The Economics of Biofuels: A New Industrial Revolutuion?

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I want to talk to you today about the economics of biofuels. I will include many facts and figures. And my topic will digress into economic history, the theory of economic growth and go beyond biofuels. This is because biofuels are one approach to decarbonizing our thirst for energy. If we did not care about the increasing concentration of carbon dioxide in the atmosphere, we would not be here today I suspect. For there is likely enough coal and oil tied up in shale and sands, to satisfy the rapidly growing world demand for energy for several hundred years. But adding carbon to the atmosphere is thought to be a serious problem by many scientists in that unexpected and dangerous climate change and rising sea levels result from atmospheric warming. It is impediment to economic growth as I shall argue later.

The concentration of carbon dioxide is close to 400 ppm by volume and scientists think that at 500 ppm there will be significant warming and perhaps catastrophic and irreversible climate change. Current levels are the highest in 650,000 years, as we know from ice core analysis. In addition, to atmospheric warming and the resulting climate changes and ocean current changes (which feeds back to climate changes), air pollution in the form of particulate matter, the oxides of sulfur and nitrogen and unburned hydrocarbons contributes to respiratory illnesses that take their toll in lost productivity and higher medical costs. Sulfur in the atmosphere contributes to acid rain that takes its toll on forests and marine life in lakes and rivers. Mining coal has its own environmental and social consequences. One hears of the deaths of miners and sees decapitated mountains and the acid runoff from mining operations. Perhaps we justify this as the cost of maintaining our standard of living. I think one thing is clear, we do not understand completely the complex consequences of our way of life on the environment that sustains us.

How did we get here? And what is a way forward that ensures sustainability and a high quality of life for the planet's inhabitants (plant and animal)? We know that for most of history humans subsisted on less than $1 per day (Angus Maddison, 2001). In modern history, the U.S. fared better. Figure 1 shows that, calculated in 1996 constant dollars, GDP per capita (that is, average output) was $1,050. That amount at the birth of our nation would rank us among the poorest countries today such as Uganda, Tajikistan and Rwanda. (To be sure, in each case, much production was and is in the home for one's own use [that is, non-market activity], so output per capita is surely underestimated.) GDP per capita rose to $33,568 in 2001 representing an almost 32-fold increase. This period represents the onset of the most rapid, intensive and sustained growth in human wealth and population since the beginning of the human race.

The table below illustrates the exponential world population growth over the past 25,000 years. It is useful to appreciate both the extremely low rate of population growth over most of history as well as the time scale over which this rate operates. For example, using Kremer's (1993) collection of world population data, the rate of population growth, measured as the average annual change in log population, was only 0.0000072 between 1 million B.C. and 1 A.D. Nevertheless, over this period, the level of population increased by a factor of 1360: from 0.125 million people in 1 million B.C. to 170 million people in 1 A.D. A second key fact about population growth apparent in the table, emphasized by Kremer (1993), is that the rate of population growth is itself generally increasing over time. This is true not only in recent centuries but also dating back to our earliest data.

The takeoff in population growth beginning about 200 years ago was made possible by the first industrial revolution and by the scientific revolution that preceded it. The scientific revolution included advances in chemistry, mathematics, biology and physics that allowed the first industrial revolution to proceed. Theoretical developments were followed by practical developments that saw science as instrumental in shaping human destiny and freeing it from the physical toil of subsistence. There was thus a rift between natural philosophy that sought to understand the world and universe as it is and instrumental science that sought to put science and engineering to use for the amelioration of the human condition (Peter Dear, 2006).

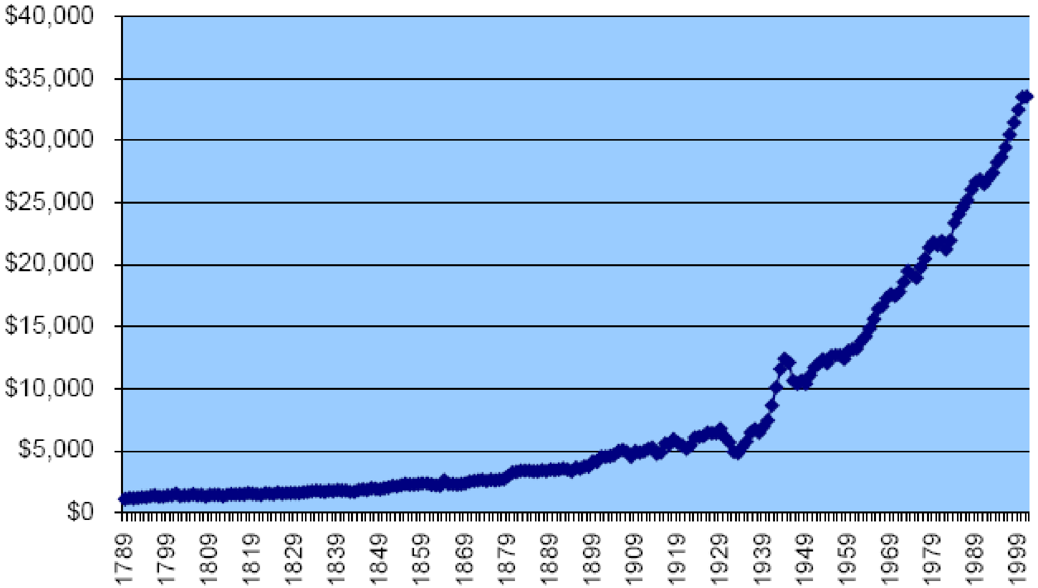

Exhibit 1. Growth in U. S. GDP per capita, 1789-2001 (1996 dollars).
Source: Johnston and Williamson (2002)

Table 1: Population Data

Year	Population Level (Millions)	Average Annual Growth Rate over Preceding Period
-25000	3.34	...
-10000	4	0.000012
-5000	5	0.000045
-4000	7	0.000336
-3000	14	0.000693
-2000	27	0.000657
-1000	50	0.000616
-500	100	0.001386
-200	150	0.001352
0	170	0.000626
200	190	0.000556
400	190	0.000000
600	200	0.000256
800	220	0.000477
1000	265	0.000931
1100	320	0.001886
1200	360	0.001178
1300	360	0.000000
1400	350	-0.000282
1500	425	0.001942
1600	545	0.002487
1700	610	0.001127
1800	900	0.003889
1900	1625	0.005909
2000	5333	0.011884

Note: The levels of population are taken from Kremer (1993), who in turn takes his data from various sources. The population growth rate is computed as the average annual change in the natural log of population over the preceding interval. Two changes relative to Kremer are made. First, the year 1 A.D. is set equal to the year 0. Second, the population in 1990 is used for the population in the year 2000. These changes are made so that the period length in the model can be set equal to 25 years. The growth rates for a few periods are slightly different from those in Kremer because he reports growth rates from his underlying sources rather than based on the levels themselves.

The first Industrial Revolution began in Britain in the late eighteenth century and was characterized by a shift to capital-intensive production methods, rapid growth in labor productivity and living standards, and the formation of large corporate hierarchies, overcapacity and subsequently, the closure of facilities. New energy sources were applied to manufacturing processes such as coal and oil-fired steam engines, which freed the location of factories that otherwise had to rely on waterpower, horsepower or wood.

The mid-nineteenth century witnessed another wave of technical change with the birth of modern transportation and communication systems. These include the railroad, telegraph and telephone, steamship, and intercontinental cable systems. Electricity and the electric light allowed 24-hour production (one of Thomas Edison's largest installations of electric lighting was in the American Thread Mill in Willimantic). Fractional horsepower electric motors allowed the dispersal of production activities. The inventions of the McCormick reaper, the sewing machine, high-volume canning and packaging equipment, Bessemer steel production, and wire nails revolutionized harvesting, production and distribution methods. Between 1869 and 1899, the capital invested for each American manufacturer grew from approximately $700 to $2,000. Between 1889 and 1919, total factor productivity grew six times faster than that which occurred during the nineteenth century (Michael Jensen, 1993 and references there).

As productivity soared during this period, production costs and final prices fell significantly. The formation of Standard Oil Trust in 1882 concentrated 25% of the world's kerosene production in three refineries and reduced the average cost of a gallon of kerosene by 70% between 1882 and 1885. The invention of the Bonsack machine in the early 1880s reduced the labor cost of cigarette production by 98.5 percent. The Bessemer process reduced the cost of steel rails by 88% between the early 1870s and late 1890s. The electrolytic refining process reduced the cost of aluminum by 96% between 1888 and 1895. In chemicals, the mass production of synthetic dyes, alkalis, nitrates, fibers, plastics and film occurred rapidly after 1880. Production costs of synthetic blue dye for example fell by 95% from the 1870s to 1886 (something Levi Strauss may have appreciated). New low-cost sources of superphosphate rock and the manufacture of superphosphates changed the fertilizer industry and ushered in the agricultural revolution.

During the last decade of the eighteenth century, surplus capacity developed as demand did not keep pace with expanding production and was exacerbated by the recession of 1893. Capacity was reduced through consolidation and closure of marginal facilities in merged firms. Between 1895 and 1904, more than 1,800 firms were bought or combined by merger into 157 firms. Some of these firms were experiencing economies of scale in which a doubling of production did not double production costs and encouraged the formation of ever-larger facilities. Some firms may also have experienced economies of scope in which a single firm can produce two goods using similar inputs (capital, labor and technology) less expensively than two firms can produce the two goods separately.

The restructuring of the American business community that began in the 1970s and continues through the 1990s and today is being brought about by a variety of factors, including changes in physical and management technology, global competition, regulation, taxes, and the conversion of former essentially closed and centrally-planned economies of eastern Europe to capitalism and foreign trade. Michael Jensen (1993) suggests that these changes are bringing about a third Industrial Revolution. The shift began with the first oil shock of 1973 that resulted in ten-fold increases in energy prices. In addition, Jensen points to the emergence of the modern market for corporate control and high-yield, nonrated bonds. Macroeconomic data for the 1980s shows that TFP in the manufacturing sector grew 1.4% annually from 1950 to 1981 and doubled to 3.3% per year during the period 1981 to 1990. Nominal unit labor costs halted their 17-year rise and real unit labor costs declined by 25% during this period. These lower labor costs resulted from increased productivity, not from lower wages or unemployment. Nominal and real hourly compensation increased by 4.2% and 0.3% per year respectively from 1981 through 1989. Manufacturing employment reached a low in 1983 following the recession, and by 1989 rebounded to a cumulative increase of 5.5%. Labor productivity, while exhibiting respectable growth from 1950 through 1981 at 2.3% per year, jumped to 3.8% per year between 1981 and 1990. The productivity of capital reversed its negative annual growth between 1950 and 1981 of -1.03% to +2.03% between 1981 and 1990.

During the 1980s, the real value of public firms’ equity more than doubled from $1.4 trillion to $3 trillion. Real median income grew at 1.8% per year between 1982 and

1989 reversing its negative annual growth rate of 1% from 1973 to 1982. Real R & D expenditures achieved record levels each year from 1975 to 1990 growing at an annual rate of 5.8%. Notwithstanding the impressive gains in productivity, efficiency and welfare, the 1980s were generally perceived to be years of greed and excess. Criticism focused on mergers and acquisitions 35,000 of which occurred between 1976 and 1990 for a total value of $2.6 trillion in 1992 dollars. This corporate restructuring continued through the 1990s and does so today. [e.g., ATT acquisition of BellSouth].

Joel Mokyr, an eminent economic historian, noted that the first Industrial Revolution in Britain was not marked with continuous and purposeful R & D, but rather by sporadic, localized inventions and their adaptation to production. Perhaps 10% of the workforce was engaged in ‘modern’ production facilities (factories using machines powered by steam). Since 1950 in the U.S., we see R & D in a wide variety of industries and purposeful R & D undertaken in several public and private venues (universities, corporate labs, government labs and testing agencies). Technical progress today is widespread and ubiquitous and its pace is punctuated with breakthroughs as well as with periods of little apparent activity. One such breakthrough may be the unraveling of the human genome. The Economist magazine in 1996 argued that our age might be compared to the Industrial Revolution (the first one) because of the pervasiveness of IT in our economy (and in the world’s industrialized economies). IT can be characterized as a general purpose technology which is a great leap of innovation that affects an entire economy.

Unlike traditional technologies that are smooth and gradual advancements, GPTs represent drastic advancements that redefine society. Examples include the steam engine, railroads, electronics, the automobile and the computer. The introduction of a new GPT may actually decrease productivity before improving it because old skills and technologies become obsolete, there are learning costs, there needs to be new infrastructure developed to support the GPT, and labor needs to adjust to new industries resulting in frictional (short-term) and structural (long-term) unemployment. GPTs drive the increasing returns that drive endogenous growth. Increasing returns to scale occur when a doubling of inputs more than doubles output. There are usually constant returns to the reproducible factors of capital and labor, but increasing returns to production technology that includes knowledge or technology, a non-rivalrous good. I will return to endogenous growth in a minute.

As an example of the delayed effect of a GPT, economist Paul David (1991) explains the surge in U.S. productivity during the 1920s as a delayed response to the introduction of the electric dynamo in the 1880s. To the extent that GPTs yield large, positive externalities on a wide range of industries some time after they are discovered, individual inventors are likely to under-invest in producing them. Therefore, government intervention may be necessary to reach optimal levels of investment in research and development. Economists Richard Lipsey, Cliff Bekar and Ken Carlaw (1998) characterize GPTs with four criteria: wide scope for improvement and elaboration, applicability across a broad range of uses, potential for use in a wide variety of products and processes, and strong complementarities with existing or potential new technologies.[1] GPTs will surface later in my discussion of biofuel technologies.

Mokyr suggests that a cluster of such GPT technologies constitutes an industrial revolution. These are 'door opening' and not just 'gap filling' inventions or innovations. Mokyr argues that we are living in such an age. He points out that while the first Industrial revolution brought workers en masse from their homes to the factory and changed production modes, the new industrial revolution through telecommuting and outsourcing is reversing the 200-year old paradigm of everyone at work at the same time and place.

Endogeneous growth theory emerged in the late 1980s as a better explanation of the economic growth experience in the world's advanced industrial economies in the latter half of the 20th century. Prior to Paul Romer's seminal paper, the model of economic growth widely studied was the Solow model that predicted growth of per capita consumption in the steady state was possible only if exogenous technical progress was growing faster than the declining marginal product of capital. Romer's argument was that technical progress occurred inside the system, in purposeful R & D and that produced increasing returns on an economy-wide basis that led to growth in per capita income in the steady state even while there are constant returns to capital and labor.

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[1] Moser, Petra and Tom Nicholas (2004). "Was Electricity a General Purpose Technology?" *American Economic Review, Papers and Proceedings*, Vol. 94, No.2, pp 388-394, ssrn.com/abstract=930649.

The Romer model stimulated an explosion of research in the 1990s on endogenous growth and in particular on sustainable growth. Sustainability in the economist's sense is generally taken to be non-decreasing per capita consumption forever. This is a tall order given that the first law of thermodynamics that says you can't make something out of nothing and thus there is likely a minimum resource intensity that allows production to proceed. In addition and perhaps more importantly, it is that production entails pollution (greenhouse gases are one form) an unfortunate consequence of the second law of thermodynamics. Even if we have zero population growth, and several nations are at or below this threshold, declining resource inputs (energy, raw materials, potable water[2], arable land, breathable air), suggest that something else has to save us. That something is technology. And somehow it must substitute reasonably well for the other inputs to production or that will fail us as well in long term survival. We are consuming renewable resources at rates that exceed their regeneration rates (so all resources can be regarded as exhaustible) and we are releasing pollutants into the atmosphere, water and ground faster than the earth can assimilate them (the doubling of CO_2 levels since the 18th century exemplifies this claim). Can technology save us from drowning in our own waste?

Now technology has done a pretty good job of saving us from the Maltusian trap. This is the paradigm that says population grows geometrically or worse exponentially and land grows linearly (as well as its output) and at some point we won't be able to feed all of us. The death rate would keep population in check, but many would live at subsistence levels (recall the $1 per day from above) as they had for thousands of years before 1500. Malthus and others did not look around them to see the first Industrial Revolution in progress and he had no concept of technological improvement. How else could the U.S. for example go from 70% of its population involved in farming in the 1870s to less than 2% today?

We face instead today not a shortage of food, but an impending shortage of oil as supplies have peaked (neglecting shales and sands and coal) and world demand is climbing rapidly. And our cumulative dumping of greenhouse gases into the atmosphere

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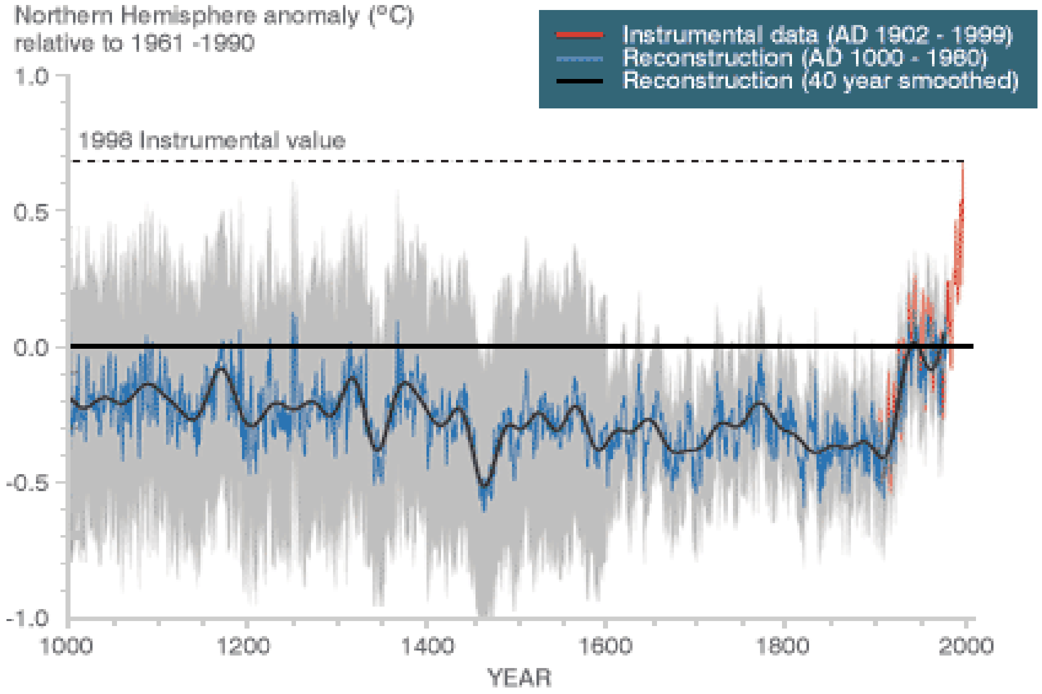
[2] See www.waterfootprint.org/reports/hoekstra_and_chapagain_2006.pdf.

threatens to turn the atmosphere from greenhouse to hothouse and is one of the most vexing yet important challenges before us. The 'hockey stick' graph illustrates this point.



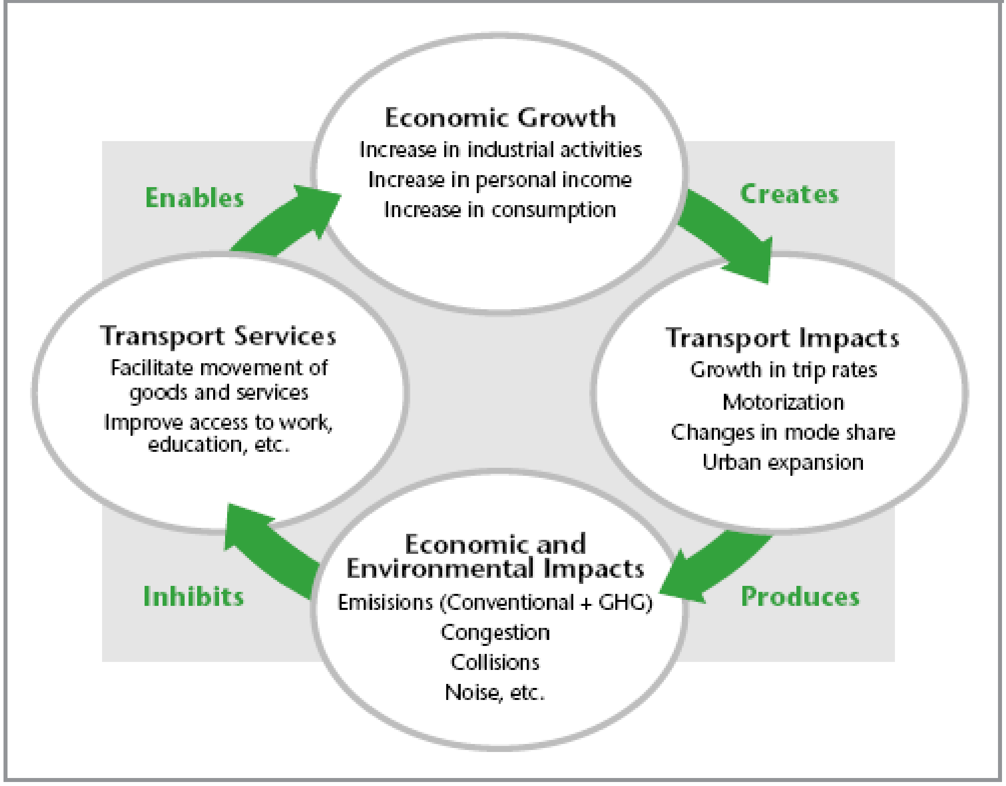
Some think nothing short of Apollo-like investment can curtail the path toward calamitous climate change. This is the mantra of the Apollo Alliance (www.apolloalliance.org) about which I will say more later. The U.S. has less than 5% of the world's population but produces nearly 25% of its carbon emissions (7 billion tons of coal, oil and natural gas are burned in the world releasing CO_2). We see China and India rapidly industrializing and with that increasing the demand for and use of fossil fuel and the concomitant release of carbon to the atmosphere. Keeping the atmospheric carbon concentration under 500 ppm while the world's economy continues to grow (3% per year for the past 30 years) is indeed a challenge. Over the past 30 years, carbon emissions rose at 1.5% per year, so the carbon intensity or the ratio of emissions to dollars of gross world product fell about 1.5% per year. If we would stabilize carbon emissions at today's level, this implies that the carbon intensity would have to fall as fast as the global economy grows. One hope is for world population to approach zero growth. With increasing average wealth, education and leisure, one hopes that the rising opportunity cost of children works to limit fertility. This is known as the demographic transition.

The good news is that the future vehicles and future buildings are not yet designed and future communities are not yet located with respect to their inhabitants' workplaces. So we can with sufficient attention and investment design a future that is sustainable and provides an acceptable quality of life for all. Princeton Professors Robert Socolow and Stephen Pacala suggest a panoply of stabilization 'wedges' or strategies to forestall the unhappy scenario if rates of carbon emissions do not fall on the one hand and to realize one in which carbon emissions remain close to current levels as growth proceeds on the other. Each 'wedge' contains specific clusters of strategies that reduce carbon emissions. The strategies include: end-user-efficiency and conservation, perhaps the easiest and least costly approach; agriculture and forestry conservation and deforestation cessation; alternative energy sources; carbon capture and storage (CCS); and power generation efficiencies. Oil accounted for 43% of global carbon emissions from fossil fuels in 2002, coal accounted for 37% and natural gas the remainder. More than half the oil was used for transport, so just making power generation more efficient and less carbonizing is less than half the answer. Transportation needs to become much more efficient and less carbonizing. This where biofuels can help, because synfuels are not the answer even if CCS is employed.

The U.S. light duty vehicle fleet that includes cars, pick-up trucks, SUVs, vans, and small trucks consumes 150 billion gallons of gasoline per year. This represents 1.3 gallons per person per day. If other nations burned gasoline at this rate, world consumption would rise by a factor of ten. And our use of gasoline engines is highly inefficient: when we take into account stop-start behavior, idling, cold weather driving, aggressive driving and mechanical losses, only about 1% of the chemical energy in the gas tank moves a payload of 300 pounds (passenger and luggage). Therefore, improving vehicle efficiency would contribute much to reducing carbon emissions. VW for example has a concept car weighing 640 pounds and gets 240 miles to the gallon. Details of this car are not available, but improvements in engine and transmission design and especially weight reduction are key factors.

Clearly, transportation is an important ingredient for economic growth as the chart below shows. But our reliance on conventional transportation modes has its costs as well. In 2001, personal consumption expenditure for transportation totaled $800 billion or about 11% of GDP. These are measurable, accounting costs, but economists include economic costs as well. These include opportunity costs and negative externalities. Clearly, time is money and congestion steals valuable time from production and leisure. In addition, the pollution produced from transportation activity costs us in the form of increased medical expenditure for respiratory illnesses, not to mention lost productivity due to illness. In a report I did with graduate students at the Center for Economic Analysis two years ago, we estimated the savings measured as averted costs from switching to a 20% blend of biodiesel in Connecticut's diesel fleet amounted to $20 million per year. So the $800 billion or about 11% of GDP is a conservative estimate of the true cost of transportation.

Figure 1.1 The challenges of making mobility sustainable



Source: Adapted from Molina and Molina 2002, p. 214.

Before looking at biofuels and policy issues in particular, I want to mention another area ripe for reducing carbon emission and creating jobs. Green building technology is evolving rapidly in this country and in Europe. One of the largest European manufacturers of prefabricated houses is now offering zero-net-energy houses. These well-insulated and intelligently designed structures with solar-thermal and photovoltaic collectors do not need commercial energy, and their total cost is similar to those of new houses built to current building codes. Because buildings have a 50- to 100-year lifetime, we need to consider efficiency retrofits. For example, roof overhangs, popular in Frank Lloyd Wright and craftsman-style homes, reduce heat buildup in walls and windows. These modifications may be difficult in existing structures, but could be considered in new and remodeling plans. A retrofitting project in Ludwigshafen, Germany provides another example: five years ago 500 houses were equipped to adhere to low-energy consumption standards (about 30 kilowatt-hours per square meter per year). This reduced the energy requirement for these houses by a factor of six. Before the retrofit, the houses were difficult to rent; today demand is three times greater than capacity. In this context, it is useful to consider that 65% of primary energy that in natural resources we harness for power is lost during conversion to useful energy that makes our lives more comfortable (at least for about 1 billion of us). 80% of primary energy comes from carbon-emitting fossil fuels and 35% of greenhouse emissions come from buildings.

Turning to biofuel, I want to first discuss ethanol as that has captured the imagination of Congress and perhaps a significant part of the Midwest's self-image that produces it. Ethanol manufacturers benefit from a $2 billion annual subsidy and sold more than 4 billion gallons in 2005 representing about 3% of all automobile fuel by volume. Ethanol production is expected to rise by 50% this year and jump to 7.5 billion gallons per year by 2012. But several studies that consider the net energy balance to produce ethanol conclude that it takes more energy to produce a gallon of ethanol than one gets from burning it. Such studies examine the life-cycle costs that include the cost of planting, fertilizing, harvesting, fermenting, and transport to end users. The process requires energy inputs at each step; diesel-powered tractors and other farm equipment, the initial heating steps use natural gas (some ethanol producers use coal) and finally transport to users consumes diesel fuel. In addition, ethanol contains 2/3 the heat content by volume compared to gasoline, so mileage is reduced up to 33% depending on the fraction of ethanol in the gasoline (E85 is currently the highest concentration).

A study released yesterday from MIT[3] reviews the existing life-cycle ethanol studies and adds a valuable twist. The graduate student used ranges or distributions of parameter values in assessing the life-cycle properties of ethanol production. Based on her "most likely" outcomes through thousands of simulations (Monte Carlo), she concludes that traveling a mile using ethanol does indeed consume more energy than traveling the same distance using gasoline. However, further analyses showed that several factors can easily change the outcome, rendering corn-based ethanol a "greener" fuel.

One such factor is the co-product credit. As corn is converted into ethanol, the material that remains is a high-protein animal feed. One assumption is that the availability of that feed will enable traditional feed manufacturers to produce less, saving energy; ethanol producers should therefore subtract those energy savings from their energy consumption. When this was done, ethanol's life-cycle energy use was less than gasoline's. In reviewing the other studies, the grad student concludes that they are basically correct in their findings as they fall within the bounds of her most probable outcomes (or her's are correct as they include the others).

But converting corn kernels to ethanol may not be the best way. Converting the nitro-cellulosic material in corn stalks and other high-cellulose plants from hybrid trees such as poplars and willows, as well as switchgrass and kenaf may yield greater quantities of alcohol per acre achieving balances significantly greater than one. These plants may grow on marginal land to produce a cash crop and preserve green space, and decarbonize our future. The following diagram illustrates the possible pathways from a variety of plant cultivars and waste streams to usable biofuels.

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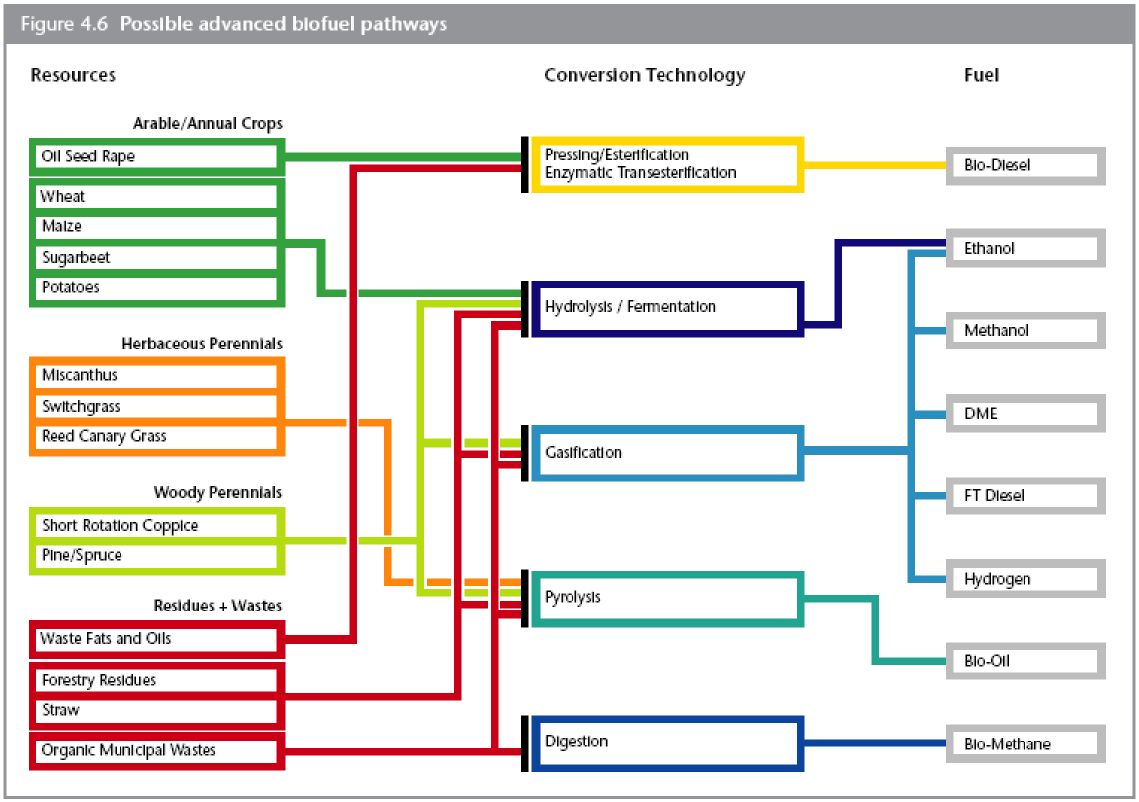
[3] http://web.mit.edu/newsoffice/2007/ethanol.html

Figure 4.6 Possible advanced biofuel pathways



Source: Adapted from **E4tech 2003**

Speaking of waste streams, I want now to look at Connecticut (our high density population imports much of its agricultural and commodity products and creates large waste streams). Let's look at Connecticut's fuel consumption.

During calendar year 2003, sales of residential heating oil in the state of Connecticut were 642.5 million gallons at an average price of $1.44/gal for a total of $922.9 million in sales. Approximately 680,000 households in Connecticut use home heating oil for their winter heating needs. Based on 2003 activity levels, if each of these households utilized biodiesel blended at 20% with petroleum based home heating fuel (requiring no modification to the existing oil burner), this would represent sales of 128.5 million gallons of biodiesel annually. While home heating fuel is potentially the most readily accessible market for biodiesel, it is only one potential market. Another is the transportation sector. Diesel engines can similarly run on biodiesel with little or no modification necessary. While auto manufacturers are not as yet willing to warranty their vehicles for the use of B100, the use of a 20% blend has gained acceptance. Sales of diesel fuel in Connecticut for calendar year 2003 were 219 million gallons at an average price of $1.64 per gallon for a total of $359.7 million in diesel fuel sales. Based on 2003 activity levels, a 20% blend of biodiesel would result in sales of 43.8 million gallons of biodiesel in Connecticut annually.

Calendar year 2003 combined home heating oil and diesel sales in Connecticut accounted for a total of 861.5 million gallons. If this figure included biodiesel blended at 20%, it would result in a requirement for 172.3 million gallons of biodiesel annually with a value of $256.5 million (in 2003 dollars). This figure becomes even more significant when you consider that the establishment of a local biodiesel production industry will serve to retain these dollars in the Connecticut economy rather than sending them elsewhere.

While the market for diesel powered passenger vehicles in Connecticut and the United States is small as compared to gasoline power, this trend is poised to shift. New diesel technology has led to a new breed of diesel automobiles that run smoother, have ultra low emissions, and have doubled, tripled and in some cases quadrupled fuel efficiency.[4] These diesel automobiles are popular in Western Europe where diesel passenger car sales accounted for 44% of all passenger vehicles sold in 2003.[5] Developing the capacity for biodiesel production in Connecticut will take advantage of the existing home heating oil market as well as position the state to benefit from the potential growth of the diesel passenger vehicle market.

In addition to reducing our dependence on finite fossil fuel, some additional benefits of biodiesel include the following:

- ✓ 100% less sulfur dioxide, 37% less unburned hydrocarbons, 46% less carbon monoxide, and 84% less particulate matter;[6]
- ✓ There is no net carbon dioxide gain as the CO2 released through biodiesel combustion was originally captured from the air by the plants during growth.
- ✓ Biodiesel has greater lubricity than conventional diesel fuel, resulting in smoother operation. New EPA requirements for low-sulfur conventional diesel fuel will ***decrease*** lubricity and require additives such as biodiesel.

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[4] Biodiesel America, Joshua Tickell (2006), Yorkshire Press. Pg74

[5] Ricardo Incorporated, Annual Diesel Report 2004, http://www.ricardo.com/pages/dieselreport.asp

[6] National Biodiesel Board, Lifecycle Summary, http://www.biodiesel.org/pdf_files/LifeCycle_Summary.PDF.

- ✓ The total fossil energy efficiency ratio (i.e., total fuel energy/total fossil energy used in production, manufacture, transportation, and distribution) for diesel fuel and biodiesel shows that biodiesel is four times as efficient as diesel fuel in utilizing fossil energy – 3.215 for biodiesel vs. 0.8337 for diesel.[7]

- ✓ Connecticut ranks as the state 9th most susceptible to cancer risks associated with air quality.[8] Seventy-five thousand children and 202,800 adults in Connecticut suffer from asthma, and reports suggest that in one year smog is responsible for 2,500 hospital visits and 100,000 asthma attacks. According to the Connecticut Center for Economic Analysis (CCEA), the estimated net benefit to Connecticut of using biodiesel for home heating and in on- and off-road heavy-duty vehicles—given the costs as calculated by the predicted spread between B20 and distillate fuel prices and the averted health costs—is almost $20 million.

- ✓ Biodiesel is environmentally safer than petro-diesel. It is nontoxic (by comparison, table salt is ten times more toxic), produces less skin irritation than soap and water, it degrades four times as fast as petro-diesel (about as fast as sugar), and has a flash point significantly higher than that of petro-diesel, thus making it safer to store and handle. These characteristics imply that in the event of a spill or leak, compared to conventional diesel, biodiesel is less likely to explode or hurt humans, animals or fish.

Governor Rell's *Connecticut Energy Vision* creates a strategic context for the establishment and use of clean and renewable fuels through the use of incentives, mandates, and leading by example.[9] The context for the establishment of a biodiesel industry is provided for in the following *Connecticut Energy Vision* policy statements:

- o "Provide a Range of Low-interest Loans or Grants to Farmers to Produce Biofuel Feedstock Crops"
- o "Establish an Incentive Program to Promote the Construction of Biofuel Production Facilities"
- o "Create a Low-interest Forgivable Loan Pool for the installation of Alternative Vehicle Fuel Pumps"

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[7] Biodiesel Lifecycle Inventory Study, U.S. Department of Energy and U.S. Department of Agriculture, May 1998. See also footnote 7.

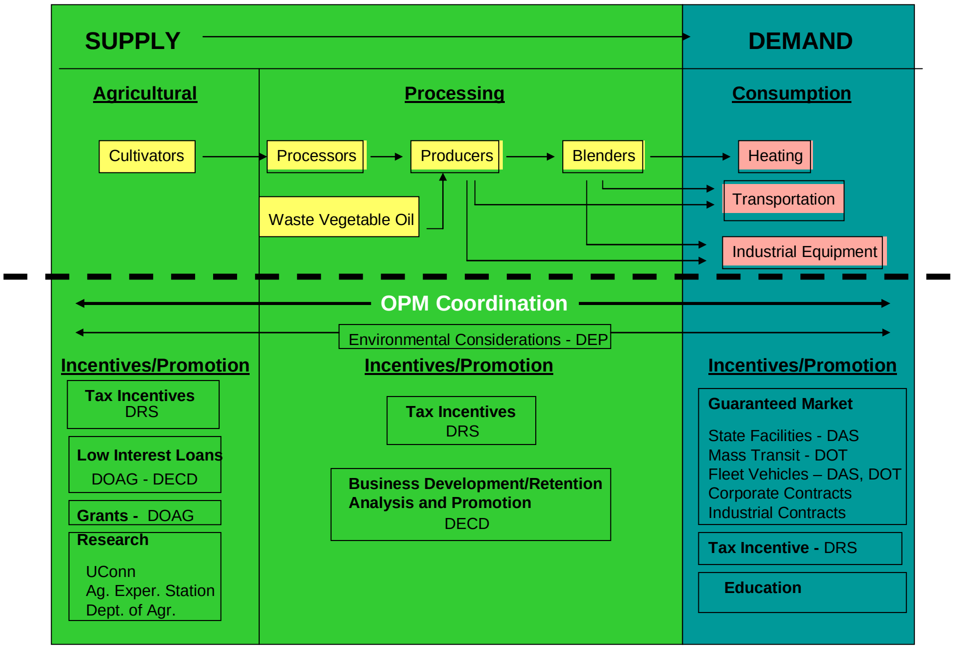
[8] http://www.scorecard.org/env-releases/hap/rank-states.tcl. Also see, "Diesel and Health in America: The Lingering Threat," www.catf.us/goto/dieselhealth.

[9] www.ct.gov/governorrell/cwp/view.asp?a=1809&Q=320142

- “Ban Exclusivity Agreement Provisions that Limit Gas Stations Access to Renewable Fuels”
- “Mandate Use of 10% Biofuels by State Vehicle Fleet by 2012”
- “Recommit State to Renewable Goals in Executive order 32”
- “Maintaining the state’s leadership in the use of alternative energy sources.”
- “Leveraging state intellectual resources to bring business and university assets together to facilitate economic growth, job creation and the development of new markets”

The context Governor Rell has created will require legislative initiatives as well as administrative initiatives. In order to establish a biodiesel industry in Connecticut all sectors of the industry must be invigorated. The supply side of the industry includes: crop cultivators, crop processors, biodiesel producers and blenders. On the demand side motivated consumers are necessary. Figure 1 shows how the incentives and promotion of each of the steps in the supply and demand side continuum must be articulated and implemented to foster a sustainable biodiesel market in Connecticut. When the entities in this chain of supply and demand have been established a Connecticut biodiesel economy will be in place.

Biodiesel Industry Development Strategy Figure 1



Regarding Supply: Connecticut's Agricultural Experiment Station is actively evaluating plant cultivars for high oil yield in our soils and climate. These cultivars promise to provide farmers with a cash crop, enrich their soil and maintain (productive) green space. Continuing research should have additional payoffs insofar as yields improve (possibly a doubling in 10 years) and taking advantage of the waste streams for other biofuel production, such as sewerage and biomass. Although Connecticut will not be able to produce biofeedstock to supply all of its biodiesel needs, the potential to cultivate even a small percentage of biofeedstock locally should be pursued.

For example, if 310,000 acres of Connecticut land were used to grow bioenergy crops (oilseeds, fast-growing poplars, willows and grasses), 15% of Connecticut's petroleum distillate fuel needs (about 1.22 billion gallons[10]) could be satisfied locally (about 22% of U.S. oil imports come from the Middle East[11]). This 'bioenergy' land could be a combination of fallow land, open space land, marginal agricultural land and forest and its new use need not change the look, feel and function of the lands' current

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[10] Energy Information Agency, 2003 figures, http://www.eia.doe.gov/emeu/states/state.html?q_state_a=ct&q_state=CONNECTICUT
[11] Kiernan, P. (2006). "Getting Real About U.S. Dependence on Foreign Oil", World Politics Watch, http://www.worldpoliticswatch.com/article.aspx?id=206.

character. The CT Department of Agriculture estimates that there are 170,000 acres currently producing corn and hay that could be available for bioenergy crops.

Current productivity of Connecticut land is about $500 per acre per year. UConn researchers estimate that the productivity of bioenergy crops will be about the same. However, significant savings in costs of fertilizers and pesticides relative to such costs for corn should be realized. In addition, planting rapeseed and soybeans in rotation actually enhances the soil. Therefore, Connecticut farmers will realize greater profit per acre growing bioenergy crops than from traditional crops.

To ensure Connecticut's ability to cultivate a small but significant portion of biofeedstock, state policy must be committed to the preservation of both agricultural lands as well as other undeveloped open spaces that might be used for cultivation. Existing land-use patterns continue to develop finite agricultural resources. Soil-based agriculture is now confined to the best remaining soils that have not been preempted by competing land uses.[12] Such a commitment is necessary to advance the viable cultivation of biofeedstock and ensure that Connecticut's future includes the ability to produce a portion of its own biofuel needs.

While it is possible to make a dent in the state's needs by providing farmers and lands in trust with plant cultivars that produce oil (a cash crop), and at the same time enrich the soil, control nematodes and other plant pathogens, and keep Connecticut green, additional feedstock will need to be imported from states producing seed oil in quantity. The industry will also need to develop mechanisms to collect and process waste vegetable oil from Connecticut restaurants and confectionaries. According to the United States Department of Agriculture, the U.S. produces over 11 billion pounds of used cooking oil and animal fat each year.[13] Waste vegetable oil represents an immediate source of feedstock for the production of biodiesel that does not require the same pre-processing as agricultural crops. To take full advantage of the potential that biofuels present, Connecticut needs to develop a large-scale biodiesel production industry capable of processing raw agricultural material grown here and imported, as well as imported virgin vegetable oil and waste vegetable oil.

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[12] State of Connecticut, Office of Policy and Management, "Conservation and Development Policies Plan for Connecticut 2005 – 2010", Page 64, available at www.opm.state.ct.us/igp/cdplan/cdplan2.htm.

[13] Biodiesel America, Joshua Tickell (2006), Yorkshire Press, pg 144

Connecticut-produced biofuel has the potential to supplement the state's needs for transportation and heating. At present, Connecticut's single, small-scale biodiesel production facility, BioPur, in Bethlehem, has a production capacity of 500,000 gallons per year. BioPur's market is home heating oil vendors who blend pure biodiesel with heating oil (bioheat). The hurdles BioPur scaled in setting up their plant such as permitting, siting, identifying supply sources, securing reliable demand and financing can be instructive for the state as it looks at developing incentives for and promoting the industry, as well as others interested in establishing biodiesel production facilities.

State policy should promote the reutilization of agricultural, industrial and brownfield sites as potential locations for new biodiesel production facilities. One potential site is the former Franklin Mushroom Farm. This may be a favorable location to develop large-scale production as it has 250 acres of land, some of which could produce feedstock and some of which could be used to plant and test new cultivars for their yield in Connecticut's soil and climate. In addition, the Farm has rail access, and access to large amounts of water and electric power. Its proximity to UConn and ECSU enhance its value as a research venue as well as one where full-scale prototype, state-of-the-art biofuel production facilities may be built. As engineering research proceeds, new units and components may be swapped out or alternate lines introduced to evaluate new technologies.

Academic research and development is one of the competitive advantages the state maintains. The University of Connecticut formed a Biofuel Consortium to address alternative energy research and use at its Storrs campus. Engineering Department faculty and students have built a micro biodiesel production plant to learn about and improve production processes and to supply UConn's diesel fleet with a homegrown fuel. The feedstock is WVO from UConn's confectionaries. UConn would like to supply sufficient B20, a blend comprised of 20% biodiesel and 80% petro-diesel, to utilize all its WVO and needs to build a larger production facility. This facility will serve as a learning laboratory for research and implementation of new process technologies that may be scaled up. At least one patent is pending for a technology that adjusts the process according to the quality of the feedstock. Such an incubator facility might profitably be located on the Depot Campus. UConn Engineering and Agriculture faculty have outlined a comprehensive research program to further the development and use of biofuels as an energy source. The Clean Energy Institute (CEI) at the University of Hartford is also involved with the development of renewable energy projects. One of CEI's current projects is to investigate the feasibility of building a biodiesel processing plant on the University's campus to produce biodiesel from the waste oil generated in campus cafeterias.

For the supply side, an optimal mix of incentives to stimulate the location of large-scale biodiesel production facilities in Connecticut might include property tax abatement, a corporate income tax credit, a sales tax exemption on machinery and equipment and a clear and concise siting and permitting process. While some of these incentives should be implemented in the short term, others may require additional study to determine the relative benefit and impact on the state's tax structure.

Regarding Demand: Perhaps the most important aspect of the demand side of a biodiesel market, at least in the early stages, will be to establish guaranteed sales. Connecticut state government currently contracts for distillate fuel for transportation and heating, therefore, the most readily available segment of the demand market for this purpose is the state. These contracts could be modified to include the use of biodiesel for state facilities (heating needs), vehicle fleets and mass transit rolling stock (trains & buses). During calendar year 2005, state facility consumption of heating oil was approximately 5.9 million gallons. A commitment on the part of the state to utilize Bioheat blended at 20% with petroleum-based home heating fuel would create a guaranteed demand of 1.2 million gallons of biodiesel annually. In this manner the state can lead by example to create sales certainty in the demand market. Similarly, municipal governments can play a significant role by contracting for the use of blended biodiesel in their school bus fleets, and other transportation and heating needs. A demand strategy must also include reaching out to the corporate sector to encourage the use of blended biodiesel to heat corporate facilities and vehicle fleets

In addition to sales that can be guaranteed as part of an initial market demand strategy, the ultimate success of an expanded biodiesel industry, or biodiesel economy, in Connecticut depends on a motivated consumer base. A key component in this tactic is public education. An informed public is more likely to adopt biofuel for heating and transportation if they understand the benefits and the risks. Public education needs to take place at all levels in Connecticut's public education system as well as with public service announcements and billboards for the general public. Public forums and town meetings are useful venues as well for educating the public and learning of their concerns and vision. State-financed demonstration projects such as a rolling bio-bus educational center, or signs indicating that Bioheat is at use warming a landmark state government building will also play a key role in educating and assuring the public that biodiesel technology has been established and is viable. The faith community and other community organizations are another avenue for such education.

Other potential activities will require legislative action to incentivize the demand for biodiesel. These could include the establishment of a sales tax exemption on the motor vehicle fuels tax for the portion of the fuel that is biodiesel (Under Ruling 2003-1, The Department of Revenue Services ruled that biodiesel is subject to the motor vehicle fuels tax) and clarification that biodiesel, used for heating purposes in any residential dwelling, building used for agricultural production, or industrial manufacturing plant shall be exempt from the sales tax as other fuel under Connecticut General Statute, Section 12-412. As with the supply side, some potential incentives should be implemented in the short term and others may require additional study to determine the relative benefit and impact on the state's tax structure. However, incentivizing both the supply and demand sides is necessary to create a sustainable market.

Economic Analysis

DECD and UConn have the resources to evaluate the economic and fiscal effects of tax policies and incentive programs described in the Governor's plan. Further, DECD and UConn have resources to perform economic analysis for optimizing the production and distribution of biofuels as well as estimating the job creation potential of various production/distribution/research configurations. Coordination with DEP will also be critical in addressing environmental concerns associated with biodiesel that focus on proper handling and disposal of the chemicals, waste, emissions and other discharges associated with the production process, as well as additional study on the potential for increased nitrogen oxide emissions in some end uses (EPA recognizes emissions reductions for typical B20 biodiesel blends of 9% for particulate matter, 10% for carbon monoxide and 21% for hydrocarbons, however, B20 was shown to increase nitrogen oxides by 2%). As Connecticut converts to more biodiesel use, DEP and DECD can quantify the effects on air quality and the potential for health benefits, especially in urban areas.[14]

Coordination with DEP and other state and local agencies will be critical to clarify the permit requirements for biodiesel production facilities. There are a number of laws and regulations that could apply to construction and operation of any industrial facility including one that produces biodiesel. The requirements that must be met and/or permits that are needed will depend on a number of items, including but not limited to the size of the facility, the production process, how much air pollution will be emitted from the facility, whether there are water discharges, chemical storage and how solid wastes are handled and managed. A well-defined process is needed so potential biodiesel producers have complete understanding of requirements up front and can manage development appropriately.

The coordination of new and existing programs to promote the production and use of biodiesel will be an essential part of this strategy. Existing incentive, loan and grant programs will be utilized in a manner that promotes a biodiesel production industry in Connecticut. Other existing programs such as the farmland preservation Purchase of Development Rights (PDR) program, administered by the Department of Agriculture, could be utilized in a manner to promote cultivation of biofeedstock. Future development of mass transportation and fleet systems need to consider the potential for utilizing biodiesel as a fuel source and utilization of biodiesel for electric generation should be seriously examined. These efforts will serve to create the necessary supply and demand to establish and maintain a bio-energy economy in Connecticut.

Connecticut has a competitive advantage in agricultural, engineering and technology resources that must be optimized. The state's academic, research and technology sectors are needed to provide ancillary support to the biofuels industry to stay

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[14] McMillen, S., et al. (2005). "Biodiesel: Fuel for Thought, Fuel for Connecticut's Future," Connecticut Center for Economic Analysis Report, available at http://ccea.uconn.edu/studies/Biodiesel%20Report.pdf.

ahead of the technological curve and to attract new business and jobs to Connecticut. The field is ripe so to speak for economic growth, by which I really mean economic development. This is an especially important issue in a densely populated state, where following a mantra of "more jobs equals growth" may negatively impact the quality of life for the majority of residents in certain communities. Essentially, an economic plan that appears ideal for a largely unemployed or undeveloped region may not be viewed in the same way for wealthy, well-developed region, as not every community wants to become an urban area.

The Corporation for Enterprise Development (CFED) characterizes economic development in this way:[15]

> "Economic development is frequently equated with economic growth, but in our view, the terms refer to different things. First, development is both a prerequisite to and a result of growth. Development, moreover, is a qualitative change, which entails changes in the structure of the economy including innovations in institutions, behavior, and technology. Growth, on the other hand, is a quantitative change in the scale of the economy – in terms of measures of investment, output, jobs, consumption, income, and others. Hence, development is prior to growth in the sense that growth cannot continue long without the sort of innovations and structural changes implicit in development. But growth, in turn, will drive new changes in the economy, causing new products and firms to be created as well as countless small incremental innovations. Together, these advances allow an economy to increase its productivity, thereby enabling the production of more outputs with fewer inputs over the long haul."

I believe there ***can*** be economic development without economic growth. If development as characterized by CFED proceeds, there may well be growth in jobs and incomes because the environment for growth in Connecticut will be enhanced.

I want to touch on two subjects in closing. I mentioned earlier that GPTs are door-opening and not gap-filling technologies that are widely applicable. Some exciting

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[15] Schweke, W., Brian Dabson and Carl Rist (1996). "Improving Your Business Climate A Guide to Smarter Public Investments in Economic Development," CFED, ISBN 1-883187-10-9, Washington, DC.

research here at UConn suggests that biofeedstocks may offer new bases for plastics, paints and solvents that would further reduce dependence on petroleum and offer lower VOCs improving public health. Further, as we examine genetically-modified cultivars for high-yield cellulosic or oil-bearing crops, we must be careful not to propagate these strains to food-producing varieties. Technology in the lab here at UConn suggests that that problem is solvable. I submit that these and other technologies under investigation are door-opening and may serve to jump start new industries. Connecticut can lead the way. Other states are making strategic investments to jump start their alternative energy industries and have joined the Apollo Alliance. The Apollo Alliance is a coalition of business, labor, environment, and community and social justice leaders and organizations. A commitment to achieving sustainable U.S. energy independence within a decade unites Alliance members. Apollo has a Ten-Point Plan to do this, which has been endorsed by hundreds of groups. As verified by credible independent sources, the plan — which calls for a national commitment of $300 billion over the decade — is self-financing, and would produce at least 3 million good new jobs and an additional $1.4 trillion in U.S. GDP within that decade, with even greater benefits beyond.

The other subject is the life-changing aspects of an industrial revolution. We saw how new industrial organization in the first Industrial Revolution took people from their homes as traditional production points to factories and offices. Thanks to IT, that trend may be reversing. Moreover, if we truly understand the moral imperative to be good stewards of our planet, we will embrace the need to adjust our lifestyles and reduce waste, increase efficiency and make the needed strategic investments to ensure a sustainable future for ourselves and our children.

I close with a quote from Isaac Asimov: “No sensible decision can be made any longer without taking into account not only the world as it is, but the world as it will be.”

I hope your day is productive and informative. Thank you for listening.

Bibliography and Further Reading

Energy statistics are available at www.eia.doe.gov, www.iea.org, and www.bp.com; carbon emissions data is available at cdiac.esd.ornl.gov.

Information about hydrogen fuel-cell technologies and demonstration programs is available at: http://hydrogen.its.ucdavis.edu/, www1.eere.energy.gov/hydrogenandfuelcells/, www.h2mobility.org/index.html, www.iphe.net/NewAtlas/newatlas.htm.

A video tour of the DIII-D fusion reactor is available at www.siam.com/ontheweb.

For more information about the ITER and ARIES fusion reactor projects, see www.iter.org and http://aries.ucsd.edu/ARIES.

Further information about high-altitude wind generators is available at www.skywindpower.com, www.magenn.com and www.lr.tudelft.nl/asset.

A webcast of the Second International Conference on Synthetic biology is available at http://webcast.berkeley.edu/events.

The 25 X 25 Vision on renewable energy is available at www.25x25.org.

Ansolabehere, Stephen, et al. (2003). "The Future of Nuclear Power," Massachusetts Institute of technology, http:/web.mit.edu/nuclearpower/.

Brown, Lester R. (2006). "Plan B 2.0: Rescuing a Planet Under Stress and a Civilaztion in Trouble," expanded and updated edition, W.W. Norton.

Canine, C. (2005). "How to Clean Coal," in OnEarth, Natural Resources Defense Council, www.nrdc.org/onearth/05fal/coal1.asp.

Cannon, J.S. and Daniel Sperling, eds. (2004). The Hydrogen Energy Transition: Cutting Carbon from Transportation, Elsevier.

Congressional Budget Office (2002). "Reducing Gasoline Consumption: Three Policy Options," www.cbo.gov/ftpdocs/39xx/doc3991/11-21-GasolineStudy.pdf.

Cramer, W., Nakicenovic, N., Schellnhuber, H.J., Wrigley, T. and Gary Yohe, eds. (2006). Avoiding Dangerous Climate Change, Cambridge University Press.

Dahowski, R.T., Davidson, C.L., Dooley, J.J., Gupta, N., Kim, S.H., Malone, E.L. and M.A. Wise (2006). "Carbon Dioxide Capture and Geologic Storage," Technology Report from the Second Phase of the Global Energy Technology Strategy Program.

Dear, Peter (2006). The Intelligibility of Nature, University of Chicago Press, Chicago.

Deutch, J., Kanter, A., Moniz, E., and Daniel Poneman (2004). "Making the World Safe for Nuclear Energy," *Survival*, vol. 46, no. 4, pp 65-79, www.iiss.org/publications/survival.

"Diesel and Health in America: The Lingering Threat," www.catf.us/goto/dieselhealth**.**

Engineering Life: Building a fab for Biology. Bio Fab Group in *Scientific American*, vol. 294, no. 6, pp 44-51, June 2006.

Farrell, A.E., Jones, A.D., Kammen, D.M., O'Hare, M., Plevin, R.J. and B.T. Turner (2006). "Ethanol Can Contribute to Energy and Environmental Goals," Science, vol. 311, pp506-508., January 27. Available at http://rael.berkeley.edu/papers.html.

Geller, H and Sophie Attali (2005). "Experience with Energy efficiency Policies and Programmes in IEA Countries," International Energy Agency.

Generation IV Nuclear Energy Systems, http://gen-iv.ne.doe.gov/.

Goodell, J. (2006). Big Coal: The Dirty Secret Behind America's Energy Future, Houghton-Miflin.

Gore, Al (2006). An Inconvenient Truth, Rodale.

Green, David L. and Andreas Schafer (2003). "Reducing Greenhouse gas Emissions from Transportation," Pew center on Global Climate Change, www.pewclimate.org/docUploads/ustransp.pdf.

Jensen, Michael C. (1993). "The Modern Industrial Revolution, Exit, and the Failure of Internal Control Systems," *The Journal of Finance*, Vol. 48, No. 3, Papers and Proceedings of the Fifty-Third Annual Meeting of the American Finance Association: Anaheim, California January 5-7, 1993, pp. 831-880.

Hill, J., Nelson, E., Tilman, D., Polasky, S., and Douglas Tiffany (2006). "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels," *Proceedings of the National Academy of Sciences*, vol. 103, no. 30, pp 11206-11210.

Hoffert, M.I., et al. (2002). "Advanced Paths to Global Climate Stability: Energy for a Greenhouse Planet," *Science*, vol. 298, pp 981-987, November 1.

IPCC Special Report on Carbon Capture and Storage, 2005, available at http://arch.rivm.nl/env/int/ipcc/pages_media/SRCCS-final/IPCCSpecialReportonCarbonDioxideCaptureandStorage.htm.

Jochem, E. (2000). "Energy End-Use Efficiency," in World Energy Assessment 2000, Chapter 6, UNDP/WEC/UNDESA.

Jochem, E. ed. (2004). “Steps towards Sustainable Development: A White Book for R & D of Energy-Efficient Technologies,” CEPE and Novatlantis, www.cepe.ethz.ch.

Jacobson, A. and D.M. Kammen (2005). “Science and Engineering that Values the Planet,” *The Bridge*, vol. 35, no. 4, pp 11-17, Winter, available at http://rael.berkeley.edu/papers.html.

Kammen, D.M., and G.F. Nemet (2005). “Reversing the Incredible Shrinking Energy R & D Budget,” *Issues in Science and Technology*, pp 84-88, Fall, available at http://rael.berkeley.edu/papers.html.

Kiernan, P. (2006). “Getting Real About U.S. Dependence on Foreign Oil,” World Politics Watch, http://www.worldpoliticswatch.com/article.aspx?id=206.

Kremer, Michael (2003). “Population Growth and Technological Change: One Million B.C. to 1990,” *Quarterly Journal of Economics*, *108* (4), 681–716.

Maddison, Angus (2001). *The World Economy: A Millennial Perspective*. Paris: Organization for Economic Co-operation and Development.

______________ (1995). Monitoring the World Economy 1820-1992, Paris: Organization for Economic Cooperation and Development.

Malthus, Thomas Robert (1798). “An Essay on the Principle of Population, as it Affects the Future Improvement of Society with Remarks on the Speculations of Mr. Godwin, M. Condorcet, and Other Writers,” London: Printed for J. Johnson, in St. Paul’s Church-Yard. www.econlib.org/library/Malthus/malPop.html.

McMillen, S., et al. (2005). “Biodiesel: Fuel for Thought, Fuel for Connecticut’s Future,” Connecticut Center for Economic Analysis Report, available at http://ccea.uconn.edu/studies/Biodiesel%20Report.pdf.

Mokyr, Joel (1997). “Are We Living in the Middle of an Industrial Revolution?” Economic Review, Federal reserve bank of Kansas City, 31-43.

Natural Resources Defense Council website: www.nrdc.org/globalwarming.

Pacala, S and R. Socolow (2004). “Stabilization Wedges: Solving the Problem for the Next 50 Years with Current Technologies,” *Science*, vol. 305, pp 968-972. See calculations at www.princeton.edu/~cmi.

Pebble Bed Modular Nuclear Reactor, www.pbmr.co.za.

Pimentel, David (2003). “Ethanol Fuels: Energy balance, Economics, and Environmental Impacts Are Negative,” *Natural Resources Research*, vol. 12, no. 2, pp 127-134, June. Available at www.ethanol-gec.org/netenergy/neypimentel.pdf.

Posiva home page (Onkalo nuclear waste management project), www.posiva.fi/englengti/.

Princeton Environmental Institute website: www.princeton.edu/~cmi.

Proceedings of the Hydrokineticand Wave Energy Technologies Technical and Environmental Workshop, Washington, D.C., October 26-28, 2005. Available at http://hydropower.inl.gov/hydrokinetic_wave.

Raghu, S., Anderson, R.C., Daehler, C.C., Davis, A.S., Wiedenmann, R.N., and D. Simberloff (2006). "Adding Biofuels to the Invasive Species Fire?" *Science*, vol. 313, p 1742.

Renewables 2005: Global Status Report. Renewable Energy Policy Network for the 21st Century, Worldwatch Institute, 2005, available at http://rael.berkeley.edu/papers.html.

Roberts, Paul (2004). The End of Oil: On the Edge of a Perilous New World, Houghton-Miflin.

Romm, Joseph J. (2005). The Hype about Hydrogen: Fact and Fiction in the Race to Save the Climate, Island Press.

Shah, Sonia (2006). Crude, Seven Stories Press.

Steffen, Alex, ed. (2006). Worldchanging: AUser's Guide for the 21st Century, Harry N. Abrams, Inc.

Sweet, William (2006). Kicking the Carbon Habit, Columbia University Press.

"The Hydrogen Economy: Opportunities, Costs, Barriers, and R & D Needs," National Research Council and the National Academy of Engineering, National Academies Press. Available at www.nap.edu/catalog.php?record_id=10922#toc.

Tickell, Joshua (2003). From the Fryer to the Fuel Tank, Joshua Tickell Media Productions, New Orleans.

____________ (2006). Biodiesel America, Yorkshire Press.

URSI White Paper on Solar Power Satellites. International Union of Radio Science, November 2005. Available at www.ursi.org.

U.S. Nuclear Energy Regulatory Commission, www.nrc.gov.

Wang, Michael (2005). “Updated Energy and Greenhouse Gas Emissions: Results of Fuel Ethanol,” 15th International Symposium on Alcohol Fuels, September 26-28. Available at www.transportation.anl.gov/pdfs/TA/354.pdf.

World Business Council for Sustainable Development (2004). “Mobility 2003: Meeting the Challenges to Sustainability, www.wbcsd.org/web/publications/mobility/mobility-full.pdf.