of the technology. In each successive new location the technology is introduced, the technology is farther along its own learning curve of refinement and cost reduction. For each new location, the speed of adoption is faster than the previous adopters as the advantages of adoption become more pronounced. As the technology matures, the speed of geographical expansion also snowballs.



Take the example of railroads. First introduced in Britain, the railroad took almost two decades to reach the mainland. When it finally did, it was a technology that the French and others readily appreciated, and moved to create a national rail system fairly quickly. Like the lines of a fire moving outward, adoption moved in fairly consistent rings of expansion. With the exception of the far north, by the 1880's, rails extended throughout the whole of Europe. While Britain adopted it first, comprehensive rail coverage lagged until the late 1870's.



Just as with the railroad example, the "first mover" of a technology generally remains the hub for that technology. For something like sail based trade, this had advantages over centuries for the early port cities which remained dominant. This raises the question: what are the hub technologies that will anchor a post-industrial economy? Which places and economies will become the first adopters? By virtue of their foresight, might those early adopters become the new anchors of the post-industrial world?

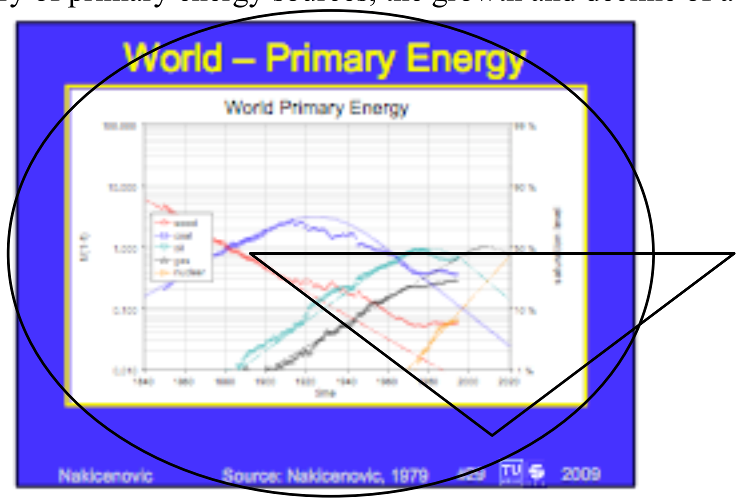
The Law of Unintended Consequences

The greatest challenge facing New Yorkers at the turn of the century was manure. Public health officials wrung hands about how to keep the streets clean of it. Workers shoveled streets around the clock. The byproduct of horse mobility had reached such a depth as a problem that some newspaper editorials worried it would mark the end of the age of cities. When the car was introduced, these clean elegant horseless coaches were hailed as the saviors of urban mobility.

The car revolution ended fears that New Yorkers would drown in a sea of manure, but ushered in the age of bad urban air and invisible impacts. The coal revolution saved Britain's forests, but began the era of global warming. The lesson is that as we seek to replace existing technologies and their attendant consequences, we must be mindful of the downside to new alternatives. We do not want to solve today's climate crisis by initiating tomorrow's nuclear debacle.

Logistic Growth Curves & Inflection Points

One of the more interesting dynamics to technological changeover has bearing on the potential future of nuclear. For the modern history of primary energy sources, the growth and decline of a new technology follows a specific pattern. As new technologies are introduced, they undergo a logistic growth curve until a replacement technology is introduced– which also undergoes its own logistic growth curve as well. Once a technology is on a logistic decline, it is unaffected by the introduction of new technologies. If this pattern holds true for nuclear, we have yet to see its emergence as the dominant primary energy source. Another lesson about the nature of technological change is to be found in the graph of its adoption. Take the transition from cars to horses. The adoption of cars took the better part of forty years, but the real sweep of transition, where the bulk of the transformation occurred took only ten years. Since this pattern is repeated for many replacement cycles, one can say in general that while the setup to a technological transition may take quite a long time, once the initiation is underway, the transformation will be swift.



Energy Scenarios with Technological Uncertainty

A final conundrum is choosing the right technological solutions for the future in conditions of uncertainty. Using a basket of different energy technologies, Nakicenovic simulated a range of possible future scenarios to see how the development of a series of technologies would develop depending on the breadth of the technology portfolio, and the varying uncertainty about their learning rates. The output from 130,000 separate scenarios was striking: the costs to a diverse energy portfolio were high, especially with increasing uncertainty. If we were able to remove uncertainty, a bifurcation of paths emerges into two possible energy futures, either of which is significantly lower cost. The catch is: since we cannot remove such uncertainties about the learning--improvement process, we are (with a high degree of probability) condemned to a path of necessarily higher costs.

3. Future Perspectives

The lecture looked at future trends in technological changes building from the historical pattern of transformation from tool making, through agricultural development into the industrial revolution. These transformations are accompanied by other dimensions of transformations such as values, knowledge, demographic, social, economic, governance and technology. Urbanization represents some of the major transformations experienced in recent times. Over 70% of the people in the world will be living in cities by 2050. This also infers similar trajectory in resource consumption pattern accompanied by emission levels under such a scale of demographic changes. Following the trend in urban growth, education levels have increased in urban areas with over 50% of the population project to have at least secondary school level education. Similarly, there will be growth in democratic practices. The greatest challenge is energy which is at the nexus of global change. Following IPCC 2007 projections, there will be global temperature rise of about $2^{o}C$. All these pose major global challenges which include sustainable access to energy and food which is emphasized in the Millennium Development Goal (MDGs), changes in energy and ecosystem services, security and reliability of systems, deep CO2 and GHG reductions. All these will require investment in research and development, and also addressing the climate, economy and investment crises. There are great potentials and diversity in the renewable resource-bases ranging from hydropower, biomass energy, solar energy, wind energy, geothermal and ocean energy. The total capacity of global renewable energy is estimated at 144000000 exajoules per year. There are also significant variations in carbon reservoirs with the ocean holding the largest pool of carbon. The greatest however, is how best can these carbon pools be exploited sustainably following the potentials they provide.

Global primary energy sources are experiencing an evolutionary change with a shift from coal to oil, gas, nuclear and renewable. T he contributions of the various sources of global primary energy consumptions will be different over time under business as usual (A2r) and the emission reduction (BI) scenarios following IPCC projections. Coal will remain the dominant source of energy under business as usual, but in the alternative scenario, renewable energy will dominate by 2030. Similarly, long term stabilization profile will have different patterns under the different scenarios.

There are strong correlations in patterns of some of the global changes taking place. Global population density for example, corresponds to global GDP density, global build-up areas and global arable land. Global bioenergy land also corresponds to areas of agricultural productivity. Therefore it is important avoid energy and food land conflicts by delimiting the potential areas for bioenergy production.

Technology will have to play an important role in order to achieve carbon-free energy and this is unlikely under business as usual under the all the projected temperature increase scenarios for both the southern and northern hemispheres. The question however, remains to what extend is the cost of investment in order to achieve the change we need using technology? Unfortunately, the more climate friendly practices do not seem to have significant investments. Energy efficiency is another important aspect in addressing the challenges. Collective transportation has an important role to play. Whatever vision we want for the future, there will be there need for behavioral changes and adjustments in lifestyle. This will requires funding in research and development. A more sustainable future will therefore require a pathway that addresses multiple challenges simultaneously. This would require globally integrated effort that bridges scales.