U.S. Environmental Protection Agency
Science Advisory Board
Looking to the Future
Renaissance Mayflower, 1127 Connecticut Avenue NW
Washington DC 20036
October 27, 2008

Meeting Summary

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Background and purpose of meeting

On October 27-28, 2008, the EPA chartered Science Advisory Board held a one-and-a half-day public meeting entitled *Looking to the Future*. The meeting focused on two questions:

- Biofuels: What are the net environmental implications?
- Epigenomic research: What are the implications for environmental health sciences and human health risk assessment?

The seminar-style meeting was followed by a half-day advisory meeting on October 28, 2008. At that meeting, the chartered SAB discussed possible implications of the October 27, 2008 discussions for ongoing SAB advice on EPA research.

Exploration of the biofuels and epigenomic topics was intended to provide the chartered SAB with an interdisciplinary introduction to these topics. It was also intended to stimulate SAB thinking generally about future advice to strengthen EPA's response to emerging science issues, especially how EPA might implement interdisciplinary approaches that incorporate important emerging research.

In 2007, the chartered SAB committed to provide ongoing advice on strategic research directions for EPA and how they can be implemented. This advice on strategic directions complemented the SAB's traditional review of EPA's annual research budget. Exploration of emerging science related to biofuels and genomics at the October 27, 2008 meeting had the goal of further stimulating SAB advice. Focus on these two significant topics was designed to highlight the need to address inherent complexities and interconnections among human and ecological systems through integrated, multi-disciplinary science and research.

Dr. M. Granger Morgan, past chair of the chartered SAB, introduced the workshop and facilitated the discussion of biofuels. Dr. Deborah Cory-Slechta facilitated the discussion of epigenomics. Dr. Deborah Swackhamer, Chair of the chartered SAB, provided concluding remarks. She thanked the speakers and Drs. Morgan and Cory-Slechta for planning the program and noted the significance of the two topics discussed.

This summary document briefly describes the discussions following the speakers' presentations. The agenda for October 27, 2008 appears in Attachment 1. Attachment 2 contains the speakers' abstracts, biosketches and the handouts that speakers made electronically available for distribution.

Biofuels: What are the net environmental implications?

Dr. Granger Morgan introduced the four speakers: Dr. Bruce Dale (Michigan State University), who gave a presentation developed in collaboration with Dr. Lee Lynd (Dartmouth College) on *Sustainable Paths to a Biofuel-Powered Transportation Sector: The Role of Innovation and Invention*; Dr. Kenneth Cassman (University of Nebraska), whose presentation was entitled *Ensuring Sustainability of Biofuel Systems*; Dr. G. David Tilman (University of Minnesota), who presented on *Environmental Impacts of Food versus Cellulose-Based Biofuels*; and Dr. Christopher Field (Carnegie Institution), who provided a presentation on *Biofuels potential: The climate protective domain.* After the speakers' presentations (see Attachment 2), Dr. Morgan asked the speakers to lead the discussion with their initial questions or comments.

In that initial discussion, speakers focused on the relationship between intensive agriculture and carbon release. Dr. Cassman described the concept of indirect land use change and its effects on greenhouse gas emissions. For example, any changes in U.S. crop area that that results in higher soybean prices theoretically results in the expansion of agriculture into the Brazillian rainforest. Because cutting down the rainforest and burning its trees results in a tremendous amount of greenhouse gas emissions, this "GHG debt" must be credited to the reason for the change in crop area in the U.S. that caused the higher soybean prices. Thus, the expansion of U.S. corn area to meet demand from the rapid increase in ethanol production capacity came largely at the expense of soybean area, which in turn resulted in higher soybean prices. This caused Brazillian farmers to clear more rainforest and plant soybeans. Because the loss of carbon from clearing rainforest is many times greater than the GHG emissions reduction from use of ethanol to replace gasoline, there would be a large negative GHG debt due to indirect land use change. Likewise, puttng marginal land that produces corn and soybeans into the conservation reserve program (CRP) to reduce environmental degradation and erosion associated with farming such marginal land, would also have a large GHG debt. This debt occurs because retiring land from production would result in higher crop prices and trigger indirect land use change in the rainforest,, and the GHG loss from clearing rainforest is many times greater than the GHG savings from retiring crop land to the CRP. But CRP land is good for the environment in the U.S. so in effect, consistent application of the indirect land use change concept can have negative impacts on local environmental quality in the U.S. in order to reduce GHG emissions on a global scale. Given the expected increase in demand for human food, livestock feed, and biofuel, there is an urgent need to invest on research with the explicit goal of achieving a large crop yield increases on existing farm land while at the same time reducing negative environmental impacts from the higher yields—a process called ecological intensification.

Dr. Field noted that EPA should not only look at carbon release, but also consider water quality and quantity impacts, use of pesticides and release of PM 2.5 in analyzing possible costs and benefits. EPA should consider indirect land use in analyzing the multiple impacts of biofuels in an effort to minimize negative impacts. Dr. Field agreed that intensive agriculture imposes a carbon debt. In his view, when lands were cleared for bioenergy purposes, society should look at the implications of deforestation. Dr. Tilman noted a long-term (150-year) study comparing cultivation practices in England, where traditional intensive agricultural practices using manure have proved as productive than modern chemical fertilizers. Dr. Dale emphasized the importance of analyzing direct land use changes occurring as a result of increased biofuel production. He emphasized, however, that lifecycle planning tools did not yet exist for analyzing indirect land uses on an international scale. The Congressional requirement for such analysis was a radical innovation, for which reliable models and data do not yet exist.

Dr. Morgan then asked SAB members for their comments and questions. The first question concerned science and research needs to address water quality and water quantity impacts of biofuels, given projected increases in human and animal population. Dr. Dale responded that there was great potential to substitute capital investments for water in processing corn and cellulosic ethanol. He estimated that corn and cellulosic ethanol could be processed with half the water used in producing gasoline, due to the lower temperatures associated with biofuel production leading to lower heat transfer losses of water. Water quantity issues could be reduced by growing biofuel stock in the right locations using efficient agricultural methods. Local impacts could be reduced if perennial grasses were grown for biofuel stock. Dr. Cassman then noted that water quality and water scarcity issues existed because of world population growth, regardless of the development and promotion of biofuels. Projected population growth and economic development will increase demand for water; cultivation of corn for biofuels only accelerates the issue. He noted that biofuel cultivation will raise the cost of water. These rising costs may foster exploration of expensive irrigation technologies that promise efficiencies and reduced environmental impacts. Dr. Tilman addressed the water use question by emphasizing emphasized that negative impacts of biofuels could best be managed by wise decisions about how and where to grow feed stocks for biofuels. He emphasized the needs for price structure and incentives to motivate farmers and other decision makers to make environmentally sound decisions. Policy makers should examine the ecological impacts of using ground water and waters pumped from low-lying wetlands to grow corn in dry, unproductive soil. Dr. Field noted the importance of recovering nutrients and improving the efficiency of fertilizer use to reduce nutrient runoff.

The second question concerned current models for assessing the impacts of crops grown for biofuels. Speakers agreed that models were limited and not sufficiently validated by monitoring results. Speakers noted the need for models and data to predict the impact of temperature on crop yields, the significance of the color of different crops, and impacts on regional weather patterns.

The next question concerned the impact of prices and subsidies for corn-based ethanol. Dr. Tilman expressed concern about increased corn production on land unsuitable for corn, which increases the need for irrigation and fertilizers. He called for research on alternatives to ethanol-based biofuels. Dr. Cassman took a different perspective. He called for research to increase agricultural output to meet both food and fuel needs because of the sharp increase projected for world population.

Dr. Morgan then asked groups of SAB members for clusters of questions for speakers to address. In the first cluster of questions, SAB members asked about: 1) recommendations for incentives to encourage efficient production of biofuel crops; 2) investments in transportation and processing to support development of environmentally-friendly biofuels; and 3) logistical factors that affect environmental impacts of biofuels. In response, Dr. Dale noted the importance of developing regional biomass processing centers that can densify and pretreat biofuel stocks. Some byproducts could be used locally as animal feed and others could be sent further away for use as fuels. Dr. Tilman emphasized the importance of determining the right crop for the right location. He called for agronomy field trials for biofuels and increased research in the application of municipal solid waste and corn stover for fuel. He called for incentives for best management practices that would increase over time, resulting in efficiencies in using nitrogen, phosphorus, and irrigated water. Dr. Field advocated an analysis of land use potential to maximize sequestration of carbon. He envisioned “tremendous opportunities” for biomass combustion of wastes for production to enhance rural development.

An SAB member then asked for speakers’ predictions of the fraction of total energy needs could be met by biofuels in the future. Dr. Dale responded that over the next few decades, with needed innovations and inventions, biofuels could replace all needs for liquid transportation fuels for the whole world and thereby benefit the rural poor internationally. He did not envision the use of battery-operated vehicles outside North America and Europe due to the relatively high costs of such vehicles, compared to subcompact vehicles like the Tata Motors Nanocar ($2,500), which use liquid fuels. The 2007 Energy Independence and Security Act mandates 57 billion liters of ethanol production from starch-based crops like corn. Dr. Cassman estimated that this amount of corn-ethanol would replace 18% of current imported oil, and if the United States could double the efficiency of its motor vehicle fleet, it would replace 36%. Dr. Tilman predicted that approximately 20% of current liquid fuels for transportation could be globally produced in a sustainable manner. This would represent less than 7% of total global fossil energy demand.. Dr. Field estimated that biofuels might meet 7-8% of total global energy needs, given current levels of technology. He agreed with Dr. Tilman that biofuels might meet approximately 20% of current liquid fuels needs for transportation. [1]

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[1] Dr. Lee Lynd, who co-authored the presentation on *Sustainable Paths to a Biofuel-Powered Transportation Sector: The Role of Innovation and Invention* with Dr. Dale, was unable to participate in the meeting. Howeveer, on reviewing this summary he asked to provide a response to this question about predictions of the fraction of total energy needs could be met by biofuels in the future:

"I have made, and continue to make, a study of this important question and the widely misunderstood answers to it. In the enclosed book chapter ("Energy Myth Three – High Land Requirements and an Unfavorable Energy Balance Preclude Biomass Ethanol From Playing a Large Role In Providing Energy Services"), my colleagues and I point out that there are a large number of studies projecting very large contributions for biomass-based energy, and also a large number of studies projecting that such a large contribution is either impossible or undesirable. Curiously, the distribution of studies is bimodal rather than peaking at a mean value. This brings up two questions: 1) Who is right?, and 2) How can reasonable people with access to the same information reach such different conclusions? Since the many studies that have taken a crack at the first question and obtained disparate answers, the second question is probably the more fruitful one to think about. All seem to agree that the issue is not the analytical framework, but rather the assumptions made about the future. The chapter closes with the following observations which I believe are relevant to the question asked by the SAB member and the answers offered:

'Ultimately, questions related to the availability of land for biomass energy production and the feasibility of large-scale provision of energy services are determined as much by world view as by hard physical constraints. If the question is: "In a world motivated to solve sustainability and security challenges, assuming that innovation and change responsive to this objective are possible, could biomass make a large contribution to provision of energy services?" We think that the answer is unequivocally "Yes". On the other hand, biomass can make a much more limited contribution to energy supply in a world based on current or extrapolated realities with respect to important technical and behavioral variables determining biomass requirements and availability. To a substantial degree, the starkly different conclusions reached by different analysts on the biomass supply issue reflect different expectations with respect to the world's willingness or capacity to innovate and change. However, change is our only option if we are to achieve a sustainable and secure future, whether we are talking about biomass or all renewable energy sources.

Rejecting energy service supply options because they require innovation and change decreases the set of alternatives that can make a meaningful contribution markedly, and perhaps to zero. Such rejection also denies the essence of our current situation: that we cannot extrapolate the current unsustainable and insecure present and get to a sustainable and future. The scenarios most conducive to biomass playing a significant energy service supply role involve complimentary combinations of several changes, with the largest contributions made possible by a combination of technical advances and behavioral changes. We suspect that this is not limited to biomass and indeed is true of most if not all paths to a sustainable future. Studies that project a small role for biomass generally change only the source of fuel and leave other variables constant. This, however, amounts to projecting that

In the second cluster of questions, SAB members asked speakers about: 1) the most significant questions that could be addressed through sensitivity analysis and provide the most fruitful focus for research; 2) opportunities presented by the biofuel issue to focus EPA research on life-cycle assessment, rather than EPA's traditional pollutant by pollutant approach to risk assessment; 3) the potential for "intervention-based research" to influence current agricultural practices in the United States and world-wide, so that agricultural practices recognized to minimize adverse environmental effects were encouraged; and 4) the need for a new science and environmental management paradigm to address the complex environmental issues associated with biofuels.

Dr. Field identified the need for a research portfolio that would address biofuels from a broad perspective. He also spoke of the need for a legislative framework to address the full range of biofuel issues. Dr. Tilman emphasized that the environmental concerns associated with biofuels are multi-dimensional and that current approaches to life-cycle analysis have been too narrow in temporal and spatial scope to capture all dimensions of the problem. Dr. Cassman spoke of the need for EPA to play a major role in research strategy planning among federal agencies, including the U.S. Department of Energy (DOE) and U.S. Department of Agriculture (USDA). He called for research on carbon sequestration and carbon impacts related to different cultivation strategies for corn and cellulosic feed stocks. Dr. Dale agreed that EPA should increase its research coordination with DOE and USDA. He noted needs to improve models of agricultural impacts, life-cycle assessment tools, models to help allocate land for critical food, fuel, and animal feed needs. He called for greater rigor in reporting research results, showing the range of statistical results.

In the third cluster of questions, SAB members asked speakers about: 1) whether and how EPA should regulate agricultural activities to minimize the adverse environmental impacts of alternative energy strategies; 2) how to integrate their research with economic models, research, and systems; and 3) how to assess the impacts of potential fuels, such as palm biodiesel in the tropics, where development may pose risks to endangered species. Dr. Dale responded that economic factors will stimulate adoption of biofuels. New technologies will reduce the costs of feed stocks and processing costs. Economic incentives to encourage environmental management practices would be useful. Dr. Cassman agreed that economics should be part of the discussion. He agreed that agricultural polluters need to "to come under environmental regulations—it will be painful but has to be done." He noted the forthcoming work of the SAB's Integrated Nitrogen Committee, which held a workshop October 20-21, 2008 to discuss strategies for nitrogen management. He cautioned against the use of subsidies, which are hard to withdraw, once awarded. Dr. Tilman agreed for the need for interdisciplinary collaboration with economists to develop analyses for policy makers. There is a need for decision makers and consumers to see the "whole true price," including the production and ecological price, of different policy options.

Dr. Field cautioned against the use of price signals to help set policy. He noted that, "while we are calorie secure, the result of the world is not. " He expressed concern that economic pressures may pull food calories away from people who are not secure and that "price signals don't protect them." Dr. Field also noted that economic analysis cannot help address rare

technologies and behaviors that arose in a world largely unconstrained by energy availability will continue in the future. This is unlikely if one believes that energy sustainability and security challenges will become yet more pressing as we move forward - a proposition for which more support is accumulating daily.'"

and endangered ecological resources. He called on the United States to define more clearly what it wishes biomass energy to accomplish and then develop the appropriate policies, based on those priorities. If the goal is to reduce the net burden on climate change, then the United States can identify the full set of climate-alternatives and appropriately set incentives. He expressed frustration that biofuels were originally viewed as a strategy aligning climate, energy independence, and rural development, but that the current science and current development of biofuels indicate that biofuels may no longer meet all those all these needs easily or equally.

Dr. Morgan closed the panel discussion by asking each speaker to comment briefly on the most pressing research priorities and policy directions for EPA. Dr. Field called for a clear priority to be set for biofuels that would make biomass energy production climate protective. Once this priority was established then research and policy efforts could help determine the most effective incentive structure. In his view, research is needed to address the overall biofuel system, including the costs and benefits of indirect land conversion, major conservation issues, food security issues, and technological development to improve agricultural efficiency on existing agricultural lands so that production will be sufficient to feed the world.

Dr. Tilman noted that EPA must build on past research on nutrient loading, sewage treatment, and criteria air pollutants to meet huge future challenges associated with energy and food production. EPA must be involved in critical biofuel decisions affecting the environment. There are risks posed by huge fertilizer impacts and increasingly intensive agricultural practices. EPA should invest in full lifecycle-analysis addressing greenhouse gas impacts and a wide range of other environmental impacts including direct and indirect land use. EPA should invest in research and foster policies that encourage environmentally friendly agricultural practices.

Dr. Cassman noted that EPA needs to provide leadership to develop appropriate models, monitoring, and measurement methods to quantify the environmental impacts of biofuels. He called for collaboration and coordination with DOE, USDA, the U.S. Geological Survey, the National Oceanic and Atmospheric Administration, and the National Science Foundation. He noted the need for improved models to better predict greenhouse gas impacts and nitrogen impacts of different biofuel policies. The priority is for research to crop raise yields and reduce ecological impacts. Such research requires collaboration between agronomists and ecologists.

Dr. Dale called for EPA to invest resources to improve lifecycle analysis, sensitivity analysis, analysis of land use partitioning, and indirect land use. He urged EPA to support and study the potential for cellulosic ethanol, including the use of grasses for ethanol.

Epigenomics research: What are the implications for environmental health sciences and human health risk assessment?

Dr. Deborah Cory-Slechta introduced the four speakers and spoke of the potential implications of their research for hazard identification and human health risk assessment at EPA. Dr. Mark Hanson (University of Southampton) provided a presentation on the *Developmental Origins of Health and Disease - the Role of Epigenetic Mechanisms*: Dr. Randy Jirtle (Duke University) spoke on *Epigenetics: The new genetics of disease susceptibility*. Dr. Michael Skinner (Washington State University) spoke *Epigenetic transgenerational activity of endocrine disruptors on reproduction and disease; the ghosts in your genes.* After the speakers' presentations (see Attachment 2), Dr. Cory-Slechta took questions for the speakers from SAB members.

An SAB member asked about the implications for chemical companies of research showing potential epigenetic impacts of stressors. Dr. Hanson responded that the current state of science does not allow prediction of epigenetic effects from chemical structure. Dr. Jirtle suggested that it may be useful to identify areas of the genome that are labile and that risk assessors should not assume that "something is safe because does not cause modifications to the genome." Dr. Hanson agreed and suggested that EPA should identify biomarkers of risk. One possible biomarker might be the promoter regioins for steroid receptor genes that can be methylated. Any stressor that affects them is of potential interest.

Another SAB member asked whether risk assessment for epigenetic effects was "condemned to agent-by-agent analysis" and whether there were opportunities to be anticipatory in designing research to protect against environmental risks. Dr. Jirtle suggested focusing on susceptibilities at early stages of life, especially fetal exposures through pregnant mothers. Dr. Skinner predicted that scientists will be able to map the epigenome within three years. They will then be able to study exposures related to people in different cohorts. Dr. Jirtle noted that the National Children's Study offered many targets for exposure analysis (e.g., placenta and cord blood samples, mothers' exposures) to complement the study of epigenetic effects. Researchers may be able to determine environmental epigenetic effects linked to cardio vascular disease and schizophrenia.

An SAB member enquired about human epigenetic variability. Dr. Skinner responded that research reporting the first genome-wide epigenome matching will be available in the spring of 2009. Baseline data will likely be available in a few years. Speakers noted that every different cell type has a different epigenome. Epigenetics presents a complex biological problem. Dr. Jirtle noted that it will be possible to track individuals with imprinted epigenomes.

The next question related to research support for epigenetics and epigenomics. Dr. Skinner reported that the National Institutes of Health has recently invested $100 million in epigenetics. To his knowledge, EPA has not been involved in the award of this funding. Dr. Hanson spoke of the need for funding centralized facilities for bioinformatics technology. Speakers noted the possibility for identifying the biomarkers for nutrition and other environmental impacts as part of the mapping of the epigenome. Dr. Hanson noted the rich data available in China, Malaya, and India for linking epigenetics and toxicology.

An SAB member asked about potential epigenetic effects from environmental stressors in other animals. Dr. Jirtle responded that many animals would not have imprinted genes but would likely have epigenetic phenomena.

An SAB member asked how researchers would make connections between diet and environmental factors with epigenetic impacts. He asked "How would you know what exposures were? How would you establish dose-response?" Dr. Hanson responded that in many countries (e.g., Sweden, Denmark, Holland) cohorts were well identified and exposures understood. He also observed that researchers would need to coordinate animal and human studies closely to fully understand exposures and dose response.

Several SAB members asked about using epigenetic information to provide protection against environmental stressors. Dr. Jirtle noted that additional research is necessary to fully understand dose and timing. Folic acid, for example, is a big benefit in reducing neurotube defects, but "what could be helpful early in development could be detrimental later in life."

An SAB member enquired about the potential of epigenetic research to address environmental justice communities that face low birth weights, multiple environmental exposures, and poor diet. Dr. Hanson stated his belief that "epigenetic basis for risk of cardiovascular and other chronic disease and noted that this research highlights the importance of multiple environmental factors, many associated with socioeconomic conditions, in affecting such epigenetic factors" He cited research on the epigenetic basis for risks to cardiac factors in diseases and noted that the research responded to people's repeated questions about the impacts of multiple exposures.

The panelists then discussed research showing the relationship between multiple, different kinds of stressors and disease. They noted research linking prenatal stress to health consequences and research by Dr. Michael Meaney showing that behavior such as mothers' licking and grooming behavior affected methylation and health impacts in their pups. Dr. Cory-Slechta noted that EPA uses uncertainty factors in risk assessment to account for vulnerability and susceptibility. These uncertainty factors are not empirically determined but do recognize variability among individuals. Epigenetics may offer a stronger scientific basis for addressing the different bases for variability.

An SAB member asked panelists to identify the health endpoints that may be most likely related to epigenetic effects. Dr. Jirtle suggested that EPA should focus on neurological effects, schizophrenia, autism, and euro-degenerative disease. Dr. Hanson suggested focusing on childhood obesity, diabetes, and childhood diseases. Drs. Hanson and Skinner suggested focusing on endocrine disruptors. Dr. Jirtle noted that when environment presents organisms with new, challenging exposures for which they were not prepared, the epigenome can be adversely affected.

Attachment 1 – Agenda
U.S. Environmental Protection Agency
Science Advisory Board
Looking to the Future
Renaissance Mayflower, 1127 Connecticut Avenue NW
Washington DC 20036
October 27, 2008

Purpose: Is to stimulate SAB thinking about priorities for meeting critical environmental problems with an integrated approach to interdisciplinary science and research.

<u>Preliminary Agenda</u>

8:00 - 8:10 am	Welcome Remarks	Dr. M. Granger Morgan, SAB
	Biofuels: What are the net environmental implications?	
8:10- 8:15 am	Introduction	Dr. M. Granger Morgan, SAB
8:15- 8:45 am	Sustainable paths to a biofuel-powered transportation sector; the role of innovation and invention	Dr. Bruce Dale, Michigan State University Dr. Lee Lynd, Dartmouth College
8:45- 9:15 am	Ensuring environmental sustainability of biofuel systems	Dr. Kenneth Cassman, University of Nebraska
9:15- 9:45 am	Lifecycle environmental and health costs and benefits of fossil and renewable fuels	Dr. G. David Tilman, University of Minnesota
9:45-10:15 am	Biofuels potential: The climate protective domain	Dr. Christopher Field, Carnegie Institution
10:15-10:30 am	Break	
10:30-12:00 pm	SAB discussion with invited speakers	
12:00-1:15 pm	Lunch	
	Epigenomics research: What are the implications for environmental health sciences and human health risk assessment?	
1:15- 1:20 pm	Introduction	Dr. Deborah Cory-Slechta, SAB
1:20- 1:50 pm	Developmental Origins of Health and Disease - the Role of Epigenetic Mechanisms	Dr. Mark Hanson, University of Southampton

1:50- 2:20 pm	Epigenetics: The new genetics of disease susceptibility	Dr. Randy Jirtle, Duke University
2:20- 2:50 pm	Epigenetic transgenerational activity of endocrine disprutors on reproduction and disease; the ghosts in your genes	Dr. Michael Skinner, Washington State University
2:50 -3:15 pm	Break	
3:15- 4:45 pm	SAB discussion with invited speakers	
4:45- 5:00 pm	Concluding remarks	Dr. Deborah Swackhamer, SAB Chair
5:00 pm	Adjourn	

Attachment 2 – Biofuel Speakers' Biosketches, Abstracts, and Handouts

Dr. Bruce Dale

Michigan State University

Professor Dale is Professor of Chemical Engineering and former Chair of the Department of Chemical Engineering and Materials Science at Michigan State University. He received his bachelors degree (summa cum laude) in chemical engineering from the University of Arizona (Tucson) in 1976 and the masters degree from that same university in 1976. Dr. Dale then studied under Professor George T. Tsao at Purdue University, receiving his Ph. D. degree in 1979. Dr. Dale's first academic position was in the Department of Agricultural and Chemical Engineering at Colorado State University, where he rose to the rank of Professor in 1988. In that same year he joined Texas A&M University where he became Professor of Chemical Engineering and Professor of Agricultural Engineering. Dr. Dale also directed two large interdisciplinary research centers at Texas A&M: the Engineering Biosciences Research Center and the Food Protein Research and Development Center. In 1996 Dr. Dale became Professor and Chair of the Department of Chemical Engineering at Michigan State University, where he also holds an appointment in the Michigan Agricultural Experiment Station. Also in 1996 he won the Charles D. Scott Award for contributions to the use of biotechnology to produce fuels, chemical and other industrial products from renewable plant resources. In 2001 he stepped down as Chair to return to full time research and teaching. Professor Dale's research and professional interests lie at the intersection of chemical engineering and the life sciences. Specifically, he is interested in the environmentally sustainable conversion of plant matter to industrial products- fuels, chemicals and materials- while meeting human and animal needs for food and feed. He led a National Research Council report entitled "Biobased Industrial Products: Research and Commercialization Priorities" which was published in May 2000.

Dr. Lee Lynd

Dartmouth

Dr. Lee Rybeck Lynd is a Professor of Engineering and an Adjunct Professor of Biology at Dartmouth College, Professor Extraordinary of Microbiology at the University of Stellenbosch, South Africa, and cofounder, Director and Chief Scientific Officer of Mascoma Corporation, a biomass energy start-up. He has been a member of the Dartmouth Faculty since 1987. Dr. Lynd holds a B.S. degree in biology from Bates College, an M.S. degree in bacteriology from the University of Wisconsin, and masters and doctoral degrees in engineering from Dartmouth. Professor Lynd is an expert on utilization of plant biomass for production of energy. His contributions span the science, technology, and policy domains and include leading research on fundamental and biotechnological aspects of microbial cellulose utilization. He has led an active research group addressing these issues over the last two decades, authoring over 75 archival papers, book chapters, and reviews as well as 11 patents and patent applications. A frequently invited presenter on technical and strategic aspects of biomass energy, Professor Lynd has three times testified before the United States Senate and was a speaker at the 2007 Nobel Conference. In 2007 Dr. Lynd was the inaugural recipient of the Lemelson-MIT Sustainability prize for inventions and innovations that enhance economic opportunity and community well-being while protecting and restoring the natural environment. In 2005 he received the Charles D. Scott Award for distinguished contributions to the field of biotechnology for fuels and chemicals. Professional activities include: co-leader, the Role of Biomass in America's Energy Future project; Focus Area Leader for Biomass Deconstruction and Conversion, DOE Bioenergy Science Center; Biofuels industry representative, committee advisory to the Executive Office of President Clinton on Reducing Greenhouse Gas Emissions from Personal Vehicles; Editorial Board Member, Biotechnology and Bioengineering; and Manager, Link Energy Fellowship Program.

Sustainable Paths to a Biofuel-Powered Transportation Sector: The Role of Innovation and Invention

Bruce Dale and Lee Lynd

Prior to the first industrial revolution, people were scarce and resources were plentiful. Now confronted with the opposite circumstance, humanity must mount a second industrial revolution featuring population stabilization, increased energy utilization efficiency, and adoption of new renewable and sustainable energy supply technologies. At present there are widely disparate evaluations of the potential of biofuels to play an important role in the transition to a sustainble world, and there is a pressing need to resolve this disparity. This presentation will address key issues associated with the feasibility and desirability of cellulosic biofuels used on a large scale - including energy balance, economic feasibility, land competition, carbon debts, and resource availability - with a focus on two questions: 1) Understanding the reasons underlying the different conclusions reached by different analysts, 2) identifying paths by which large-scale biofuels use would be feasible and desirable. Innovation and invention will play key roles in the development of a large scale biofuel industry, as they have in the development of the petroleum refining industry. The talk will close by commenting on the general applicability of lessons learned from the biofuel example.

Background Reading

Bruce E. Dale. 2008. Biofuels: Thinking Clearly about the Issues. *Journal of Agricultural & Food Chemistry* 56:3885–3891.

Joseph E. Carolan, Satish V. Joshi, and Bruce E. Dale. 2007. Technical and Financial Feasibility Analysis of Distributed Bioprocessing Using Regional Biomass Pre-Processing Centers. *Journal of Agricultural & Food Industrial Organization* 5 (SPECIAL ISSUE: Explorations in Biofuels Economics, Policy, and History):Article 10, pp 1-27.

Seungdo Kim, Bruce E. Dale. 2005. Life cycle assessment of various cropping systems utilized for producing biofuels: Bioethanol and biodiesel. *Biomass and Bioenergy* 29:426–439.

Sustainable Paths to a Biofuel-Powered Transportation Sector: The Role of Innovation and Invention

Lee R. Lynd and Bruce E. Dale
Dartmouth College & Michigan State University

Presented at:
U. S. Environmental Protection Agency
Science Advisory Board Meeting
Washington, DC
October 27, 2008

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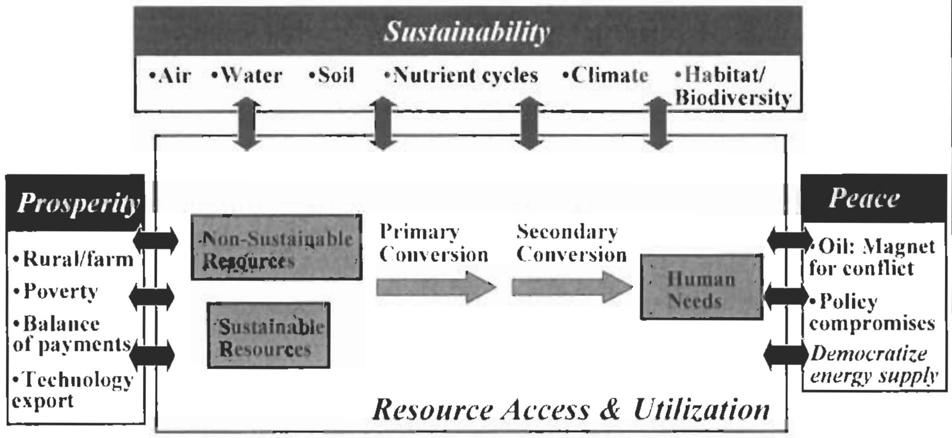
1. Preliminary considerations.

Dimensions of well being for human society…

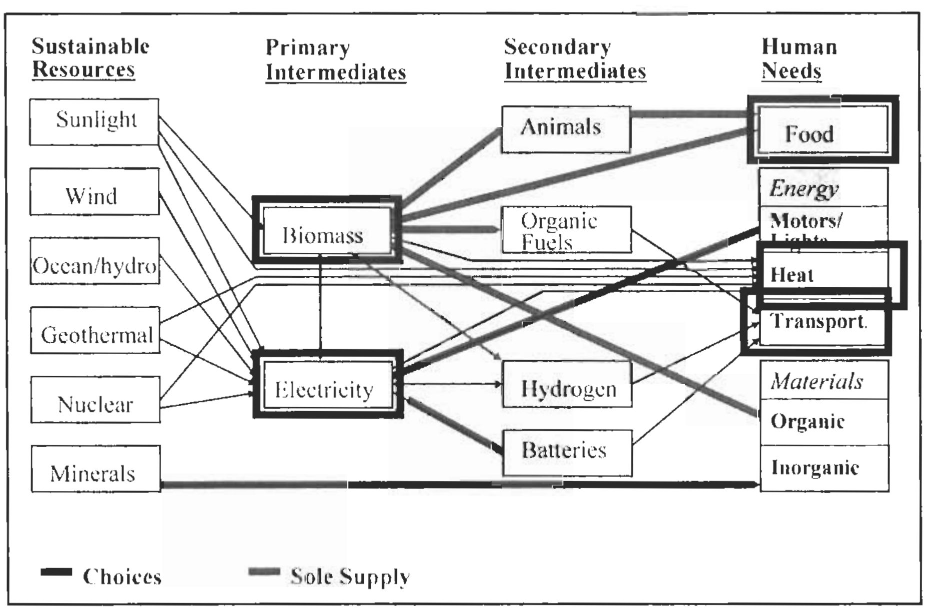


… are dominated by resource access and utilization, particularly energy

Today & always

A convergence of factors makes this critical now - defining challenge of our time– we will invent and innovate to meet the challenge as we have done before

Imagining a Sustainable World



Energy Carrier	Price: Common Units	$/GJ
Fossil		
Petroleum	$100/bbl	17.4
Natural gas	$10/kscf	11.0
Coal	$55/ton	2.5
w/ carbon capture @ $150/ton C		6.5
Electricity	$0.045/kWh	11.3
Biomass		
Soy oil	$0.50/lb	30.0
Corn kernels	$5/bu	14.4
Cellulosic crops[a]	$50/tonne	3.0
Cellulosic residues		Some < 0

[a] e.g. switchgrass, short rotation poplar

Modified from Lynd et al., Nature Biotech., 2008

At $3/GJ, cellulosic biomass purchase price competitive with oil at $17/bbl.
Cellulosic biomass: The cheapest GJ in a carbon-constrained world.

Different Plant Feedstocks are Responsive to Different Objectives

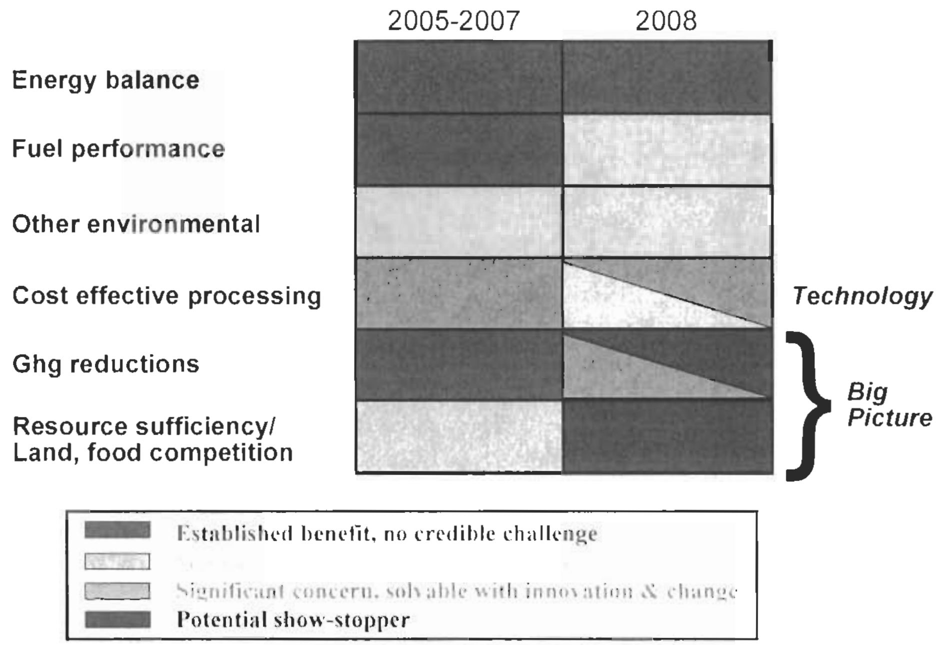
	Large Scale Production		Rural Economic Development		Petroleum Displacement (Security)		Fossil Fuel Displacement/ GHG Reductions		Soil Fertility & Ag. Ecology	Low Cost Fuels (feedstock & conversion)	
	Per unit	Total	Now	Future	Per unit	Total	Per unit	Total		Now	Future
Cellulosic											
Starch-rich											
Sugar-rich											
Oil seed											

Ratings:
excellent
fair
poor

Cellulosic biofuels are the focus of all studies foreseeing (very) large-scale widespread fuel obtained from plants.

- Environmentally benign/beneficial production
- Low purchase cost
- Large potential scale of production

Cellulosic Biofuels: Changing Perceptions of Challenge



Why persist in considering biofuels if they have such large challenges?

Because other transportation alternatives have large challenges too.

Hydrogen - Should be in the running in light of efficiency and low pollution potential, but is about the worst way to move and store energy imaginable

Where will it come from?

Distribution & storage forecast to be 2x cost of fuel generation.

Electricity (EVs, renewable power --> H_2, plug in hybrids)

Even with 2.5 higher efficiency than current fleet, providing for today's transportation energy consumption would require doubling U.S. power generation.

Plug in hybrids make good use of off-peak generating capacity, but will only achieve ghg emissions if power comes from low carbon sources.

Whereas cellulosic biomass is ~\$3/GJ, electricity is currently ~\$11/GJ

- Expected efficiency of biomass --> liquid fuels, electricity --> H_2 both ~ 70%
- Fuel cell efficiency is high, but efficiency losses in H_2 storage and distribution are much larger than for liquid fuels

There will be increasing pressure on power generation - some forecast ≥ 2x price increase in the coming decade - without new transportation demand.

2. GHG accounting for cellulosic biofuels.

Cellulosic Biofuels & Greenhouse Gas Emissions

Through 2007, analysis focused on fuel production & utilization cycle

a) *Removal* of CO_2 via photosynthesis

b) Agricultural energy inputs (typically small, e.g. $\leq$ 7% of feedstock heating value)

c) Processing energy inputs (typically zero)

d) Return of CO_2 in amount equal to a) when biomass-derived fuel is burned

Picture generally very positive (e.g. ~10% of gas base case), widely accepted

Potentially large additional factors beyond fuel production & utilization cycle

Decreases ghg benefits (much recent attention)

Land conversion prior to energy crop production.

These land conversion analyses **neglected**
1) Use of standing biomass & 2) Land management options <u>post</u> land use change

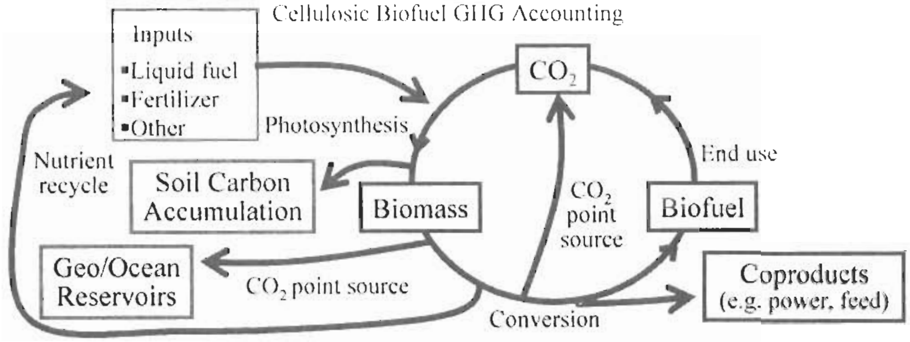
Increases ghg benefits (not much attention thus far)

Soil organic matter accumulation

Carbon capture and sequestration (required for many coal scenarios to be low C)

Coproduce animal feeds along with cellulosic biofuels– large potential **reduction** in land requirements for food/feed/fuel

Cellulosic Biofuel GHG Accounting



CO_2 Equivalent Emission (% Gasoline base case, per mile, not cumulative)	EtOH & Power	EtOH & FT Fuels & Power
Primary Cycle	0	0
Inputs	+10	+8
Coproducts	-56	-4
N recycle	-3	-2
Soil carbon accumulation	-130 (-19 to -240)	-101 (-15 to -186)
CO_2 capture, sequestration	-128	-98
Land conversion	+, potentially large	

3. Minimizing cellulosic biofuel land conversion carbon debts & <u>Innovating</u> and <u>inventing</u> to minimize land use for cellulosic biofuels

Or: "Going from Mega Acres to Nega Acres"

Innovating: Make use of existing technology to change the game, eg:

1. Harvest & use standing biomass during land conversion
2. Improve land management post conversion using cover crops & reduced tillage (Searchinger & Fargione both assumed worst case: plow tillage)

End result of these two relatively simple innovations is that "carbon debt" from forest conversion is greatly reduced if not entirely eliminated

Inventing: Create new technology & approaches to meet needs

A viable cellulosic ethanol industry will require inventions including:
- Pretreatment to make available calories in structural carbohydrates
- Use of all components of plant material, including protein

Net result of these two inventions will be to completely change how we feed animals, particularly ruminant animals, resulting in much less land required to feed our livestock and provide fuel…"nega-acres"

Land Conversion GHG Emissions

Recent papers of Searchinger et al. and Fargione et al. highlighted potentially large carbon emissions from land conversion

Fargione et al.

"Biofuels are a potential low-carbon energy source, but whether biofuels offer carbon savings depends on how they are produced."

Carbon debt accompanying conversion of various unmanaged lands to established biofuels (corn ethanol, biodiesel from soy, palm) is large and requires a long time (17 to 429 years) to repay.

Production of biofuel from prairie grass on abandoned or marginal cropland repays the conversion carbon debt in less than a year with large carbon savings thereafter.

Searchinger et al.

Focuses on converting existing US corn land to biofuel production.

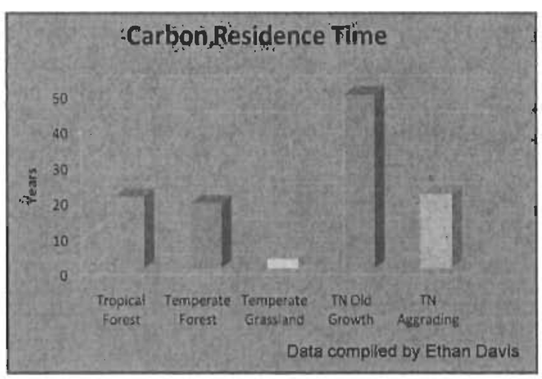
Use a global model to calculate *indirect land conversion impacts* - changes elsewhere to compensate for decreased grain production in the US.

Payback period for the carbon debt calculated for indirect land conversion:

- Corn EtOH: 42 to 640 yr
- Switchgrass EtOH: 52
- Cane EtOH: 4 to 42 yr

Land Conversion GHG Emissions

Carbon residence time: C inventory/rate of C accumulation



For ecosystems with a large carbon inventory, e.g. forests, land conversion may be accompanied by a large carbon debt unless:

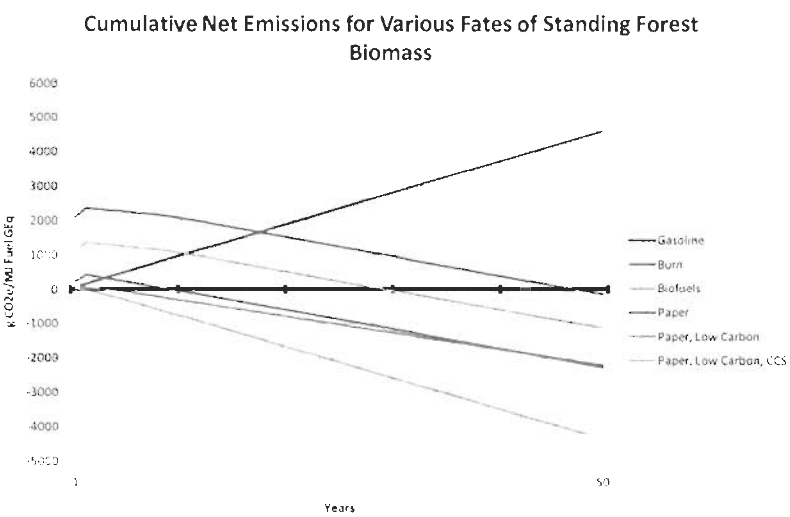
1) **standing biomass is used to displaces ghg emissions and/or**
2) **forest land is managed after conversion to minimize ghg emissions**

Grassland conversion does not generate any significant carbon debt

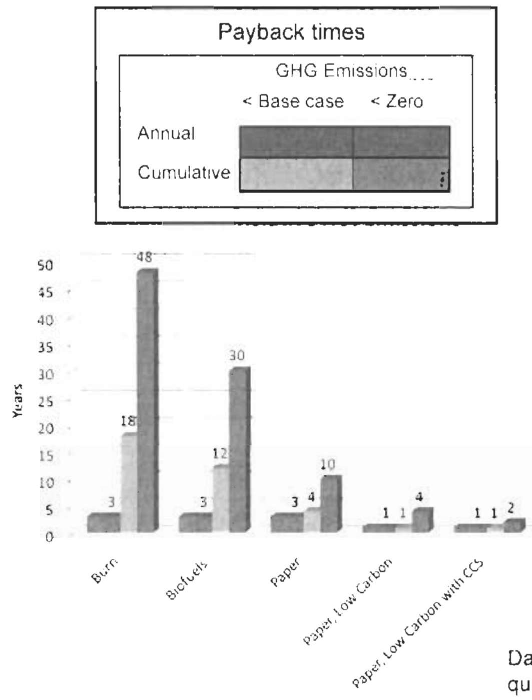
Consider conversion of a temperate forest (Tennessee, aggrading) to switchgrass and biofuel production - Davis, Laser & Lynd

Chosen to illustrate range of outcomes and key sensitivities, not necessarily because it is the most desirable large scale option

- **Fate of standing biomass**
  - Burn
  - Biofuels
  - Paper
- **Additional management options**
  - Default - tilling, no carbon capture and sequestration
  - Low carbon conversion - (no tilling, but lower biomass productivity)
  - Carbon capture & sequestration
- **Accounting**
  - Life-cycle approach - based on changes relative to what would happen in the absence of land conversion and utilization of standing biomass
- **Conversion technology**
  - Mature (on a per unit fuel basis avoided emission benefits *higher* than current technology, soil carbon and sequestration benefits *lower* than current technology)



Davis, Laser, & Lynd - In-process analysis, quantitative results may change.



A large range of outcomes is possible, depending on whether or not land conversion is approached with the intent to minimize carbon debts

Even for the particularly challenging case of forest land conversion, rather small payback times result if uses are found for cleared biomass that offset ghg emissions.

Low carbon land conversion and/or carbon capture and sequestration further reduce payback times.

Davis, Laser, & Lynd - In-process analysis, quantitative results may change.

Land Management Post Land Use Change

1. Ethanol demand to corn price
2. Corn price to corn or soybean supply
3. Corn or soybean supply to land use change
4. Land use change to greenhouse gas consequences
5. Land management post land use change- assumed worst case of plow tillage

Very different predictions result from different models (FAPRI, GTAP, FASOMGHG) ...we do not discuss these issues here, but they are serious and deserve careful attention

Land doesn't cease to be managed once the land use change is executed.

What are the GHG consequences of different post land change management options?

Specifically, investigate cover crops & reduced tillage for temperate zone forests and grassland conversion, combine with corn stover utilization as fuel in the biorefinery

Indirect Land Use Change Scenarios

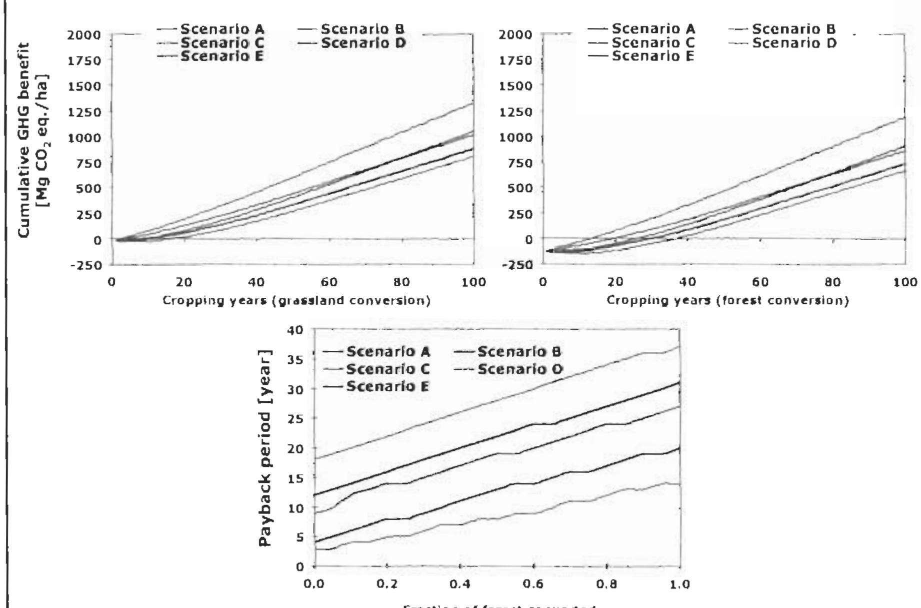
- Divert existing cornfield to ethanol production, and then convert grassland (or forest) to cornfield dedicated to animal feed production—harvest and use some corn stover as fuel for biorefinery

Scenario	Description
A	Cropping management: current tillage practice
B	Cropping management: no tillage practice
C	Cropping management: no tillage practice combined with winter cover crop
D	Cropping management: plow tillage
E	Scenario A with an assumption that ethanol would displace marginal gasoline fuel (from Athabasca oil sands)

* Data for DAYCENT from 8 U. S. corn producing counties, different climates,etc.

Paper in review for publication in *Environmental Science & Technology*

Cumulative GHG Benefit



A Large Variable Space only Starting to be Explored

Biomass Source (8)

1. Sustainable wastes S, F
2. Excess/degraded cropland F
3. Integration into new agriculture
4. Forests, no land conversion
5. Grassland --> HPCB
6. Forestland --> HPCB
7. Nonsustainable ag. land --> HPCB
8. Sustainable ag. land --> S HPCB

Biomass Fate (7)

A. Burning S
B. Biofuel
C. Power
D. Lumber F
E. Paper
F. Chipping
G. Low carbon land conversion

Other Variables (9)

Conversion technology
- i. Current S, F
- ii. Mature
- iii. CCS

Accounting
- iv. Direct F
- v. Indirect (LCA) S

Food production efficiency
- S, F vi. Current/extrapolated
- vii. Increased

Mobility efficiency
- S, F viii. Current/extrapolated
- ix. Increased

Factorial combinations 8x7x9 = 504

S: Considered by Searchinger et al.

F: Considered by Fargione et al.

Cellulosic Biomass Source	Large at-risk C inventory	Food Competition	Observations
Sustainable wastes	No	No	Widespread agreement, sustainability must be verified
Excess/degraded cropland	No	No	Widespread agreement not problematic
Integration into new agriculture	No	Little or none	Potentially very large, Seldom considered
Forests, no land conversion	No	No	Widespread agreement broad needs served by increased "weed" harvest
Grassland → HPCB	No	None to some	Relatively low carbon inventory; Lots of abandoned pasture in NE, drainage-limited
Forestland → HPCB	Yes	No	**Mean age of C ~ 20 years → large potential debt**
Nonsustainable ag. land → HPCB	No	Only transiently	Land in ag. now, will not be for long - could beneficially support feedstock production
Sustainable ag. land → HPCB	No	Yes	**Problematic in a food-limited world—*if in fact food is limited***

*HPCB = High productivity cellulosic biomass

For most but not all sources of cellulosic biomass, large land conversion carbon debts and food competition are either not a problem or readily avoided.

4. Inventing: Create new technology & approaches to meet needs

A viable cellulosic ethanol industry will require inventions including:

- Pretreatment to make available calories in structural carbohydrates
- Use of all components of plant material, including protein

Net result of these two inventions will be to completely change how we feed animals, particularly ruminant animals, resulting in much less land required to feed our livestock…"nega-acres"

Two Technical Advances Required for Cellulosic Biofuels

1. Key enabling advance: Effective, economical pretreatment to increase accessibility/digestibility of cellulose and hemicellulose (60-80% of forages)
2. Later advances: Complete utilization of all biomass components: carbohydrates, lignin, protein, lipids, minerals, pigments, pectin, organic acids, etc.
3. Taken together, these advances will significantly alter how we provide calories & protein to feed animals, particularly ruminant animals.

Will People Go Hungry Because of Biofuels?

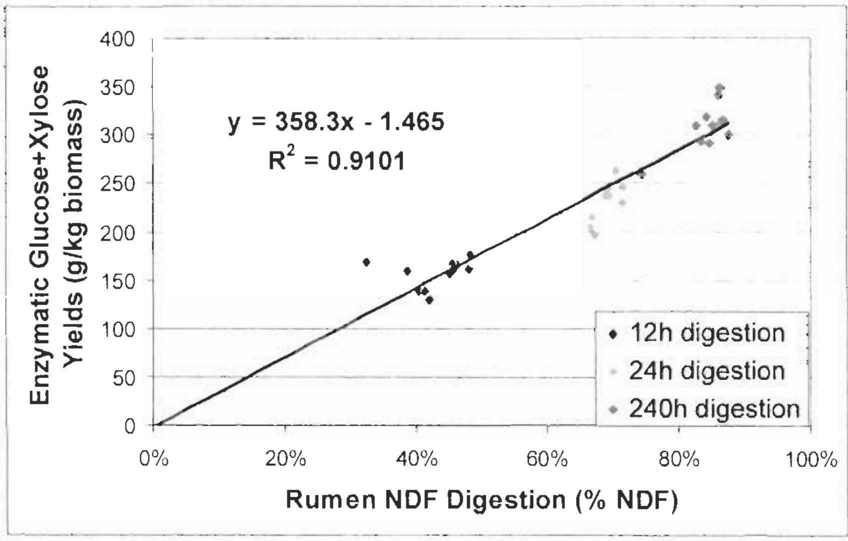
- Three major U.S. crops *alone* (corn, soy, wheat) produce 1300 trillion kcal & 51 trillion grams protein/yr
- Could meet U.S. human demand for protein & calories with 25 million acres of corn (~5% of our cropland)
- *Most U. S. agricultural production (inc. exports) is fed to animals-- i.e., we are meeting <u>their</u> protein/calorie needs from our land resources. Their needs are:*
  - 1040 trillion kcal/yr (6 times human demand)
  - 56.6 trillion gm protein/yr (10 times human demand)
- Thus we can address perceived "food vs. fuel" conflict by providing <u>animal feeds</u> more efficiently, on less land
- Dairy & beef cattle consume more than 70% of all calories and protein fed to livestock
- As nations grow richer, they want more protein, especially more meat....

Tale of Two Biorefineries

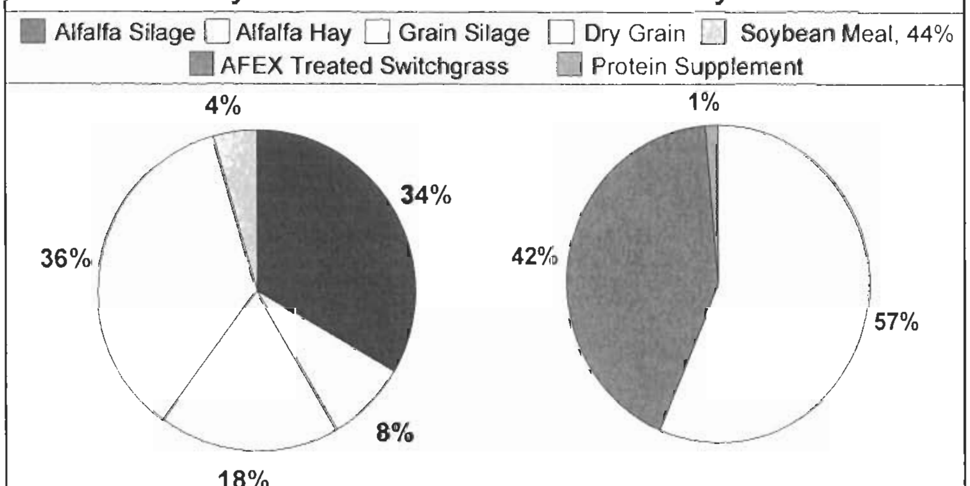
Mobile Cellulose Biorefinery | **Stationary Cellulose Biorefinery**

Improve Cellulose Conversion for Biorefinery
= Improve Cellulose Digestibility for Cows

Enzymatic and Rumen Fluid Digestion of AFEX-Treated Grass



Dairy Diet- Black Hawk County Iowa Farm

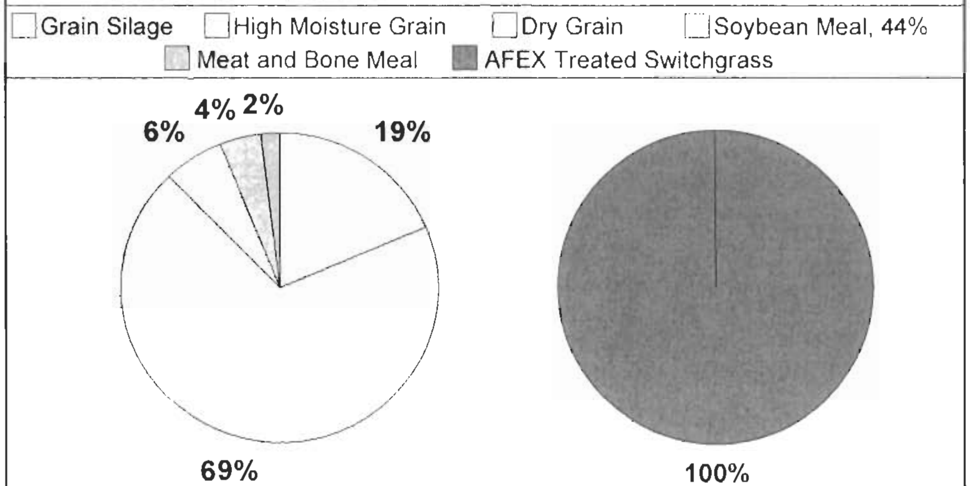


$150,242/yr
265 acres/yr

$92,388/yr
167 acres/yr

Using high digestibilty grass feeds reduces land requirements by 1/3 and GHG due to removal of corn from the animal diet—assumes 6 ton/acre switchgrass

Beef Diet- Aberdeen South Dakota Ranch



$248,381/yr	$134,897/yr
436 acres/yr	227 acres/yr

High digestibilty grasses reduce land needed for animal feeds by almost 50% & reduces GHG by replacing corn in diet.

Some early conclusions:

Innovating on the biofuels supply chain (eg, using standing biomass instead of just burning it, and/or managing the land appropriately after the conversion) can greatly reduce or eliminate the "carbon debt"

- Harvesting standing biomass for biofuel production reduces payback time by 20 years (from about 50 to about 30 years)
- Applying best management practices reduces the payback time by about 25 years (from 40 to about 15 years)
- These two approaches would be additive: thus the total savings could be as large as 20 + 25 years = 45 years, *paying back the entire carbon debt for forest conversion in the first year...*
- Grassland conversion "debt" is essentially zero in all scenarios we have studied
- Land use conversion will involve a mix of forest and grassland, therefore the carbon debt *may well be zero for real systems...it is far too early to be making regulations based on our current level of scientific understanding*

Minimizing cellulosic biofuel land requirements & food competition by invention:

Invention will follow defined and knowable paths, even if the specific invention that is generated is unknown.

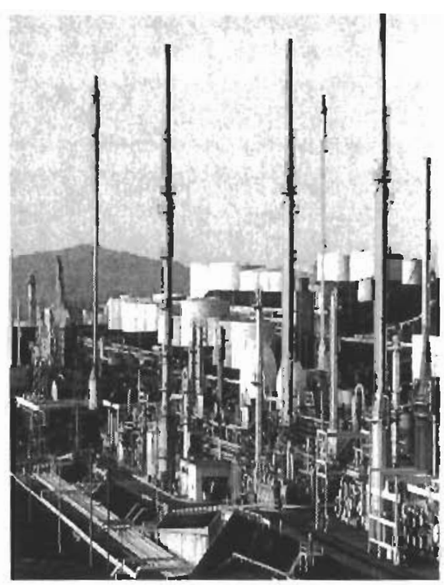
For cellulosic biofuels, invention will take place in:

1) pretreatment (making cellulosic biomass calories more available for animal feed) and
2) improving feedstock use efficiency (making biomass protein more available for animal feed)

Since over 80% of crop and pasture land is used to produce feed (not food for direct human consumption) there is every reason to believe we can produce lots of cellulosic biofuels and lots of animal feed using much less land *if we can ever get to large scale cellulosic biofuels*

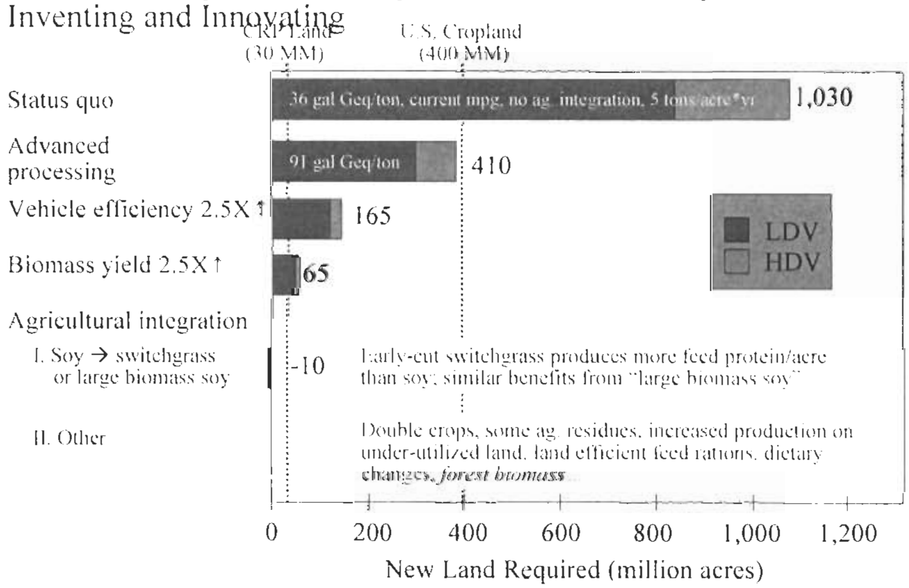
Please don't blow up the (corn ethanol) bridge to the future by ill-founded and premature regulations on indirect land use change, technology generally improves if we give it a chance.

Technological Improvement Takes us from This To This



Or From This "Cell Phone" / To this One

New Land Required to Satisfy Current U.S. Mobility Demand: Inventing and Innovating



When new land requirement = 0, the land conversion carbon debt = 0, displaced food production = 0

Questions ??

Dr. Kenneth G. Cassman

University of Nebraska

Dr. Kenneth G. Cassman currently serves as Director of the Nebraska Center for Energy Sciences, and is the B. Keith and Norma F. Heuermann Professor of Agronomy at the University of Nebraska. He received a BSc degree in biology from the University of California--San Diego (1975) and a PhD in Agronomy and Soil Science from the University of Hawaii (1979). His expertise is centered within the disciplines of soil science, agroecology, and plant ecophysiology. Research activities have focused on: (1) plant nutrition, root ecophysiology, soil fertility and nutrient cycling to improve fertilizer efficiency and to reduce negative effects on environmental quality; (2) crop yield potential, soil carbon sequestration, and greenhouse gas emissions in maize-based cropping systems of the USA Corn Belt; (3) the long-term sustainability of intensive crop production systems and global food security. Recently he has focused attention on the role of agriculture in contributing to renewable energy supplies through production of ethanol and biodiesel fuels from cereal, oilseed, and sugar crops and the environmental impact of expanded biofuel production from agricultural crops.He served on the California Task Force on Sustainable Agriculture (1985-86), the Board of Directors for the Nebraska Crop Improvement Association (1996-2004), the Nebraska Crop Advisors Executive Board (1996-2002), the Council on Agriculture Science and Technology (CAST) Task Force on Animal Agriculture and Global Food Security (1996-99), Chair of the Nebraska Environmental Livestock Environmental Quality Task force (1998-2001), and on the Science and Policy Committee for the 3rd International Nitrogen Conference (2003-04). In addition, he has been active as an external program reviewer for a number of scientific institutions, including: CIMMYT (1997 and 2000), IITA (2001), ICRISAT (2008), the graduate program at the Wageningen Agricultural University in the Netherlands (1998), and the Department of Soil Science at the University of Wisconsin. Professor Cassman has been elected Fellow of the American Association for the Advancement of Science, the Agronomy Association of America, the Soil Science Society of America, and the Crop Science Society of America, and has received a number of national and international awards for research excellence. His research has been widely published in seminal journals.

EPA-SAB October 27 Meeting Abstract

Kenneth G. Cassman[1], University of Nebraska

Rapid economic growth in the world's most populous countries, political instability in regions with greatest petroleum supplies, greater consumption than discovery of new petroleum reserves, and an abrupt rise in energy prices have driven global expansion of biofuel production from sugar, starch, and oil seed crops. As a result, a 50-year trend of declining real prices for the world's major crop commodities has been reversed, and we are in a demand-driven commodity market created by the convergence of energy and agriculture. Current rates of gain in crop yields are not adequate to meet this increased demand without a large expansion of crop area at the expense of rainforests, wetlands, and grassland savannah. Therefore, a large acceleration in the rate of crop yield gains on existing farm land is required, both here in the U.S. and globally, to ensure the environmental and economic sustainability of biofuel systems. But achieving yield gains while also reducing the negative environmental impacts of high-yield agriculture on soil and water quality and greenhouse gas (GHG) emissions has been an elusive goal. It requires a process of "ecological intensification" that involves interdisciplinary, systems-oriented research for which there has been little funding support from USDA, DOE, and NSF. Instead, most of our public-sector agricultural research portfolio has focused on measuring and understanding the environmental impact of agriculture without regard to crop productivity and on genetic crop improvement through biotechnology, while the private sector has emphasized productivity with little regard for environmental impact. To ensure the long-term viability of biofuel systems, these trends must change, and change quickly. A substantial increase in research investment is needed that is focused tightly on the *dual goals* of accelerating the rate of gain in crop yields and doing so in a manner that decreases the environmental footprint of agriculture. Although development of cellulosic (non-food crop) biofuels will reduce the competition between food and biofuels, large-scale commercialization of cellulosic biofuels (+4 billion L/yr annual production) is at least 7-10 years off. In the meantime, food-crop biofuels production capacity will continue to build out under present policies, and the environmental challenges embodied in this expansion must be addressed proactively.

Citations:

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Council for Agricultural Science and Technology (CAST). 2006. Convergence of Agriculture and Energy: Implications for Research and Policy. CAST Commentary QTA 2006-3. CAST, Ames, Iowa.

Liska AJ, Yang HS, Bremer V, Walters WT, Kenney D, Tracy P, Erickson G, Koelsch R, Klopfenstein T, Cassman KG. 2007. Biofuel Energy Systems Simulator: LifeCycle Energy and Emissions Analysis Model for Corn-Ethanol Biofuel (ver. 1.0, 2007). University of Nebraska, www.bess.unl.edu.

Liska A. and Cassman KG. 2008. Towards standardization of life-cycle assessment metrics for biofuels: Greenhouse gas emissions mitigation and net energy yield. J. Biobased Materials and Bioenergy 2:187-203.

Naylor RL, Liska AJ, Burke MB, Falcon WP, Gaskell J, Rozelle SD, and Cassman KG. 2007. The Ripple Effect: Biofuels, Food Security, and the Environment. *Environment*. 49: 30-4.

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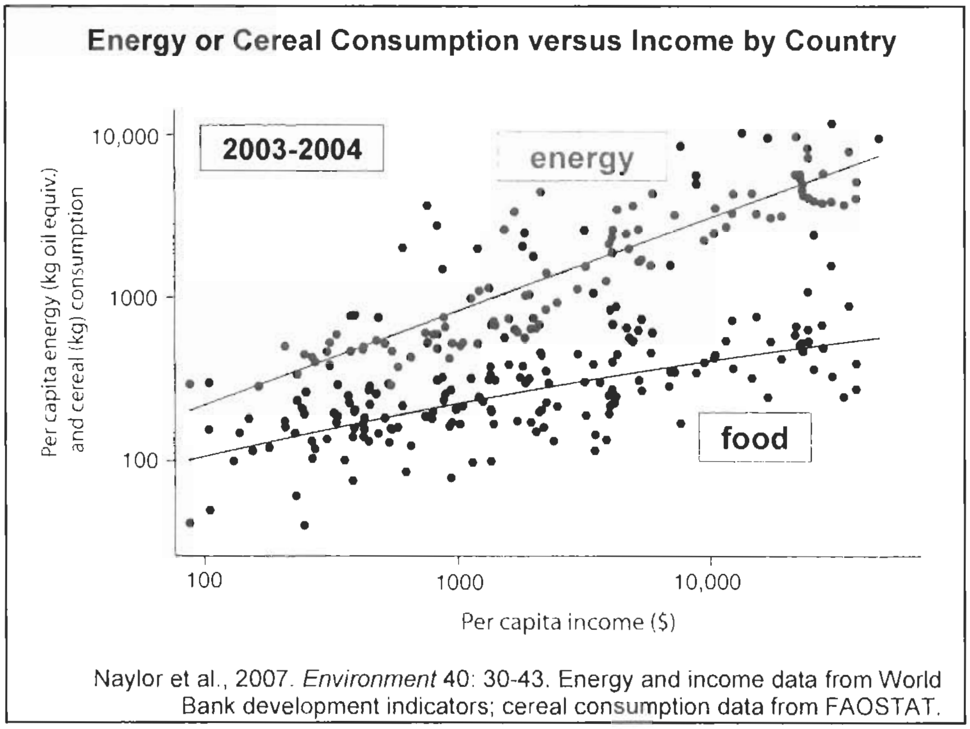
[1] Heuermann Professor of Agronomy, and Director—Nebraska Center for Energy Sciences Research

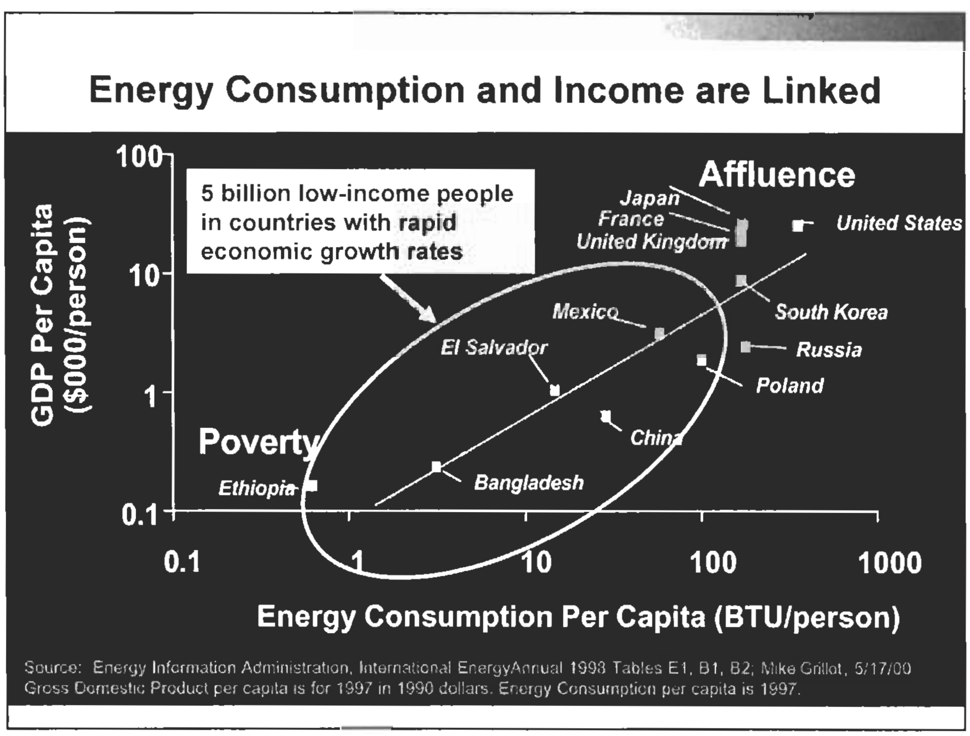
Ensuring Environmental Sustainability of Biofuel Systems

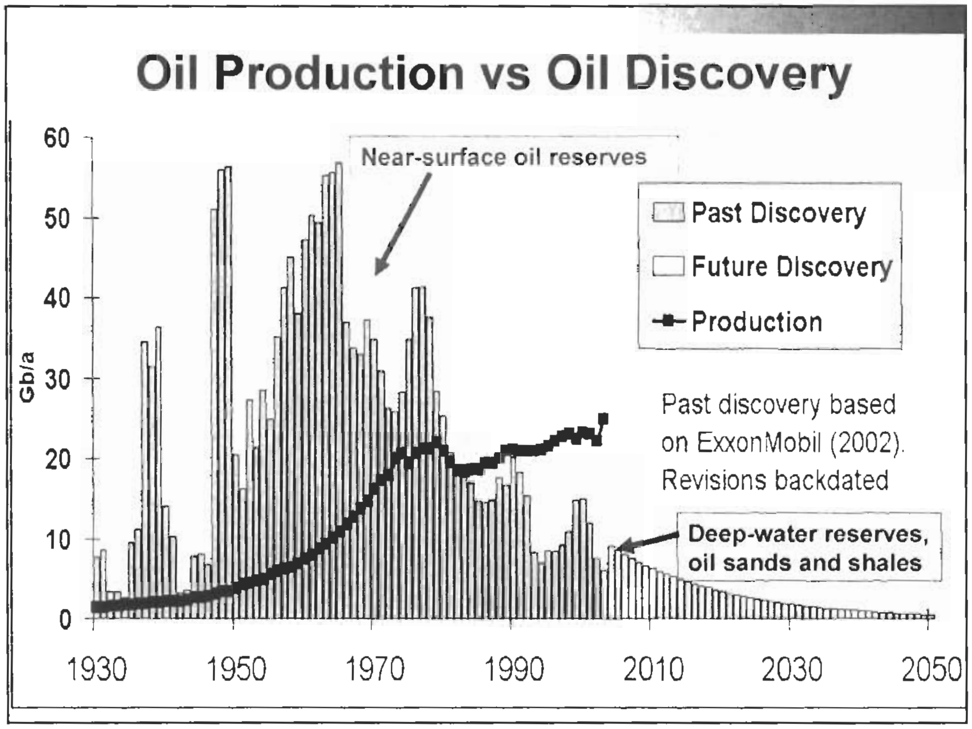
Kenneth G. Cassman
Heuermann Professor of Agronomy, and
Director, Nebraska Center for Energy Sciences
University of Nebraska—Lincoln
www.ncesr.unl.edu

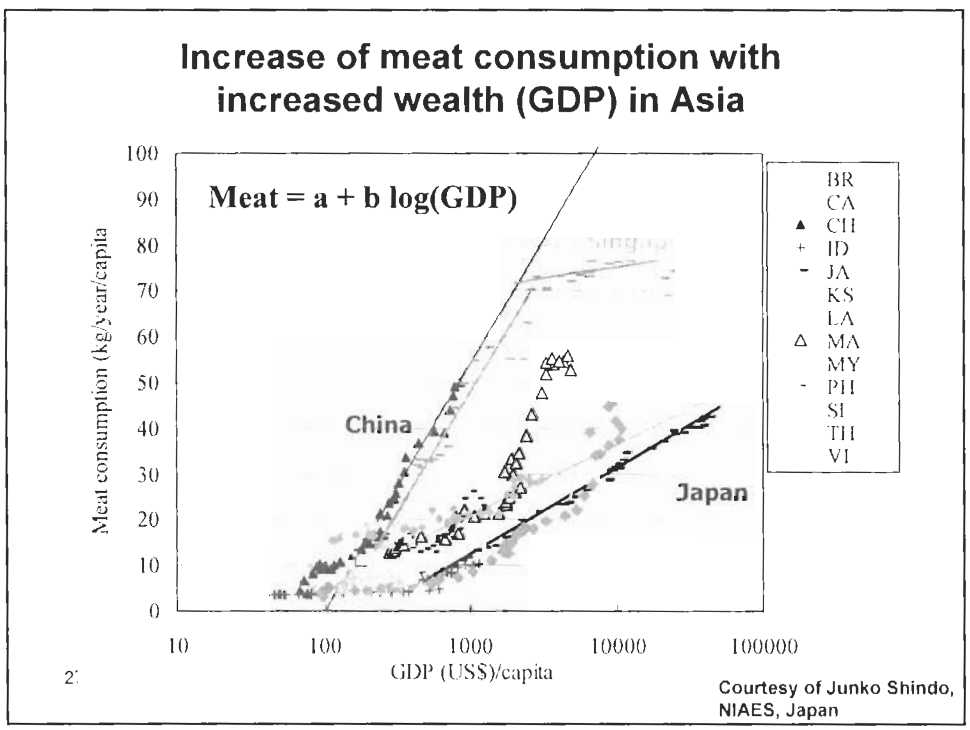
Mega Trends Affecting the Food and Energy Supply—Demand Balances

- Rapid rate of economic growth in most populous developing countries
  - Per capita increases in consumption of energy and livestock products
- Uncertainty of petroleum supply
  - Political instability in oil-producing countries
  - Decreasing replacement of petroleum reserves
  - Rising prices for petroleum and motor fuels
- Climate change and increasing public concern about protection of environmental quality and natural resources


Energy or Cereal Consumption versus Income by Country
2003-2004
energy
food
10,000
1000
100
Per capita energy (kg oil equiv.) and cereal (kg) consumption
100
1000
10,000
Per capita income ($)
Naylor et al., 2007. Environment 40: 30-43. Energy and income data from World Bank development indicators; cereal consumption data from FAOSTAT.


Energy Consumption and Income are Linked
5 billion low-income people in countries with rapid economic growth rates
Affluence
Japan
France
United Kingdom
United States
South Korea
Russia
Poland
Mexico
El Salvador
China
Poverty
Ethiopia
Bangladesh
100
10
1
0.1
GDP Per Capita ($000/person)
0.1
1
10
100
1000
Energy Consumption Per Capita (BTU/person)
Source: Energy Information Administration, International EnergyAnnual 1998 Tables E1, B1, B2; Mike Grillot, 5/17/00
Gross Domestic Product per capita is for 1997 in 1990 dollars. Energy Consumption per capita is 1997.


Oil Production vs Oil Discovery
Near-surface oil reserves
Past Discovery
Future Discovery
Production
Past discovery based on ExxonMobil (2002). Revisions backdated
Deep-water reserves, oil sands and shales
Gb/a
60
50
40
30
20
10
0
1930
1950
1970
1990
2010
2030
2050


Increase of meat consumption with increased wealth (GDP) in Asia
Meat = a + b log(GDP)
China
Japan
BR
CA
CH
ID
JA
KS
LA
MA
MY
PH
SI
TH
VI
Meat consumption (kg/year/capita)
GDP (US$)/capita
10
100
1000
10000
100000
Courtesy of Junko Shindo, NIAES, Japan

Addressing environmental challenges associated with biofuels

- **Don't shoot at the caboose of a fast moving train**
- **Think globally, act locally**
  - **Population must plateau at about 9 billion by 2050**
  - **Requires a massive increase in wealth, energy use, and food consumption (<u>on average</u>) despite reduced per capita consumption in developed countries**
- **Must have sustainable options to meet this demand for food and energy within 10-15 yrs**
  - **Transitional systems vs long-term solutions**

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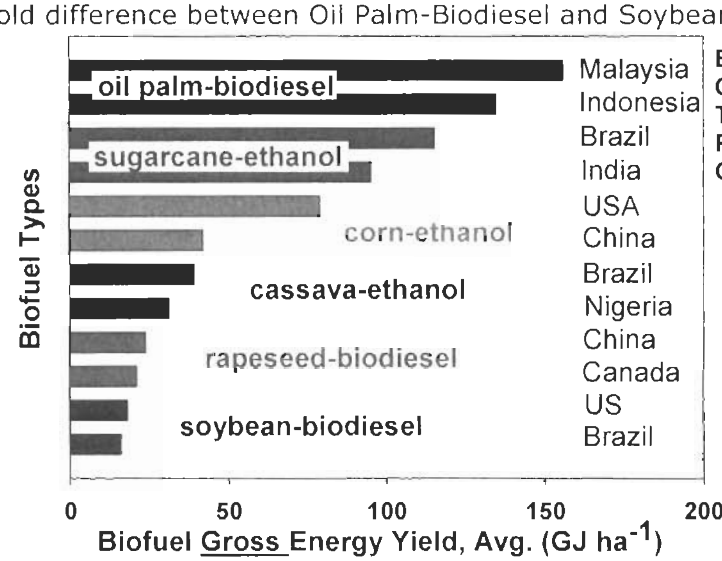
Increasing Biofuel Energy Yield (GJ ha^{-1}) Limits Competition with Food & Uses Land Economically

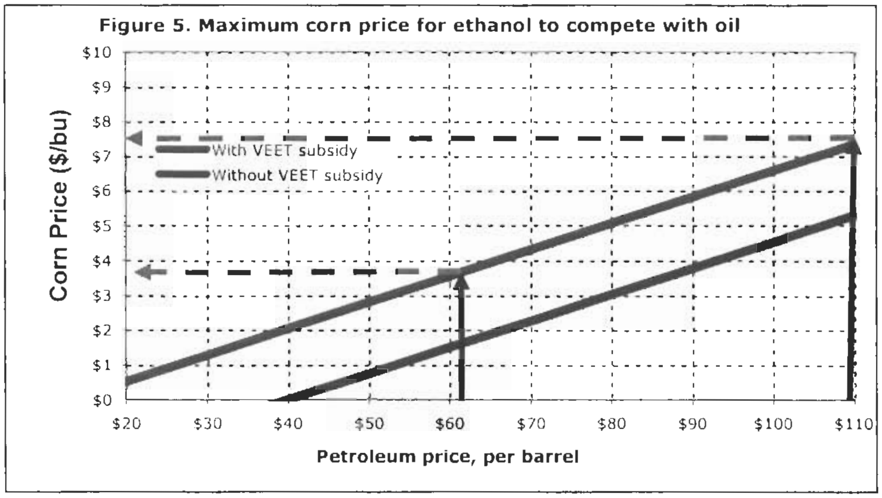
10-fold difference between Oil Palm-Biodiesel and Soybean-Biodiesel!



Based on Crop Yields of Top 2 Crop Producing Countries

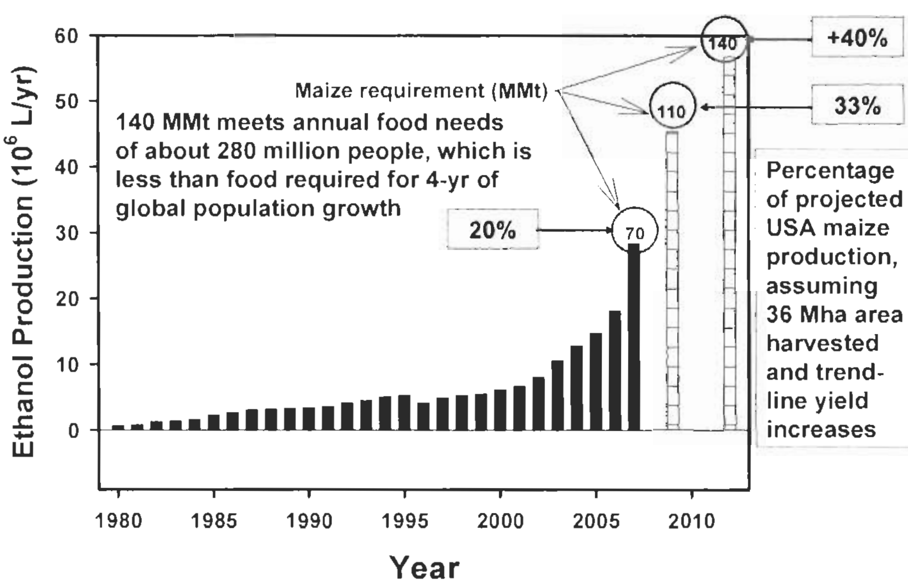
Source: Liska and Cassman *Journal of Biobased Materials and Bioenergy*, 2, 187-203, 2008

Breakeven price of corn for ethanol production at different petroleum prices

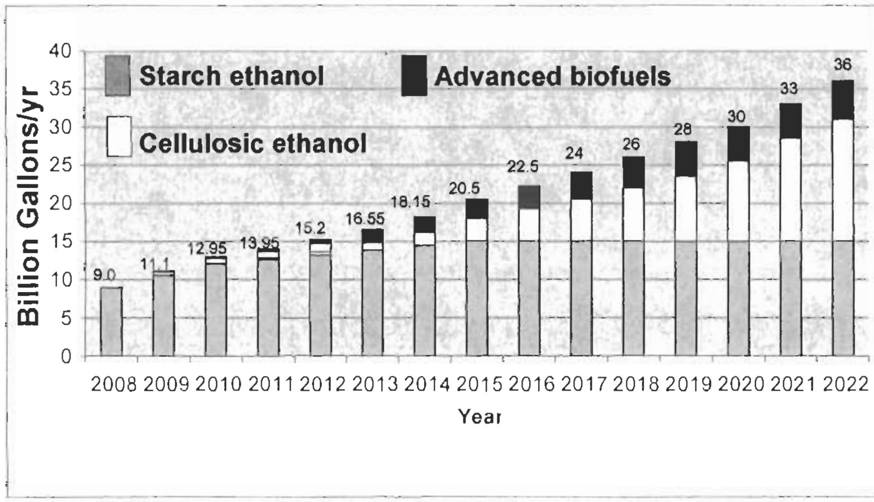


Source: R. Perrin, Univ. Nebraska

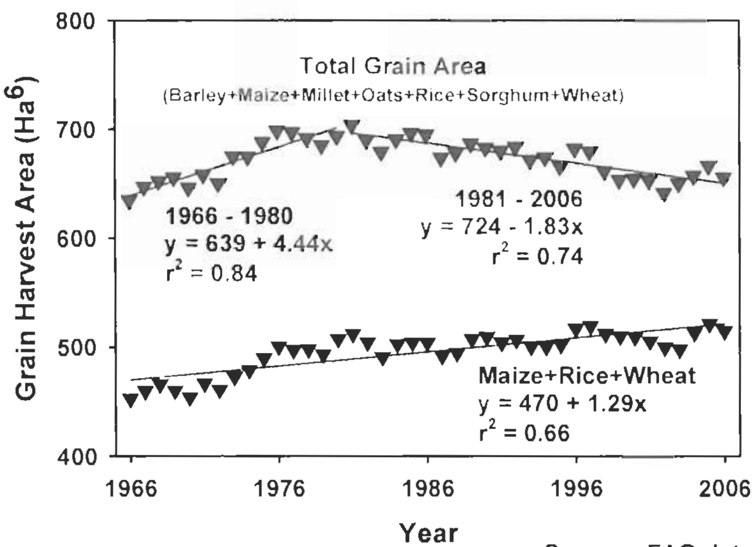
Expansion of USA Maize-Ethanol Production



Renewable Fuel Standard Biofuel Production under the 2007 Energy Independence and Security Act (EISA)



Global Cereal Area Trends, 1966-2006

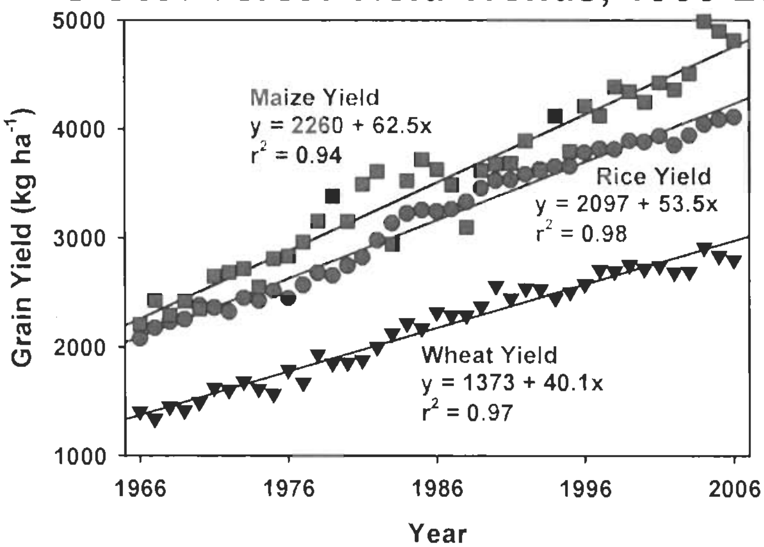


Source: FAO data archives

Decreasing water supply in all major irrigated areas

Yet, irrigated agriculture produces 40% of global food supply on just 18% of the cropped area.

Global Cereal Yield Trends, 1966-2006



THESE RATES OF INCREASE ARE NOT FAST ENOUGH TO MEET EXPETED DEMAND! Source: FAO data archives.

Rate of gain for all cereals is linear, not exponential, which means that the ***relative*** rate of gain is decreasing: relative rates of gain in 1966.

Global rate of increase in yield of maize, rice, and wheat, 1966-2006.

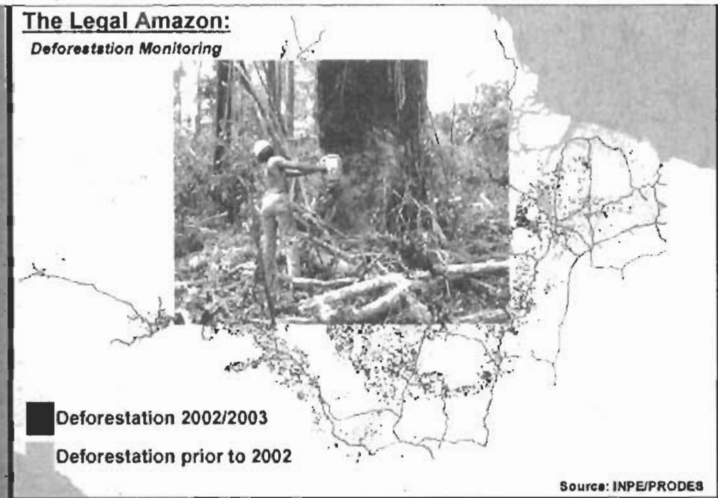
Crop	Mean yield (kg ha-1)		Rate of gain¶ ($kg\ ha^{-1}\ yr^{-1}$)	Proportional rate of gain (%)	
	1966			1966	
Maize	2260		**62.5**	2.77	
Rice	2097		**53.5**	2.55	
Wheat	1373		**40.1**	2.92	

Rate of gain for all cereals is linear, not exponential, which means that the ***relative*** rate of gain is decreasing: relative rates of gain in 2006.

Global rate of increase in yield of maize, rice, and wheat, 1966-2006.

Crop	Mean yield (kg ha-1)		Rate of gain¶ ($kg\ ha^{-1}\ yr^{-1}$)	Proportional rate of gain (%)	
		2006			2006
Maize		4759	**62.5**		1.31
Rice		4235	**53.5**		1.26
Wheat		2976	**40.1**		1.35

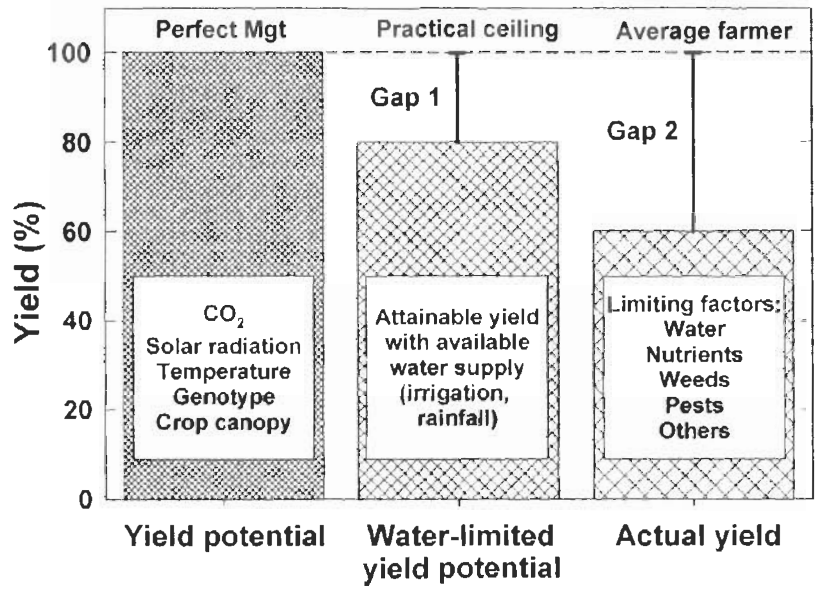
Potential Ripple Effect: accelerated deforestation due to abrupt increase in demand for food, feed, and biofuel crops



Nearly 30 million hectares of tropical forest have been cleared since 1988

- Vast majority converted into rangeland for commercial cattle production
- Deforestation is continuing at a rate of over 2.0 million hectares per year
- New rangeland provides opportunity for future field-crop cultivation

Potential Ripple Effect: unsustainable crop production on marginal land by poor farm families without other options



Source: Cassman et al. *Annual Review of Environment and Resources 28*:315, 2003

Cassman, Ecological Intensification

Proc. Natl. Acad. Sci. USA 96 (1999) 5953

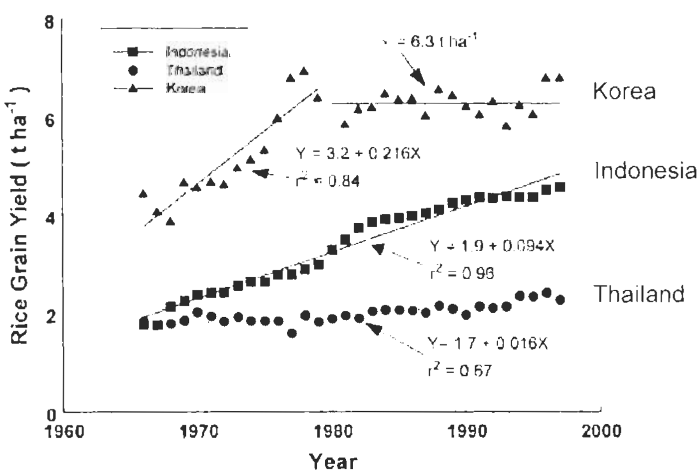
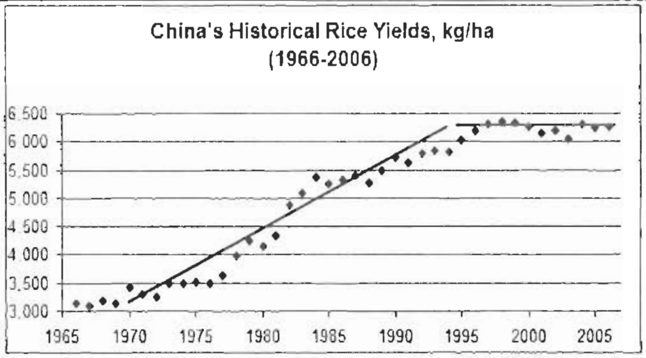


FIG. 1. National average rice yields from 1967 to 1997 in three Asian countries (http://apps.fao.org).



In China, all rice is irrigated, and there is yield stagnation as average farm yields approach the genetic yield potential ceiling

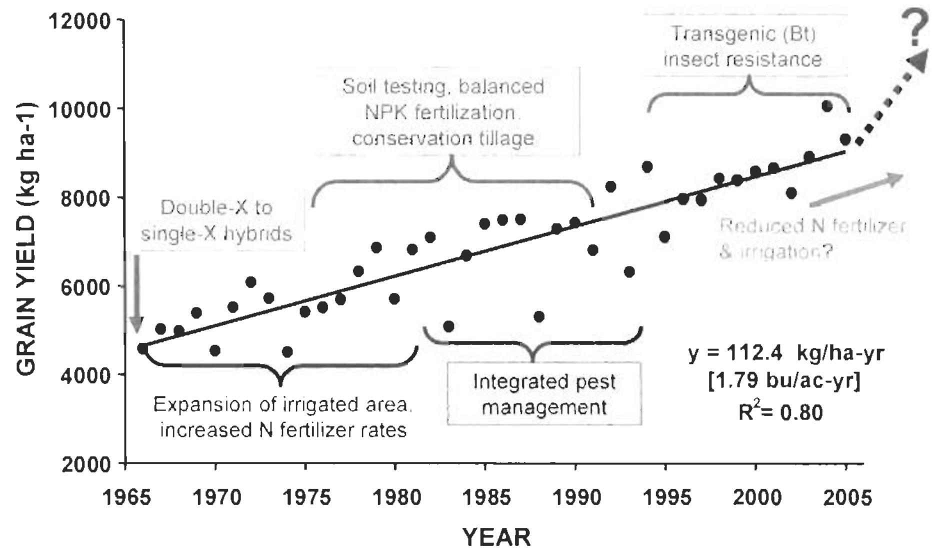
In Indonesia, rice is grown with and without irrigation; yield stagnation due to both bumping up against the genetic yield potential ceiling and stress in rainfed environments

Bottom Line on Yield Trends

- **Little increase in yield potential of maize or rice for the last 30-40 years (see publications)**
- **Current rates of gain in crop yields and land area available for crop production are not adequate to meet expected demand for food, feed, fiber, and fuel**
- **Little scope for a quantum leap in crop yields from biotechnology *despite* the hype from some major seed companies**
- **Little scope for increasing irrigated crop area due to competition for water with other sectors**
- **Expansion of crop area limited by lack of good quality arable soils and concerns about loss of wildlife habitat and biodiversity**
  - **USA conservation reserve land**
  - **Rainforests and wetlands in Latin America, SE Asia, SSA**

USA Corn Yield Trends, 1966-2005[1]

(embodies tremendous technological innovation)

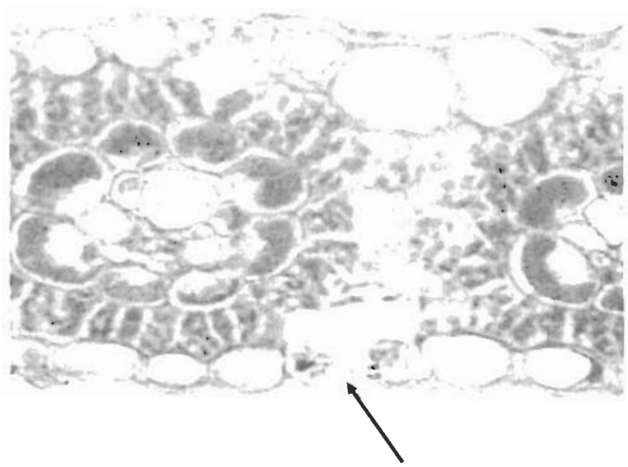


From: Convergence of Energy and Agriculture, www.cast-science.org 23

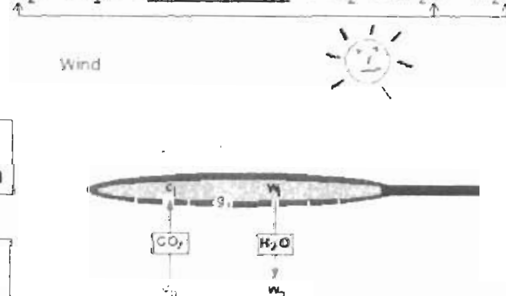
Will there be enough corn?

- **New York Times article, June 5 2008 :**
  - **"Monsanto Offers a Plan to Increase Food Supply", by Andrew Pollack**
  - **"*Monsanto, the leader in agricultural biotechnology, pledged Wednesday to develop seeds that would double the yields of corn, soybeans and cotton by 2030 and would require 30 percent less water...*"**
  - **"The announcement by CEO Hugh Grant came "*as world leaders are meeting in Rome to discuss rising food prices and growing food shortages*"**
  - James E. Specht, a soybean breeder at the University of Nebraska, said he doubted it could be done. "*The hype-to-reality ratio of that one is essentially infinity,*" Mr. Specht said. "*Seeing an exponential change in the yield curve is unlikely.*"

Basis of Crop Water Loss: Leaf architecture



$CO_2 + 2H_2O +$ **solar energy** $\rightarrow O_2 + CH_2O + H_2O$



Leaf Interior
c_i = 40-60 ppm

Atmosphere
c_a = 385 ppm

Leaf Interior
w_i = 100% RH

Atmosphere
w_a = 50% RH

Photosynthesis $A = \frac{g}{1.6}(c_a - c_i)$

Transpiration $E = g(w_i - w_a)$

$$WUE = \frac{A}{E} = \frac{c_a - c_i}{1.6(w_a - w_i)}$$

For a sunlit soybean leaf (C3 type of photosynthesis):

During the time it takes for 1 CO_2 molecule to pass thru an open stomatal pore,
400 H_2O molecules simultaneously escape from that same pore !!!!

(~6.1g CO_2 per 1000g H_2O) (Nobel, 1999)

Plants must thus exchange 164 kg H_2O to acquire 1 kg CO_2

Slide provided by J. Specht, Univ. of Nebraksa

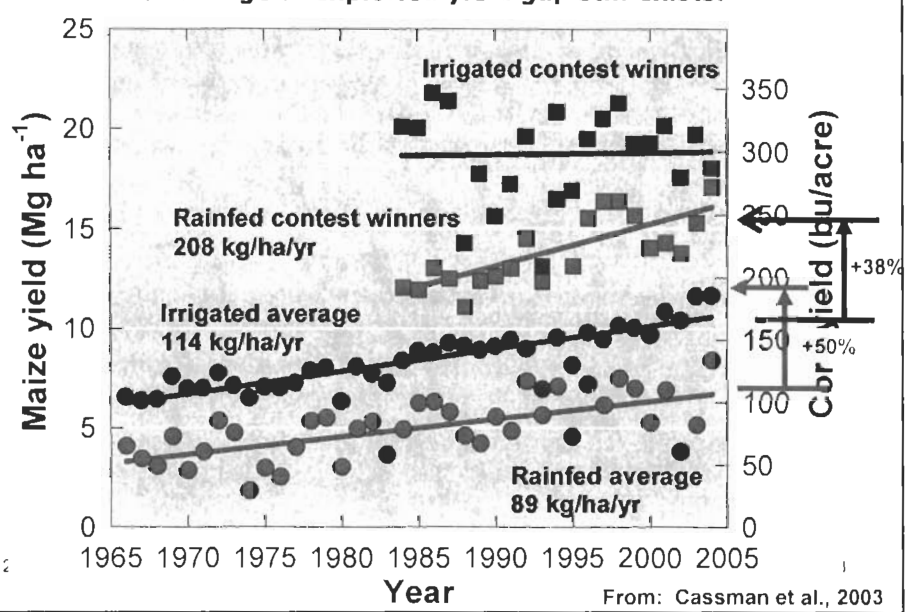
R. Ford Denison Hypothesis: Evolution versus genetic improvement by humans[1]

- Evolution has already tried and rejected options for improving plant traits that give individual plants a competitive advantage against neighboring plants
  - Photosynthesis, nitrogen efficiency, drought
  - Up or down regulation of single gene expression already tested by evolution
- Evolution has not optimized traits that improve productivity of a dense community of plants of the same species, or quality traits for specific end uses
  - Greater harvest index, resistance pests/diseases in luxuriant environments (large LAI, high leaf [N])
  - Novel proteins, nutritional qualities, fine oils, pharmaceuticals

[1]Darwinian agriculture: When can humans find solutions beyond the reach of natural selection? 2003. Quarterly Review of Biology. 78:145-167.

<u>Nebraska contest-winning and average yield trends</u>

No increase in yield potential ceiling since the 1980s, but a large unexploited yield gap still exists.

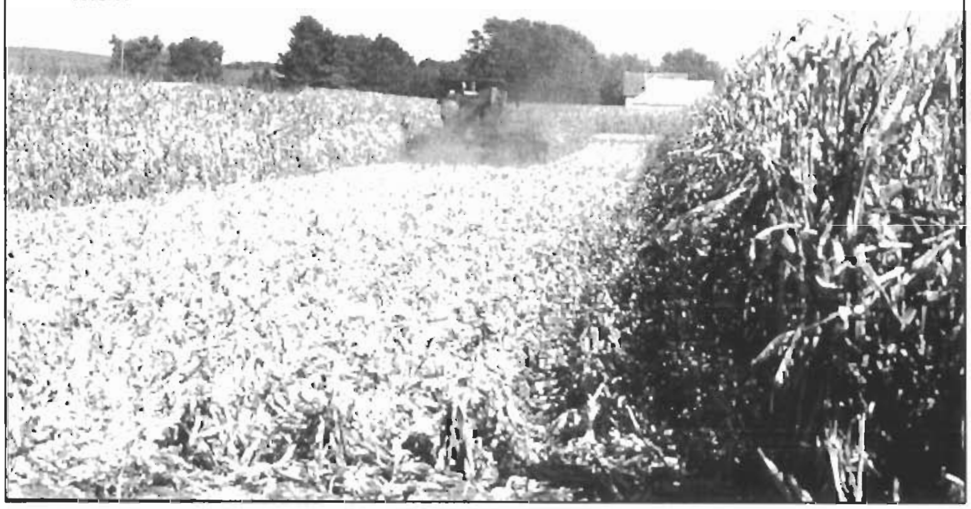


From: Cassman et al., 2003

Large exploitable gap between average and record yields.

USA contest-winning corn field, 1997, Sterling NE.

310 bu/ac (ethanol yield of 800 gallons/ha): How to close the gap between highest possible yields (called yield potential) and average farm yields in an environmentally sustainable manner?



Need for Ecological Intensification¶

- Development of high-yield crop production systems that protect soil and environmental quality and conserve natural resources
- Characteristics of EI systems:
  - Yields that reach 80-85% of genetic yield potential
  - 70-80% N fertilizer uptake efficiency (vs 30-40% now)
  - Improve soil quality (nutrient stocks, SOM)
  - Integrated pest management (IPM)
  - Contribute to net reduction in greenhouse gases
  - Have a large net positive energy balance
  - In irrigated systems: 90-95% water use efficiency

¶Cassman, 1999. *in* Proc. Natl. Acad. Sci (USA):5952-5959

Ecological Intensification Requires

- Interdisciplinary, systems research
  - agronomy, soil science, plant physiology/pathology/entomology, geology/hydrology, meteorology, conventional breeding and molecular genetics, computer science, engineering, animal science, economics and policy.,,,,,
- Requires substantial funding—equivalent to support levels for genomics per FTE
- Production- and landscape-scale research
- An appropriate balance among simulation, validation, and measurement

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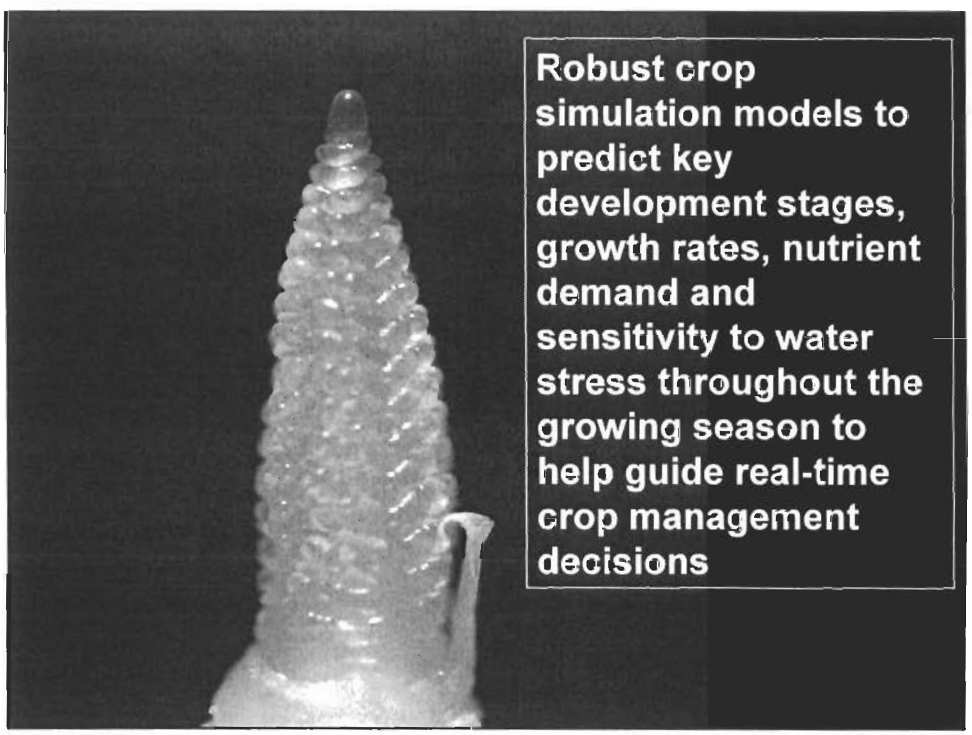
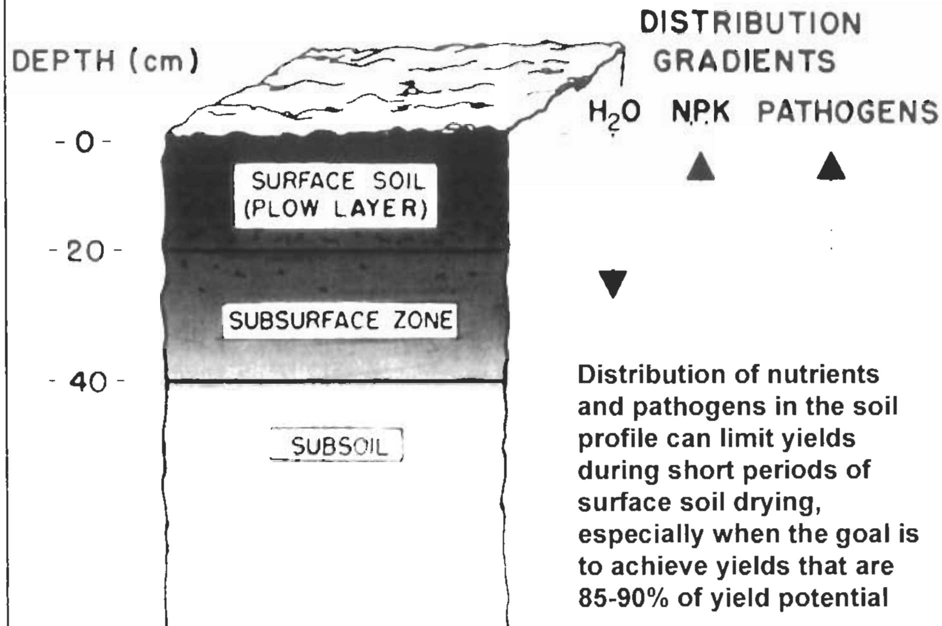


Margin for error is razor-thin when attempting to produce crops near the yield potential ceiling----especially for N fertilizer management and for achieving a cost-effective balance of all essential nutrients in spatially variable fields

Nutrient-disease interactions: Severity of verticillium wilt on cotton is more severe in potassium-deficient plants; plants well-supplied with potassium have greater tolerance of verticillium wilt disease progression.



Distribution of nutrients and pathogens in the soil profile can limit yields during short periods of surface soil drying, especially when the goal is to achieve yields that are 85-90% of yield potential

Energy Independence and Security Act of 2007

- Life-cycle assessment (LCA) of greenhouse gas (GHG) emissions:

  "the aggregate quantity of GHG emissions (*including direct emissions and significant indirect emissions such as from land use changes*), related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution"
- Sets GHG emission reduction thresholds vs gasoline:
  - **Starch-ethanol (corn): -20%**
  - **Cellulosic ethanol: -60%**
  - **Advanced biofuels: -50%**
- Appropriate life-cycle methods and models will be established by the EPA by 2009

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Need to get corn-ethanol right

- Rapid expansion of production capacity
  - 60% of current capacity from plants that have come on line since January 2005; 75% by end of 2009
- Direct-effect fossil fuel use and emissions can be obtained from updated data for crop production and biorefinery performance
  - Important to use values consistent with industry performance as it currently functions: yields, inputs, energy use, DDG use
  - Exception: nitrogen losses (can use IPCC defaults)

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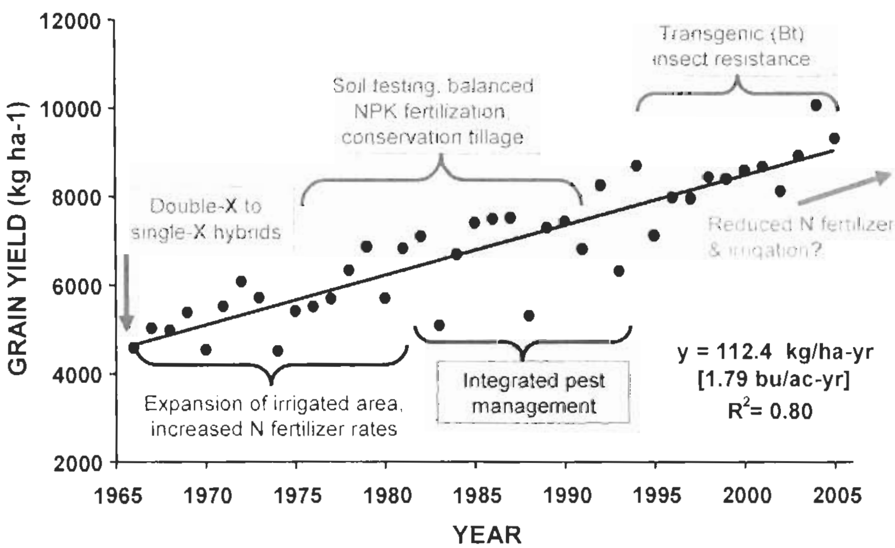
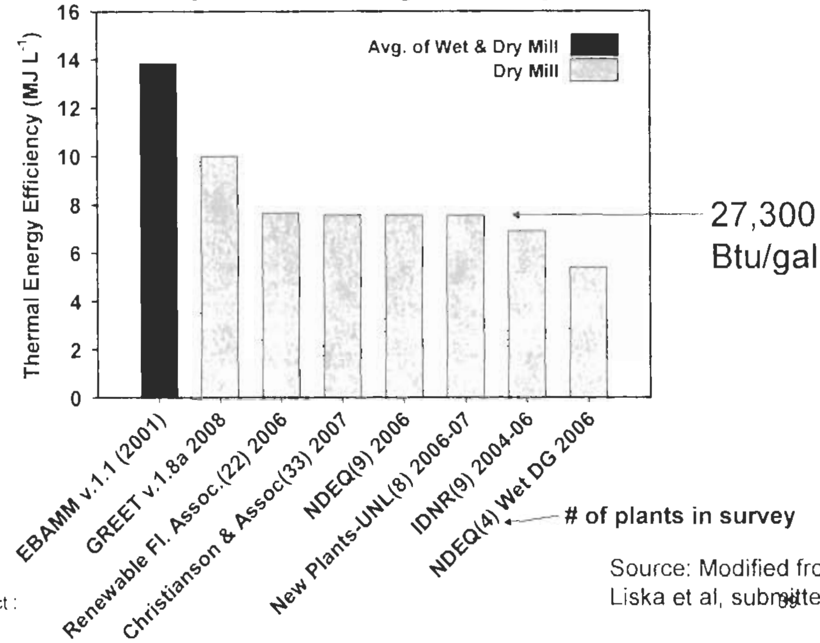
USA Corn Yield Trends, 1966-2005[1]

(embodies tremendous technological innovation)



From: Convergence of Energy and Agriculture, www.cast-science.org 38

Previous biorefinery thermal efficiency estimates vs. recent surveys and state regulatory agency records



Source: Modified from, Liska et al, submitted

27 Oct :

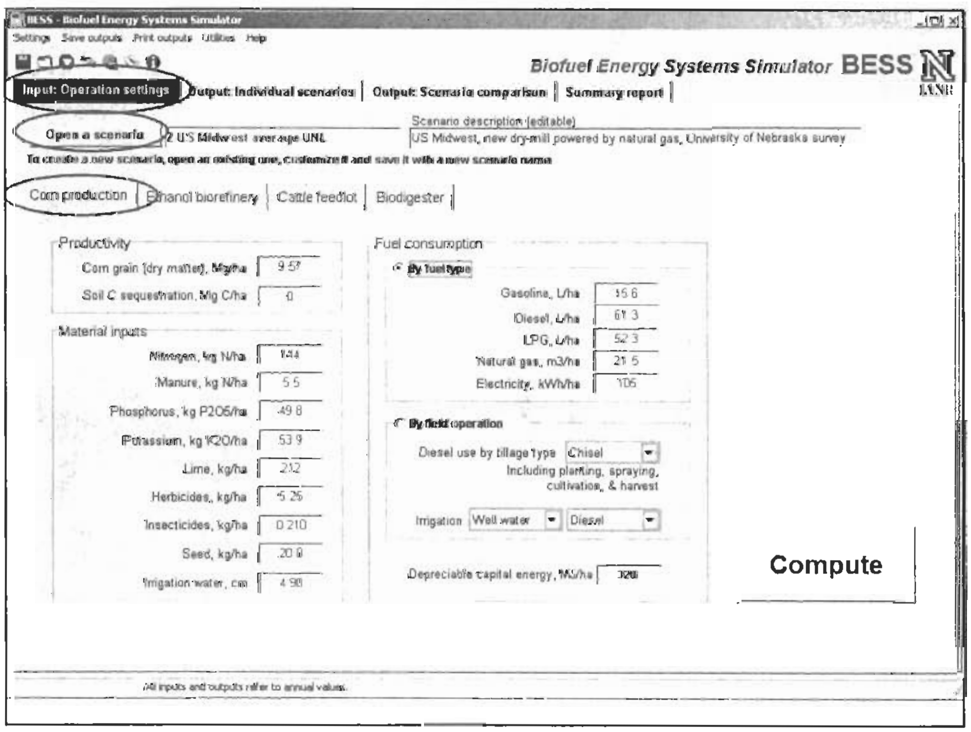
Corn ethanol co-product distillers grains are a nutritious livestock feed:

- 30% CP(65% UIP), 0.8% P, 11% fat, 40% NDF
- High fiber energy source with high digestibility
- Energy content and feeding value ~125% (wet or dry) of corn; can replace 40% of beef cattle diets
- Sulfur content - .35 to 1.0%, variable

Biofuel Energy Systems Simulator (BESS)

[available at: www.bess.unl.edu]

- Most up to date estimates for direct-effect GHG emissions for corn ethanol based on best current science and input from all key disciplines (engineers, agronomists, soil scientists, animal nutritionists, industry professionals)
- User-friendly, transparent, and well documented
- Default scenarios based on state or regional-scale data, but can also be used for certification of an individual ethanol plant, its associated corn supply and co-product use
- Can be used for estimating carbon-offset credits for emissions trading with an individual ethanol plant as the aggregator
- BESS can be used for compliance and certification



Inventory of GHG emissions from corn-ethanol life-cycle:

IA avg. natural gas biorefinery

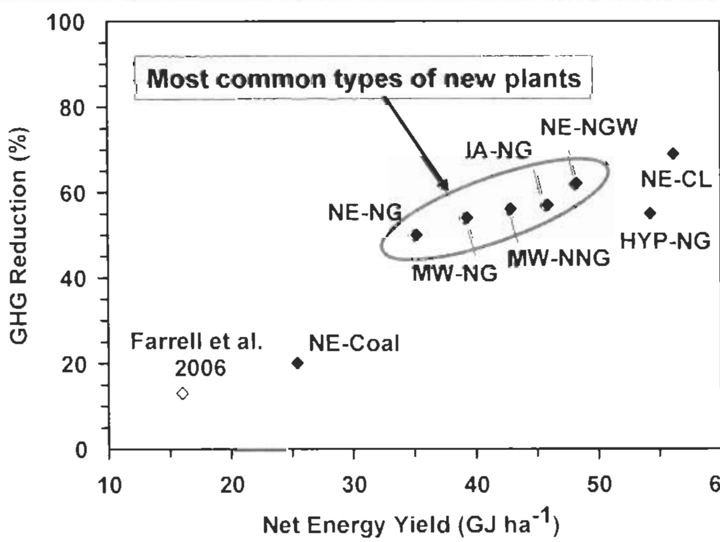
N2O* = 50% crop GHG emissions, 25% of life-cycle emissions

*includes synthetic N, manure, crop residue, volatilization, leaching & runoff (IPCC 2006)

Component	GHG emission category	gCO2eq MJ^{-1}	Mg CO2eq*	% of LC
Crop Production				
	Nitrogen fertilizer, N	4.20	33,614	7.37
	Phosphorus fertilizer, P	0.953	7,618	1.67
	Potassium fertilizer, K	0.542	4,337	0.951
	Lime	2.82	22,577	4.95
	Herbicides	1.51	12,079	2.65
	Insecticides	0.018	141	0.031
	Seed	0.193	1,540	0.338
	Gasoline	0.355	2,837	0.622
	Diesel	1.73	13,848	3.04
	LPG	1.24	9,916	2.17
	Natural gas	0	0	0
	Electricity	0.348	2,785	0.611
	Depreciable capital	0.268	2,144	0.470
	N emissions**-N2O	14.1	112,550	24.7
	TOTAL	28.3	225,986	49.6
Biorefinery				
	Natural Gas Input	19.7	157,356	34.5
	NG Input drying DG	0	0	0
	Electricity input	6.53	52,201	11.4
	Depreciable capital	0.458	3,663	0.803
	Grain transportation	2.11	16,851	3.69
	TOTAL	28.8	230,071	50.4
Co-Product Credit				
	Diesel	0.216	1,731	0.380
	Urea production	-5.10	-40,795	-8.95
	Corn production	-11.4	-91,311	-20.0
	Enteric fermentation-CH4	-2.64	-21,102	-4.63
	TOTAL	-18.9	-151,476	-33.2
	EBAMM co-product credit	(-24.9)	(-198,975)	(-43.6)
Transportation of Ethanol from Biorefinery		1.40	11,196	
LIFE-CYCLE NET EMISSIONS		39.5	315,777	
GHG-intensity of ethanol, g CO2eq MJ^{-1}		39.5	315,777	
GHG-intensity of gasoline***, g CO2eq MJ^{-1}		92.0	735,715	
GHG reduction relative to gasoline, %		52.5	419,938	**57.1%**

BESS version 2008.3.0 **Source: Liska et al, submitted**

Current Corn Ethanol Life-Cycle Performance: 50-65% GHG Reduction and significant Net Energy Yield



BESS version 2008.3.0, www.bess.unl.edu

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Our Recommendation to California Air Resources Board*: Create 3 classes of Ethanol Facilities for GHG Regulation

1) Title V permitted facilities; major source, e.g. 100 tons VOC/yr (includes all wet mills and coal powered facilities in Nebraska and Iowa, 9 out of 31 facilities in 2006)
2) Dry mills using natural gas (largest group)
3) Dry mills using natural gas, with advanced efficiencies (e.g. high cattle densities, closed-loop facilities, DG as energy source)

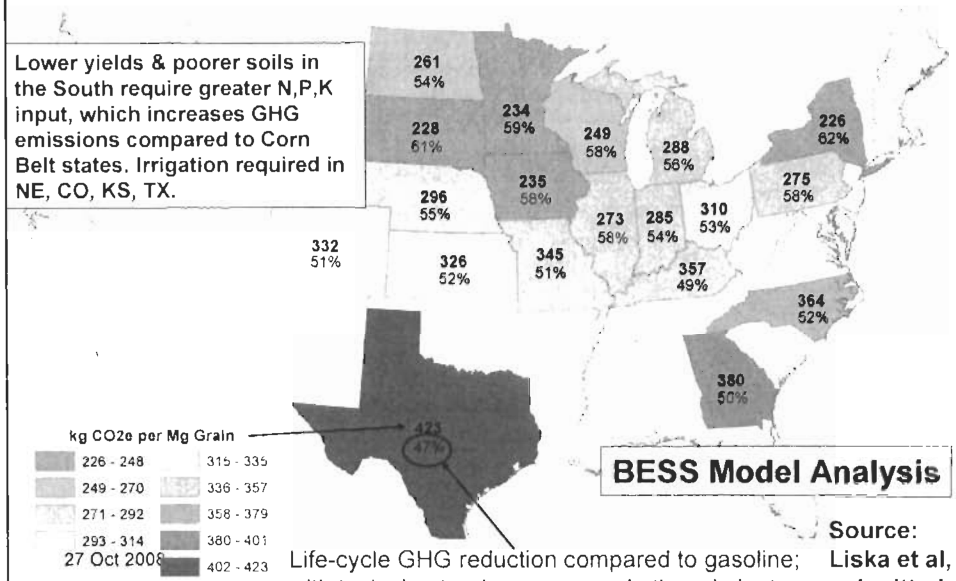
Class	I	II	III
Description	Title V (coal with dry DG)	Natural Gas dry mills, dry DG	Natural gas dry Mills, wet DG
Thermal Energy, MJ L-1	12.81	7.61	5.44
BESS Life-cycle GHG emissions reduction	7%	51%	62%

*March 26, 2008 memo to CARB

Most sensitive input parameters on GHG emissions reductions & net energy yield of corn-ethanol

1. **Crop yield and nitrogen fertilizer efficiency**
2. **Biorefinery thermal energy inputs: MJ per liter (e.g. wet vs. dry distillers grains)**
3. **Conversion yield: liters ethanol per kg grain**
4. **Biorefinery electricity use**

Regional Variability in GHG-Intensity of Corn Production and Life-Cycle GHG Reductions from Corn-Ethanol Assuming a New Nat. Gas Biorefinery



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Life-cycle GHG reduction compared to gasoline; with typical natural gas-powered ethanol plant

Source: Liska et al, submitted

Challenges to large-scale development of the cellulosic biofuels industry

- Harvest, handling, storage of huge amounts of biomass
- More cost-effective pretreatment and enzyme technologies
  - Can they utilize multiple feedstock sources?
- Improved options for use of co-products
  - Feedstock for industrial chemicals?
- Large-scale deployment (>1 billion gallon/yr)is 7-10 years off
  - Meantime, biofuel production capacity builds out until prices of maize, sugarcane, and oil palm reach breakeven point as a biofuel feedstock

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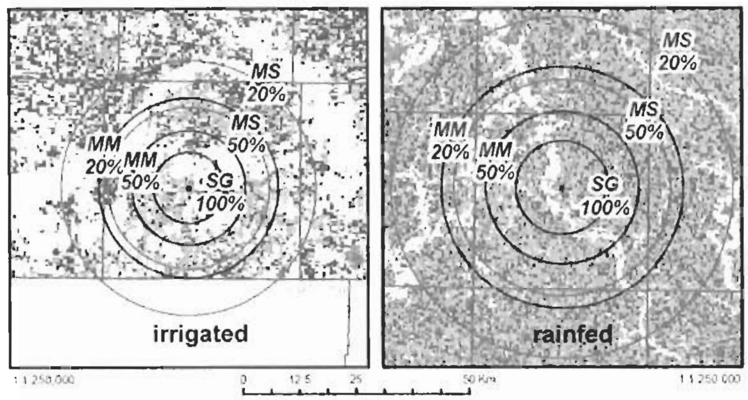
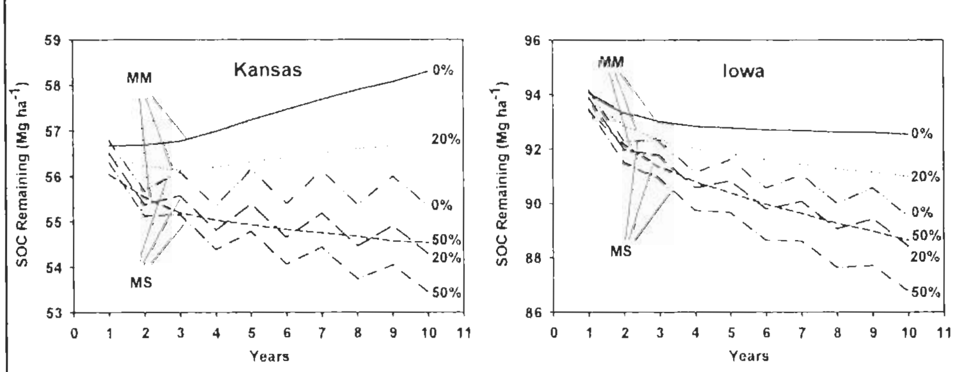
Cellulosic Ethanol Life-Cycle Assessment: Biomass Cultivation Area for Switchgrass or Maize Crop Residue, with Removal Levels & Crop Rotations



Maize acres (yellow), soybean (green), wheat and sorghum (brown), other crops (gray), non-crop acres (white), and water (blue); SG 100%, switchgrass complete harvest; MS 50% and MS 20%, maize-soybean rotation, with either 50% or 20% maize residue removal, respectively; MM 50% and MM 20%, continuous maize with either 50% or 20% residue removal.

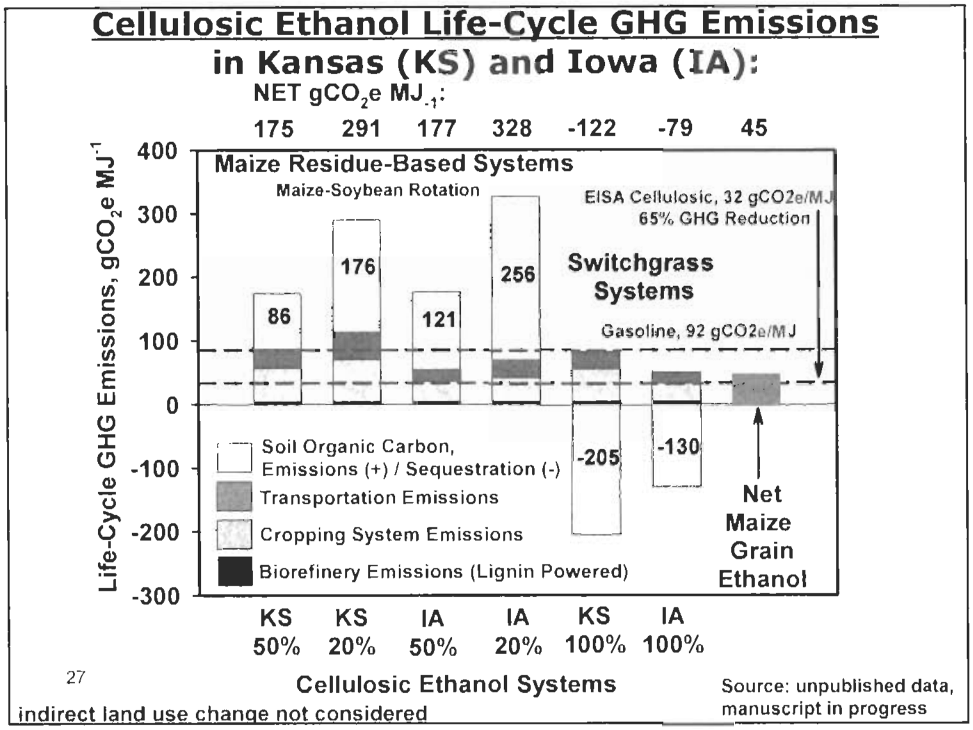
Source: BESS-Cellulosic ethanol, BETA version

Loss of Soil Organic Carbon (SOC) under Continuous Maize (MM) and Maize-Soybean (MS) Rotation with Differing Residue Removal Levels for Cellulosic Ethanol Production



Soil C trends estimated using D-K Model

Source: unpublished data, manuscript in progress



Conclusions

- We must plan to meet food and energy demand of 9 billion people (much wealthier on average than today) by ~2040
  - Will require ~75% more food production and 2-3x more energy use even with major efforts to improve energy efficiency and conservation
- It is possible to develop biofuel systems that contribute to reduced demand for imported oil and mitigate GHG emissions without sacrificing food security
  - Corn-ethanol has potential to be a component, but only if the food vs fuel trade-off can be avoided
- Current USA & global research portfolio will not get us there, neither for corn or other crops, without an explicit focus on accelerating crop yield gains on existing farmland while reducing the environmental footprint of agriculture
- ***Ecological intensification*** of agricultural is the only means to achieve food security, expanded biofuel-bioproduct production, and protection of ecosystem services
- For cellulosic ethanol, yield density determines economic viability, soil C sequestration is key for environmental sustainability

Final Conclusions

- Developing effective environmental policies, regulation, and incentive framework depends on projections of future environmental impact under different scenarios
- Unfortunately, the balance between research investment in developing simulation models without adequate underpinning investment in measurement and monitoring of driving forces and environmental indicators can lead to huge differences in estimates of current and future environmental impact
  - Soil carbon sequestration or loss
  - Impact of climate change on crop yields
  - Nitrous oxide emissions from agriculture
  - Nr deposition rates and emissions from agriculture
  - N fertilizer use efficiency of major crops and future biofuel crops

Citations

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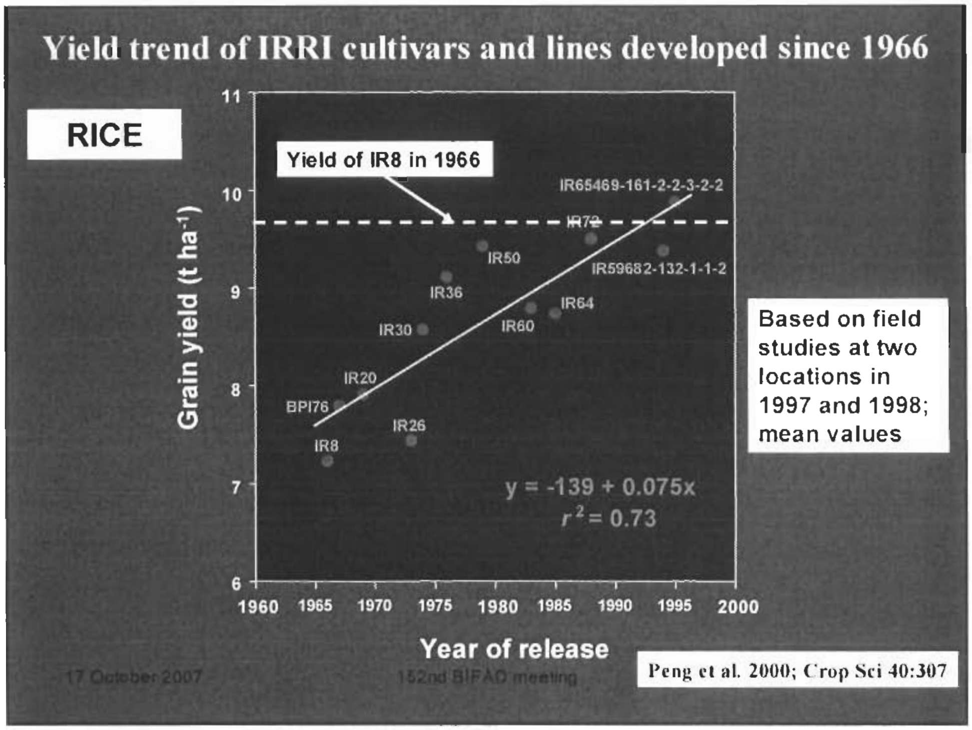
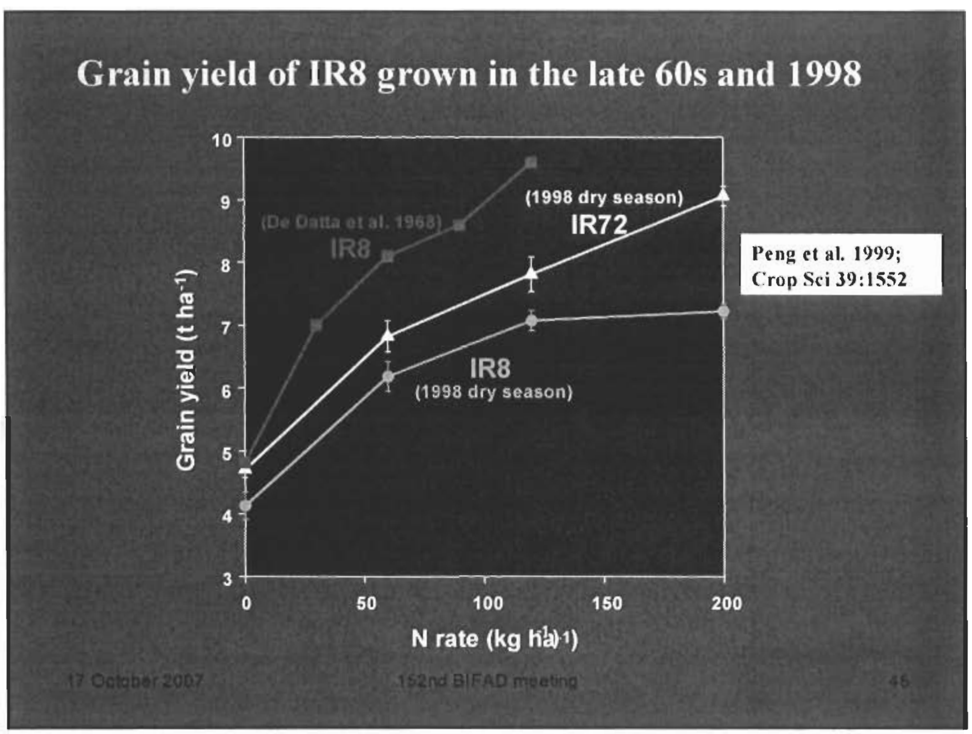

Yield trend of IRRI cultivars and lines developed since 1966
RICE
Yield of IR8 in 1966
IR65469-161-2-2-3-2-2
IR72
IR50
IR59682-132-1-1-2
IR36
IR64
IR30
IR60
IR20
BPI76
IR26
IR8
y = -139 + 0.075x
r² = 0.73
Grain yield (t ha-1)
Year of release
Based on field studies at two locations in 1997 and 1998; mean values
Peng et al. 2000; Crop Sci 40:307
17 October 2007
152nd BIFAD meeting


Grain yield of IR8 grown in the late 60s and 1998
(De Datta et al. 1968)
IR8
(1998 dry season)
IR72
IR8
(1998 dry season)
Grain yield (t ha-1)
N rate (kg ha-1)
Peng et al. 1999; Crop Sci 39:1552
17 October 2007
152nd BIFAD meeting
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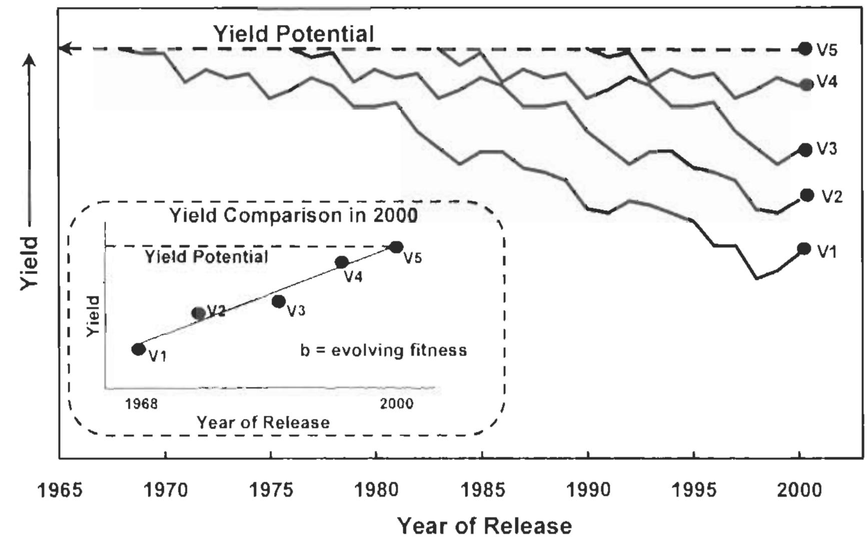
Conceptual framework for stagnant yield potential and red-queen breeding to maintain disease/insect resistance and adaptation to evolving agro-ecosystems (soils, [CO_2], climate change)



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From: Cassman et al., 2003, ARER

Dr. G. David Tilman

University of Minnesota

Dr. G. David Tilman is Regents Professor of Ecology and holds the McKnight University Presidential Chair in Ecology at the University of Minnesota. He is an experimental and mathematical ecologist studying the impacts of the loss of biological diversity and of other types of human-driven global change on the functioning and stability of ecosystems and on the services that ecosystems provide society. David Tilman is deeply interested in the interface of science, society, ethics and environmental policy. He has given expert testimony to committees of the US Senate and House and to the White House's Office of Management and Budget, has had his scientific findings on biodiversity added to the Congressional Record by a member of congress, and given invited briefings to the Minnesota House and Senate. He has served on scientific advisory committees for the White House (the Biodiversity and Ecosystems Panel of the President's Committee of Advisors on Science and Technology), for Public Radio International's The World, and for the National Academy of Sciences (Board on Environmental Studies and Toxicology). In 1996 he founded a new publication, Issues in Ecology, to foster communication among ecologists, the public and governmental decision makers. He served as its Editor-in-Chief for eight years. He has also served on the editorial boards of scientific publications including Science, Proceedings of the National Academy of Science, and Ecology. Honors include selection as a Guggenheim Fellow, and election as a Fellow of the American Association for the Advancement of Science, as a Fellow of the American Academy of Arts and Sciences and as a member of the National Academy of Science. Prizes and awards include Sweden's Per Brink Award, Pew Scholar in Conservation Biology, and the Ecological Society of America's Cooper Award and MacArthur Award. In 2001 he was designated the most highly cited environmental scientist for the decade by the Institute for Scientific Information, an honor he also received in 2003 and 2005 for the decades from 1992-2002 and 1995-2005. After earning his Ph. D. at the University of Michigan in 1976, Dr. Tilman has spent his academic career at the University of Minnesota, but also has served as a Member of Princeton's Institute for Advanced Study, a Senior Visiting Fellow at Princeton University, and a Fellow of the National Center for Ecological Analysis and Synthesis.

Lifecycle Environmental and Health Costs and Benefits of Fossil and Renewable Fuels

by David Tilman, University of Minnesota*

Negative environmental and health consequences of fossil fuels and concerns about petroleum supplies have spurred the search for renewable transportation biofuels. To be a viable alternative, a biofuel should provide, in total across its full lifecycle, net energy gains and environmental benefits, be economically competitive, and be producible in large quantities without reducing food supplies. We use these criteria to evaluate, through life-cycle accounting, ethanol from corn grain, biodiesel from soybeans and cellulosic biofuels derived from alternative crops transformed into biofuels via either biochemical or thermochemical processes.

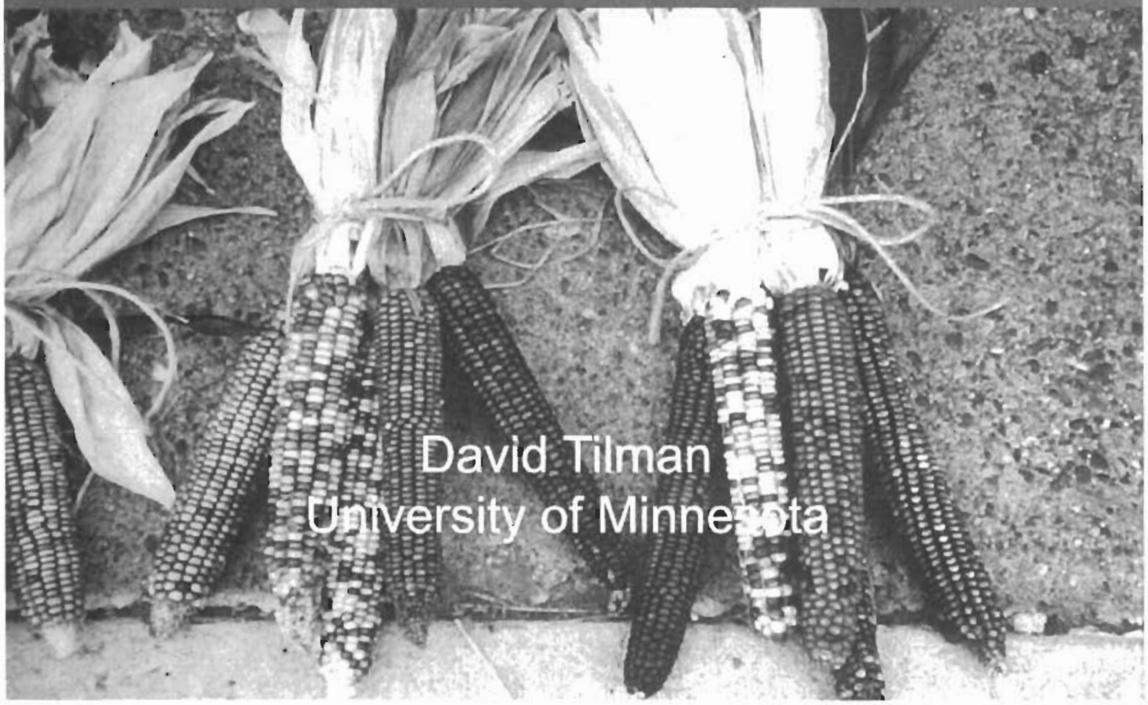
Corn ethanol yields 25% more energy than the energy invested in its production, whereas soybean biodiesel yields 93% more. Compared with ethanol, biodiesel releases just 1.0%, 8.3%, and 13% of the agricultural nitrogen, phosphorus, and pesticide pollutants, respectively, per net energy gain. Relative to the fossil fuels they displace, greenhouse gas emissions are reduced 12% by the production and combustion of ethanol and 41% by biodiesel. Biodiesel also releases less air pollutants per net energy gain than ethanol. These advantages of biodiesel over ethanol come from lower agricultural inputs and more efficient conversion of feedstocks to fuel. Neither corn ethanol nor soybean biodiesel can replace much petroleum without greatly impacting food supplies. Even dedicating the full 2005 U.S. corn and soybean crops to biofuels would meet only 12% of gasoline demand and 6% of diesel demand. Because of fossil energy needed to produce these crops and convert them to biofuels, the net energy gain from converting all US corn and soybeans to biofuels for each would only be 3% of current gasoline and diesel energy use.

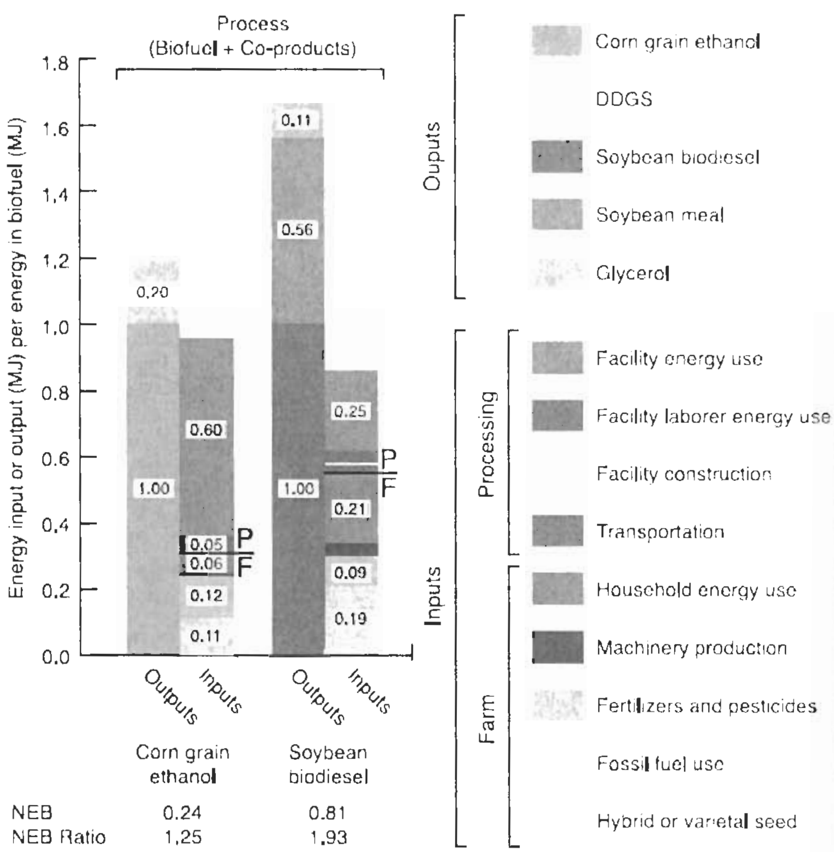
Whether or not a given biofuel offers carbon savings and other environmental benefits relative to a fossil fuel depends on how the biomass crop is produced. Converting rainforests, peatlands, savannas, or grasslands to cropland to produce food-based biofuels in Brazil, Southeast Asia, and the United States creates a 'biofuel carbon debt' by releasing 17 to 420 times more CO2 than the annual greenhouse gas (GHG) reductions these biofuels provide by displacing fossil fuels. In contrast, biofuels made from waste biomass or from biomass grown on abandoned agricultural lands planted with perennials incur little or no carbon debt and offer immediate and sustained GHG advantages. If grown with low inputs of agrichemicals, they also offer potentially great increases in the quality of surface and ground waters.

Fine particulate matter ($PM_{2.5}$) emissions from fossil fuels and biofuels, which can potentially impose large health costs on society, are another environmental concern that must be used in evaluating alternative energy sources. By using the EPA's RSM and BenMAP analytical tools on a county-by-count basis for the US, we quantifyied and then monetized the lifecycle climate and health effects of greenhouse gas (GHG) and fine particulate matter ($PM_{2.5}$) emissions from gasoline, corn ethanol, and cellulosic ethanol, we found that, for each billion ethanol-equivalent gallons of fuel produced and combusted in the US, climate and health costs are about $500 million for gasoline, about $600–1000 million for corn ethanol depending on biorefinery heat source (natural gas, coal, or corn stover), but only $100–200 million for cellulosic ethanol depending on feedstock (corn stover, switchgrass, prairie biomass, or *Miscanthus*). Moreover, a spatially-explicit lifecycle analysis that tracked $PM_{2.5}$ emissions and exposure relative to US population shows regional shifts in health costs dependent upon fuel production systems. Because climate and $PM_{2.5}$ health costs are roughly equal, the total monetized benefit of shifting from gasoline to properly-produced cellulosic biofuels is twice as large as when only GHG benefits are considered.

*Based on collaborative projects with J. Hill, S. Polasky, E. Nelson, H. Huo, L. Ludwig, D. Bonta, D. Tiffany, J. Neumann, H. Zheng, J. Fargione, and P. Hawthorne

Environmental Impacts of Food versus Cellulose-Based Biofuels





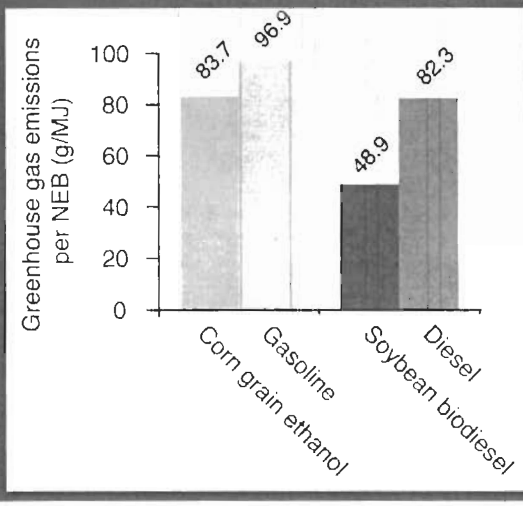
Lifecycle Energy Inputs And Outputs For Corn Ethanol & Soybean Biodiesel

(Hill et al. 2006)

Lifecycle Emissions

(relative to fossil counterpart; H=Higher; L = Lower)

- Greenhouse gasses



- Criteria pollutants

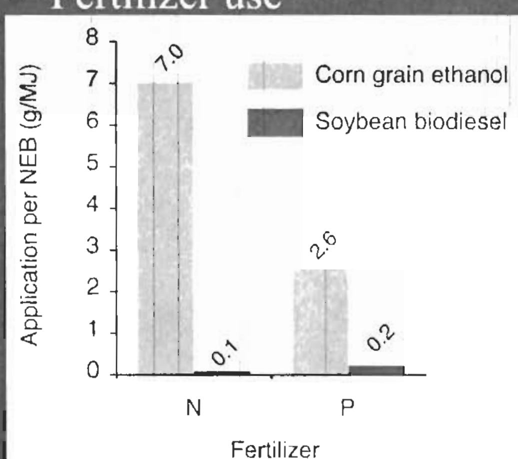
	VOC	CO	PM 10	SOx	NO x
Corn grain ethanol	H	H	H	H	H
Soybean biodiesel	L	L	L	L	H

Corn Ethanol:
14% less GHG then Gasoline

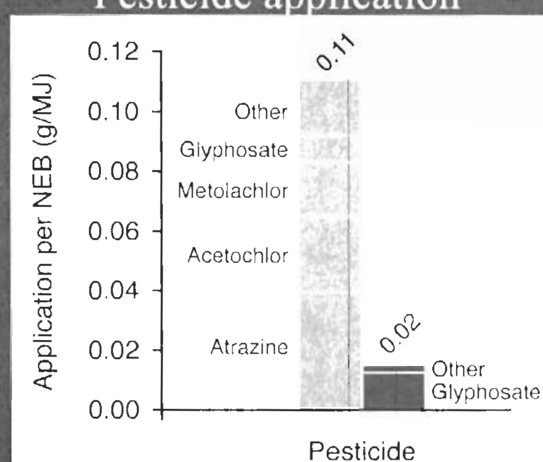
(Hill et al. 2006)

Environmental Effects of Corn Ethanol and Soybean Biodiesel

- Fertilizer use



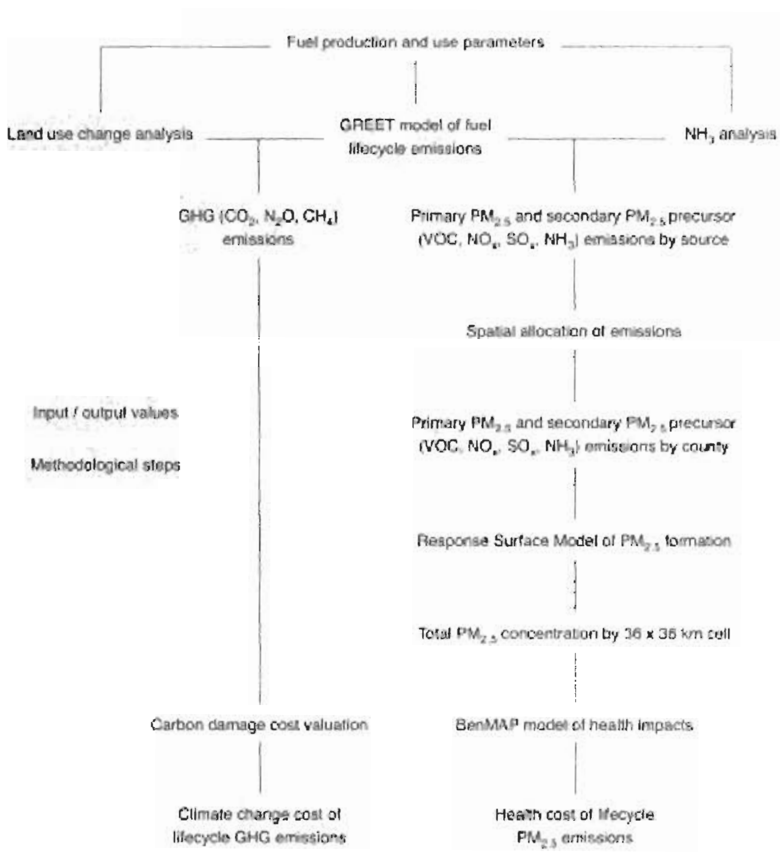
- Pesticide application



Much of N, P and pesticide enter surface and ground waters
Increased corn from irrigation uses 5000 gallons of water for each gallon of ethanol made

Potential of US Food-Based Biofuels

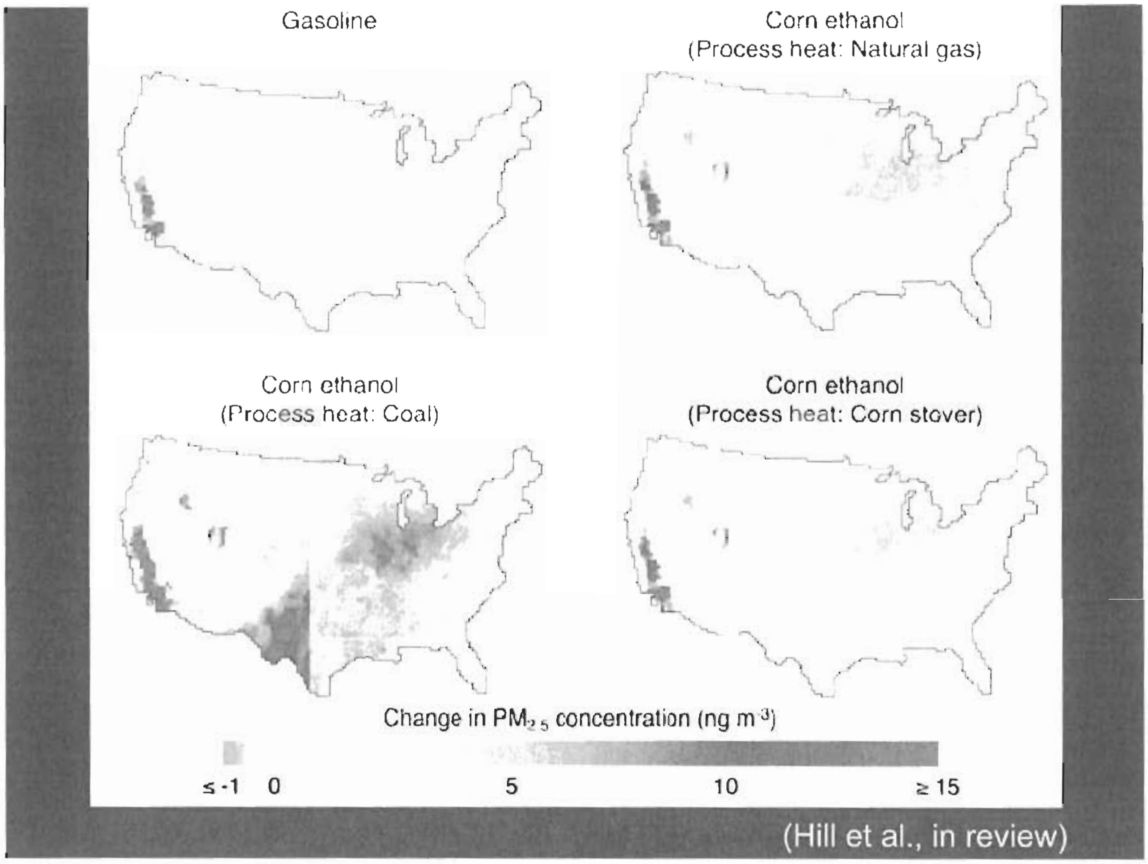
	Entire 2005 US crop to biofuel
Corn ethanol	12% of gasoline ***2.5% Energy Gain***
Soybean biodiesel	6% of diesel ***3% Energy Gain***

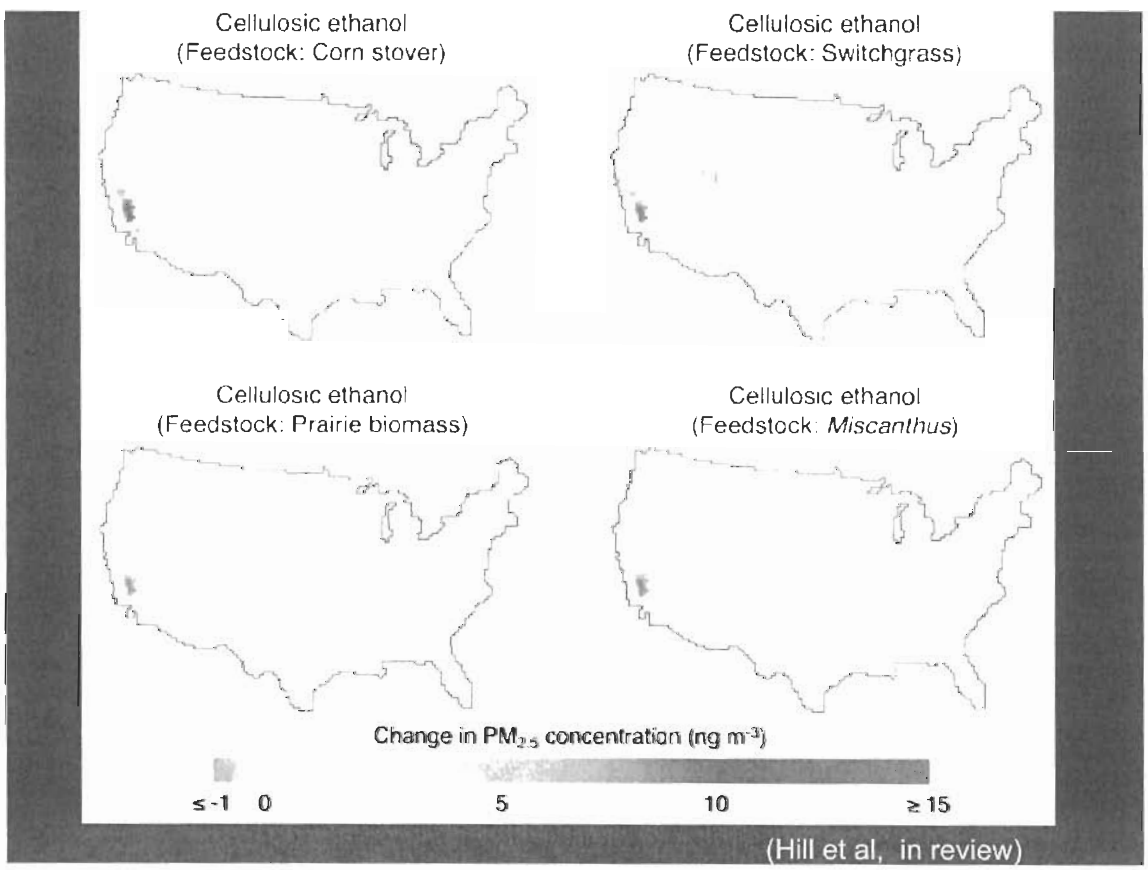


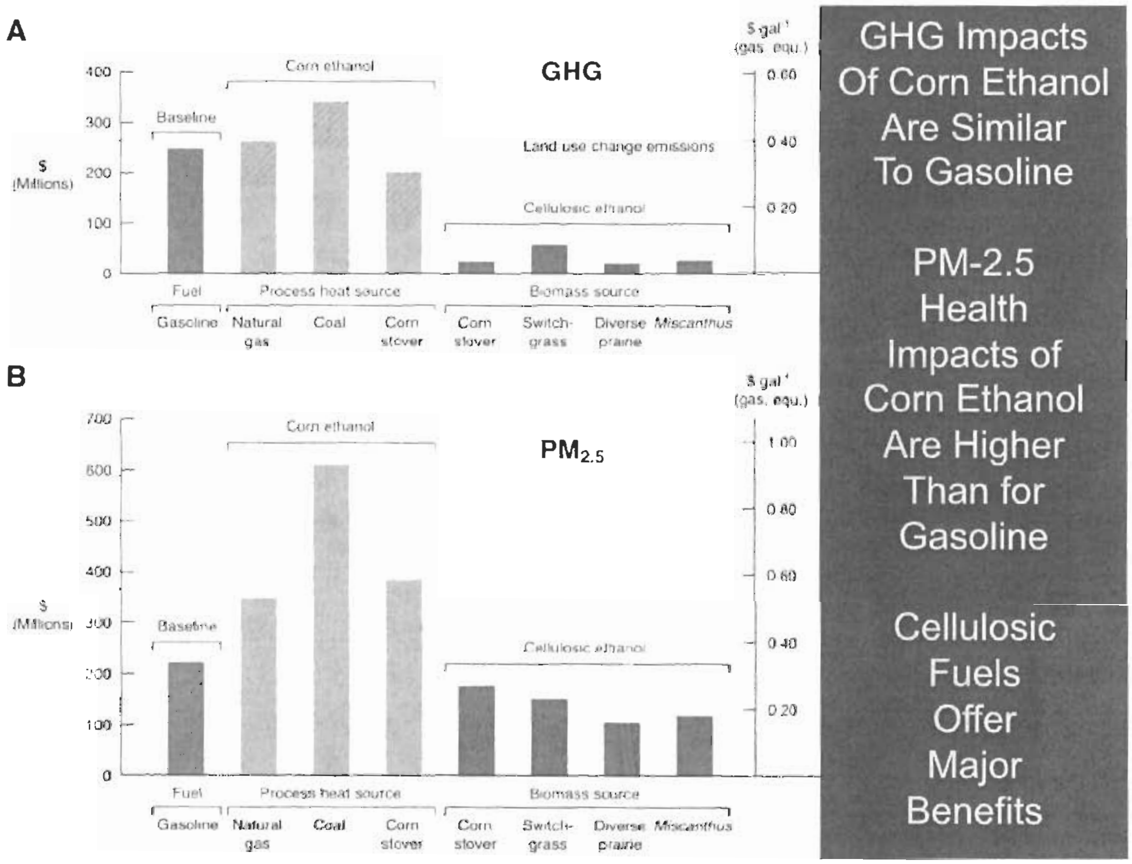
Lifecycle Health and CO_2 Costs Of Alternative Biofuels:

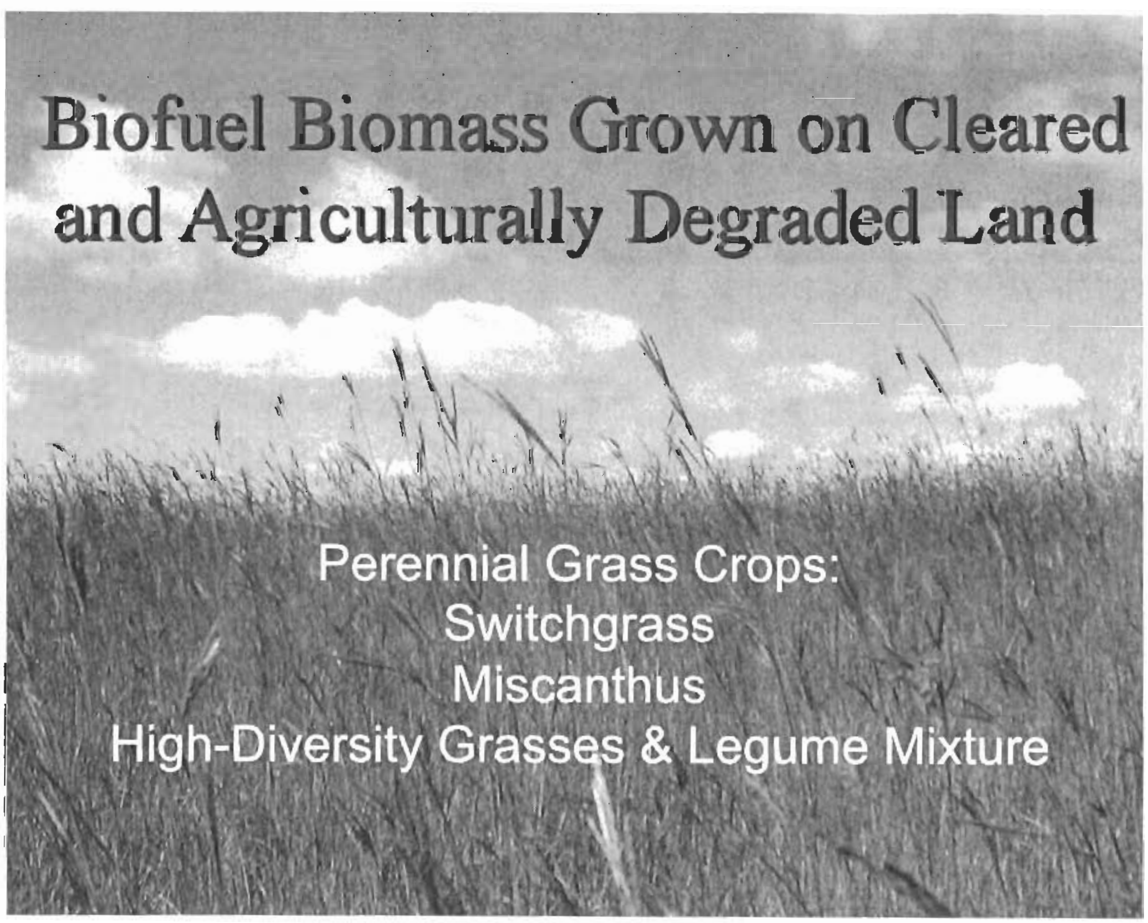
Ethanol from Corn or from Perennial Grasses or from Corn Stover

(Hill et al., in review)

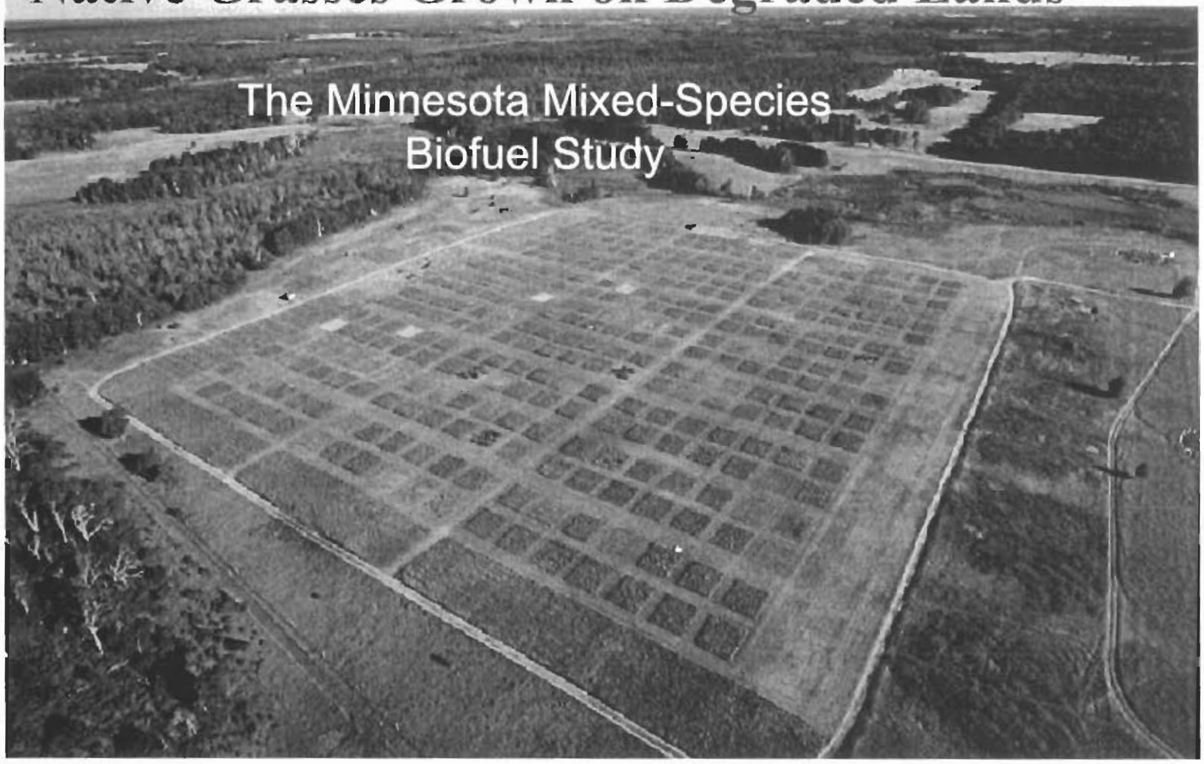

Gasoline
Corn ethanol
(Process heat: Natural gas)
Corn ethanol
(Process heat: Coal)
Corn ethanol
(Process heat: Corn stover)
Change in $PM_{2.5}$ concentration (ng m^{-3})
≤ -1
0
5
10
≥ 15
(Hill et al., in review)


Cellulosic ethanol
(Feedstock: Corn stover)
Cellulosic ethanol
(Feedstock: Switchgrass)
Cellulosic ethanol
(Feedstock: Prairie biomass)
Cellulosic ethanol
(Feedstock: *Miscanthus*)
Change in $PM_{2.5}$ concentration (ng m^{-3})
≤ -1
0
5
10
≥ 15
(Hill et al, in review)

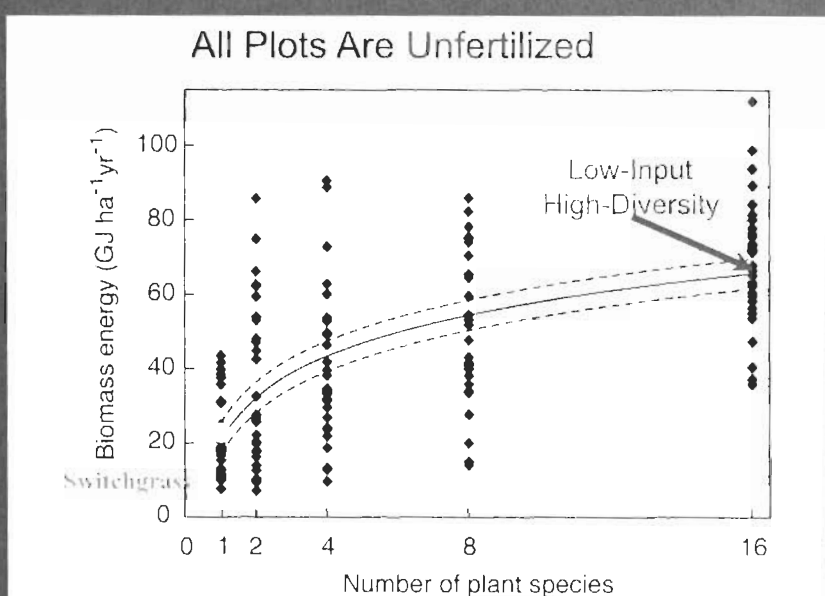

A
GHG
$ (Millions)
$ gal⁻¹ (gas. equ.)
Corn ethanol
Baseline
Land use change emissions
Cellulosic ethanol
Fuel
Process heat source
Biomass source
Gasoline
Natural gas
Coal
Corn stover
Corn stover
Switch-grass
Diverse prairie
Miscanthus
B
PM2.5
GHG Impacts Of Corn Ethanol Are Similar To Gasoline
PM-2.5 Health Impacts of Corn Ethanol Are Higher Than for Gasoline
Cellulosic Fuels Offer Major Benefits


Biofuel Biomass Grown on Cleared and Agriculturally Degraded Land
Perennial Grass Crops:
Switchgrass
Miscanthus
High-Diversity Grasses & Legume Mixture

Biofuels from High-Diversity Mixtures of Native Grasses Grown on Degraded Lands



High Diversity Grasslands Produced 238% More Biofuel Than Monocultures



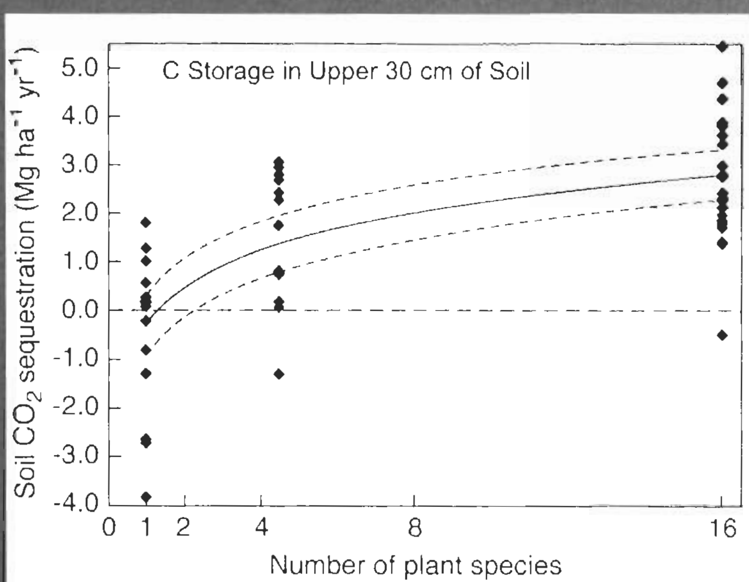
Effects of diversity came from legumes that fixed N and perennial warm-season grasses that efficiently used converted this N to make biomass

(Tilman et al. 2006 *Science*)

Soil Is A Major Carbon Sink

- Small changes in soil carbon storage can have a large impact on atmospheric carbon dioxide levels.
- The carbon stored in the world's soils is about 1,400 billion tons.
- This is more than twice the carbon in trees and other plants (560 billion tons).
- This is about twice that in the atmosphere (750 billion tons as carbon dioxide).

Diverse Prairie Stores More C in Soil



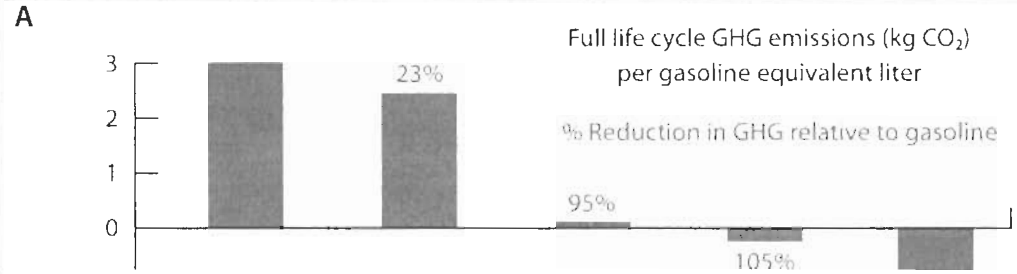
High-Diversity Prairie Biofuels Are Carbon Negative

4.4 t/ha CO2 Storage in Soil (0-100 cm depth) and Perennial Roots; 0.3 t/ha Fossil CO2 Released to Produce Biofuel

Net Sequestration of 4.1 t/ha of CO_2 (1.8 tons/acre) After Biofuel Production and Use

(Tilman et al. 2006 *Science*)

Greenhouse Gas Reductions for Next Generation Biofuels Based on GREET Analyses Using Latest Data (US Average Data for Corn Yields & Inputs)



Fuel	Gasoline	Corn Ethanol	*Miscanthus* Ethanol	Switchgrass Ethanol	Prairie Biomass Ethanol
Land Type	N/A	US Average	Wetter Lowlands	Drier Uplands	Drier Uplands
Nitrogen Fertilizer	N/A	150 kg/ha	50 kg/ha	75 kg/ha	0 kg/ha

Each Biomass Crop Will Have Its Own Optimal Conditions for Growth

US Biofuel Potential?

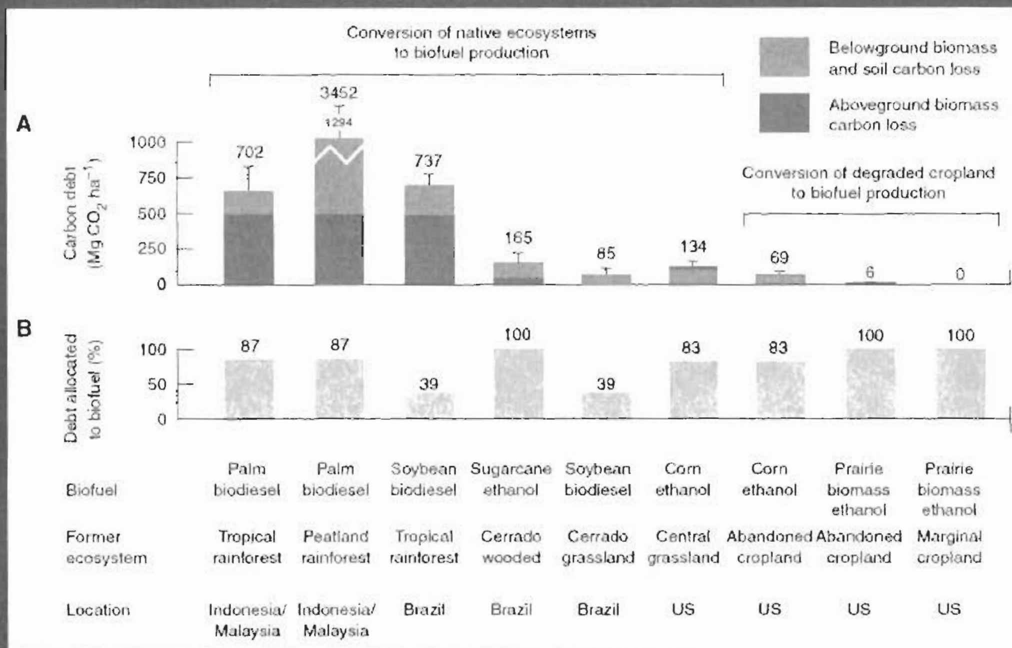
Residual ('Waste') Biomass And Dedicated Plantings Of Switchgrass, Diverse Mixed Prairie And Other Perennials Can Give Sustainable Liquid Fuel Yields Of ~30 Billion Gallons Per Year Of Ethanol That Exceed the GHG Benefits Mandated in 2007 EISA (giving GHG reductions ~75% to 100% less than gasoline)

Biofuels and Greenhouse Gas Benefits

If properly produced, biofuels can provide major greenhouse gas benefits relative to gasoline and other fossil fuels.

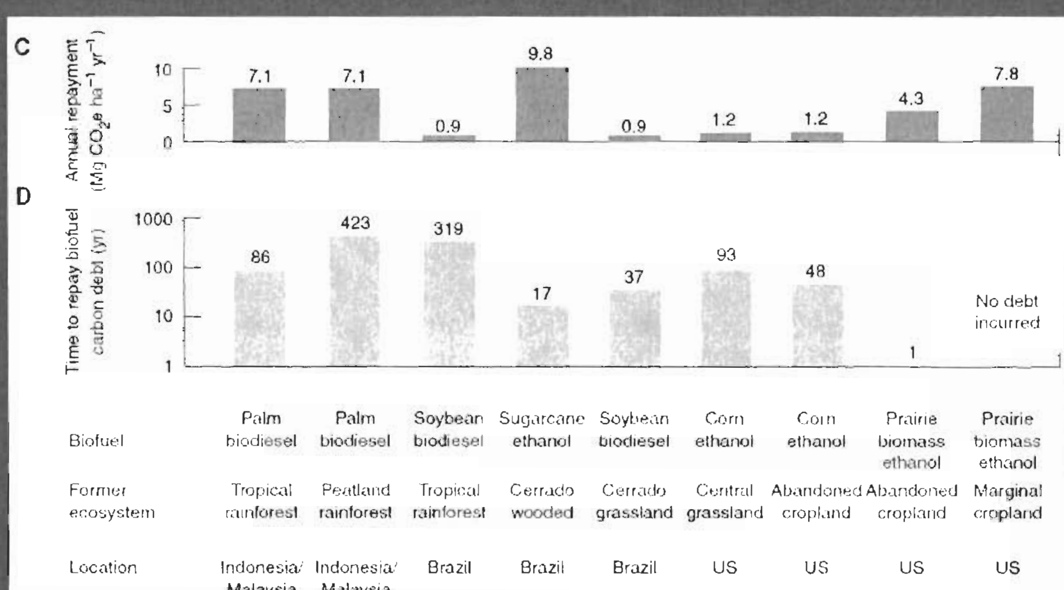
But , the direct or indirect clearing of land to grow biofuel crops can release immense amounts of carbon dioxide

Greenhouse Gas Release (as CO_2 equivalents) from Land Clearing for Biofuel



(Fargione et al. 2008)

Greenhouse Gas Repayment Rates and Times for Various Biofuels



Food Crops for Biofuels?

- 50% of US corn crop is used to feed livestock
- Remainder is exported, processed for human consumption, or converted to ethanol
- Soybean oil
- constitutes 80%
- of US edible oil consumption

Indirect Land Use Change

Diverting Croplands to Biofuel Crops

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change

Timothy Searchinger,[1*] Ralph Heimlich,[2] R. A. Houghton,[3] Fengxia Dong,[4] Amani Elobeid,[4] Jacinto Fabiosa,[4] Simla Tokgoz,[4] Dermot Hayes,[4] Tun-Hsiang Yu[4]

Most prior studies have found that substituting biofuels for gasoline will reduce greenhouse gases because biofuels sequester carbon through the growth of the feedstock. These analyses have failed to count the carbon emissions that occur as farmers worldwide respond to higher prices and convert forest and grassland to new cropland to replace the grain (or cropland) diverted to biofuels. By using a worldwide agricultural model to estimate emissions from land-use change, we found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years. Biofuels from switchgrass, if grown on U.S. corn lands, increase emissions by 50%. This result raises concerns about large biofuel mandates and highlights the value of using waste products.

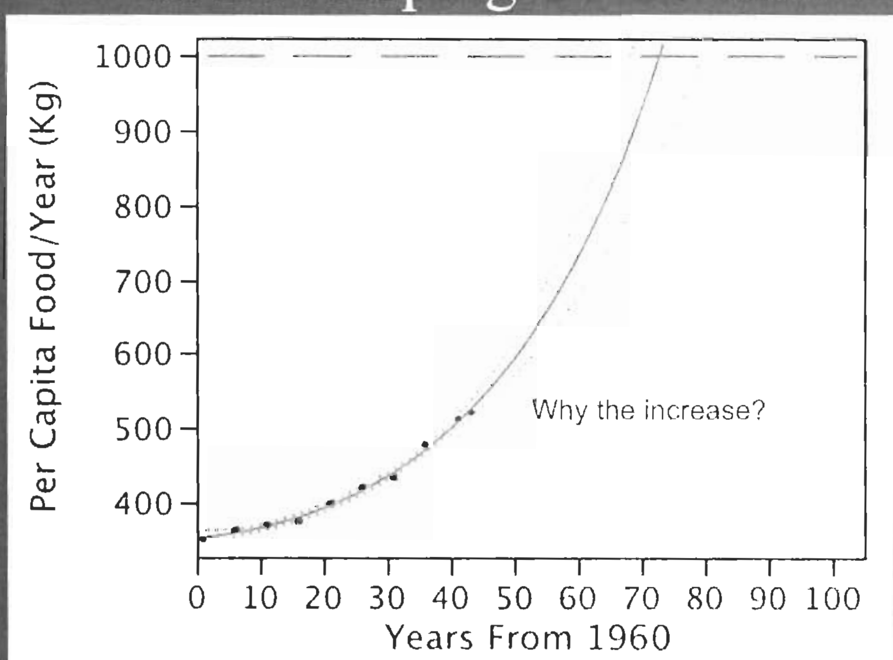
Food is an International Commodity

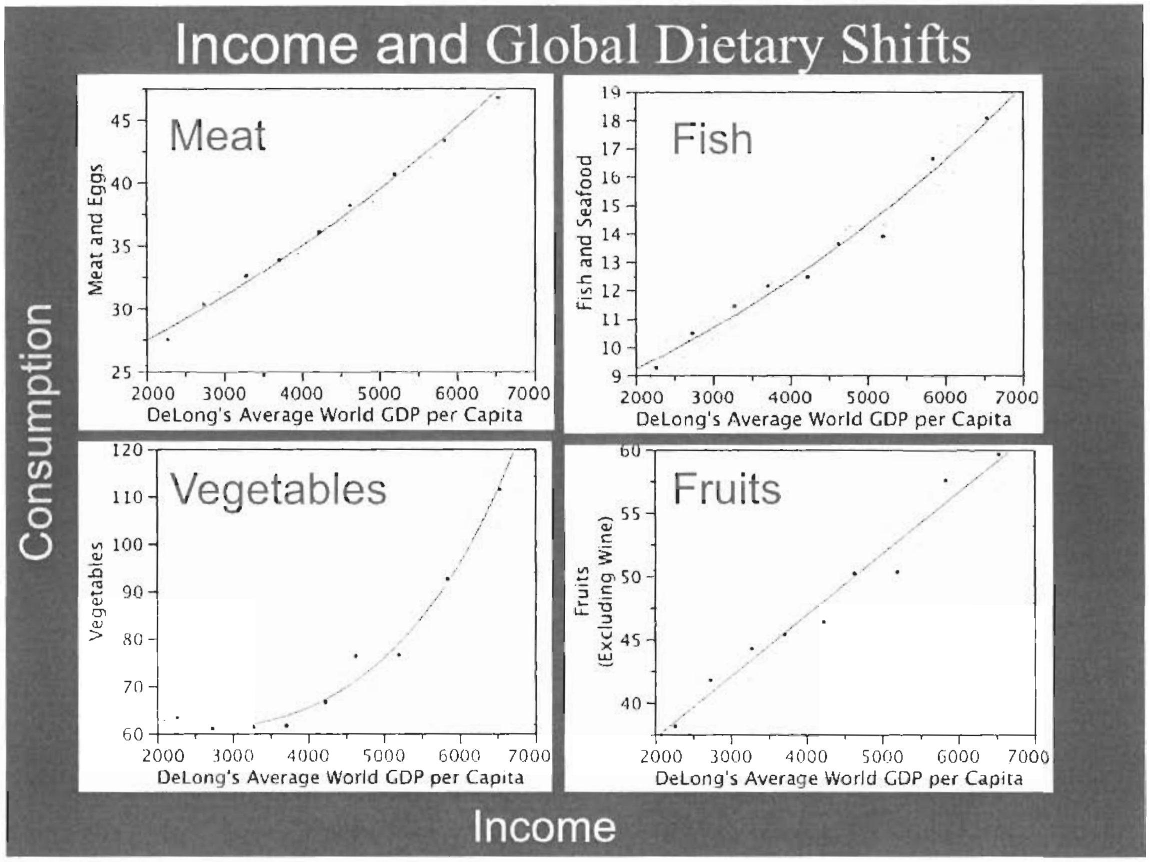
All nations of the world are linked via agricultural trade

Food & fertile agricultural land diverted to biofuels in one nation impact its own food supply and that of other nations

FAPRI and other general equilibrium agricultural models

Per Capita Food Consumption in Developing Countries





Future Global Food Demand

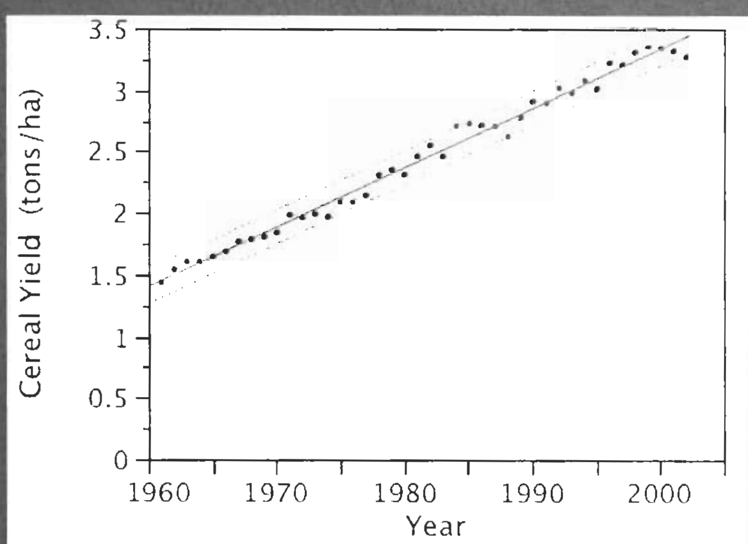
Based on projected global increases in population and per capita incomes, and on observed dietary shifts with income, total global food demand would increase 120% to 170% in 50 years

Increase Yield or Land?

Production = Yield • Land Area
[tons/hectare • hectares]

Environmental Impacts of Global Food Production at 120% to 170% More Than Current Levels

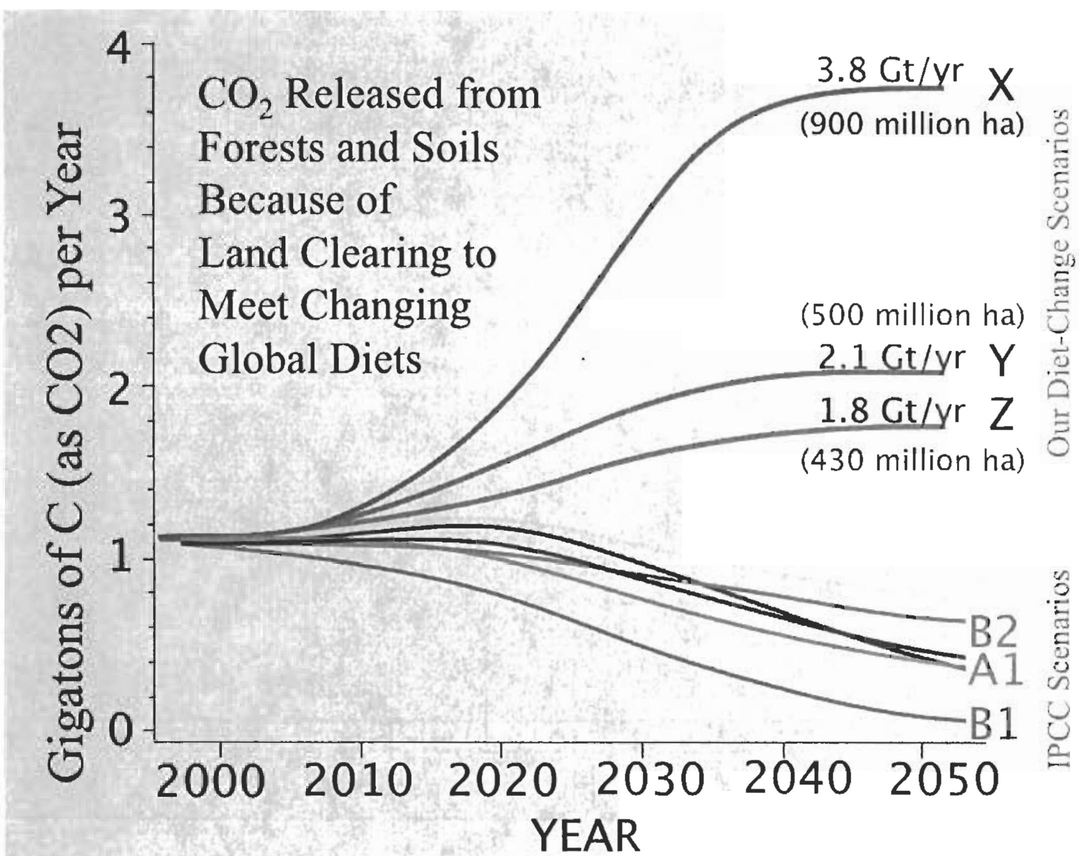
Global Cereal Yield Trends



If This Rate Of Yield Gain Could Be Maintained For 50 More Years, Global Cereal Yields Would Increase By 70%

For a Weighted Mix of All Major Crops Combined, Global Yields Are on Trajectory to Increase 66% in 50 Years

With These Projected Yield Increases, Food Production Increase of 120% to 170%
Also Would Require from 35% to 65% More Crop Land
(~500 to 950 million hectares)
And, about 540 More Million Hectares of Pasture Land for Meat/ Dairy Production



Meat and Dairy Greenhouse Gas Loading by 2050

If current per capita meat and dairy consumption trends in the developed, developing and least developed nations continue, methane and nitrous oxide from livestock would have a GHG equivalence of about 3 gigatons/year of C emissions.

Biofuels Have the Potential to be Beneficial or Harmful

To Assure that Domestic or Imported Biofuels are Beneficial,
there must be a
Full Lifecycle Analysis
and a
Certifiable and Auditable Documentation Trail of this Lifecycle

Dr. Christopher Field

Carnegie Institution

Dr. Christopher Field is the director of the Carnegie Institution's Department of Global Ecology and professor by courtesy in the Department of Biological Sciences at Stanford University. Trained as an ecologist, Chris has conducted environmental research from tropical rainforests to deserts to alpine tundra in the Americas, Asia, Africa, and Australia. He is a specialist in global-change research. He has developed an evolutionary approach to understanding the spatial organization of plant canopies and the adaptive significance of leaf aging. These studies led to work on the role of nitrogen in regulating plant growth and photosynthsis. They also suggested ways that plant physiological responses could be summarized with a few parameters, providing a basis for predicting many aspects of ecosystem function at very large scales.Recently, he has emphasized formalizing approaches for summarizing plant responses into models that simulate ecosystem exchanges of carbon, water, and energy at the global scale. These models, which synthesize surface data on climate and soils, satellite data on vegetation type and canopy development, and functional generalizations from physiology and ecology, help test hypotheses and understand the future status of terrestrial ecosystems, especially responses to and influences on global change factors like increased atmospheric carbon dioxide or altered climate. Field is active in developing the international community of global change researchers, with involvement in organizations like SCOPE, IGBP, and the Global Carbon Project. An author or more than 100 scientific papers, he is a member of the US National Academy of Sciences and a leader in several national and international efforts to provide the scientific foundation for a sustainable future.

Biofuels potential: The climate protective domain

Chris Field
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- Biofuels are the only currently viable option for powering the world's existing vehicle fleet, using fuels that potentially release less CO_2 than gasoline or diesel.
- Combined with geological storage, biofuels represent one of the few options for an energy source with negative CO_2 emissions, one that leads to a net decrease in atmospheric CO_2
- Many countries are investing in large biofuels programs, motivated by concerns over global change, energy security, and rural development.
- Liquid biofuels already provide some developing and developed countries with a local renewable energy resource and jobs for rural populations.
- There are many ways to do biofuels wrong, so that the costs in damage to the environmental or to human well-being exceed the benefits, but there are also some ways to do biofuels right.
- Current crops used to produce liquid biofuels are all food crops. With these crops, increasing the fraction allocated to biofuels can decrease the availability of food, and increasing the area can lead to loss of natural ecosystems rich in biodiversity or carbon stocks.
- Biofuels from waste, from crops grown with a focus on improving marginal or abandoned land, and from diverse natural ecosystems have the potential for net benefits in terms of climate, energy security, and rural development, with low or no costs in environmental degradation or human well-being
- Global production and use of liquid biofuels have tripled since 2000, with much more to come if current policy targets are implemented. With larger and larger levels of production, it becomes increasingly difficult to successfully manage environmental impacts.

Suggested reading

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. Land Clearing and the Biofuel Carbon Debt. Science **319**:1235.

Field, C. B., J. E. Campbell, and D. B. Lobell. 2008. Biomass energy: the scale of the potential resource. Trends in Ecology & Evolution.

Gallagher, E. 2008. The Gallagher Review of the indirect effects of biofuels production. The Renewable Fuels Agency, Hastings, East Sussex.

Hill, J., E. Nelson, D. Tilman, S. Polasky, and D. Tiffany. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. Proceedings of the National Academy of Sciences **103**:11206.

Searchinger, T., R. Heimlich, R. A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T. H. Yu. 2008. Use of US Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change. Science **319**:1238.

CARNEGIE SCIENCE | GLOBAL ECOLOGY

October, 2008

Biomass Energy: the Climate Protective Domain

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Stanford University
GCEP Global Climate & Energy Project

- Food/Biomass energy interactions
  - Roz Naylor, Holly Gibbs
- Biomass in areas converted to bioenergy
  - Greg Asner, Scott Loarie
- Albedo feedbacks from bioenergy agriculture
  - David Lobell, Matt Georgescu
- Available land, potential yield, GHG balance
  - Chris Field, Elliott Campbell

Biomass energy -- landscape

- Only currently viable option for powering existing vehicle fleet, using potentially lower CO_2 fuels
- Many countries investing, motivated by concerns over global change, energy security, and rural development.
- Global production and use of liquid biofuels tripled since 2000, with much more to come.
- Already provide some countries with a local renewable energy resource and rural jobs
- Current crops used to produce liquid biofuels are almost all food crops. Increasing the fraction allocated to biofuels can decrease the availability of food, and increasing the area can lead to loss of natural ecosystems rich in biodiversity or carbon stocks

Biomass energy –moving forward

- Biofuels from waste, from crops grown with a focus on improving marginal or abandoned land, and from diverse natural ecosystems have the potential for net benefits in terms of climate, energy security, and rural development, with low or no costs in environmental degradation or human well-being
- There are many ways to do biofuels wrong, so that the costs in damage to the environmental or to human well-being exceed the benefits, but there are also some ways to do biofuels right.
- Liquid biofuels for transportation almost always yield less useful energy and more create more environmental challenges than biomass used for direct combustion
- With larger and larger levels of production, it becomes increasingly difficult to successfully manage environmental impacts
- Combined with geological storage, biofuels represent one of the few options for an energy source with negative CO_2 emissions, one that leads to a net decrease in atmospheric CO_2

Constraints

Food ⟷ Fuel

Fossil offsets ⟷ Other emissions

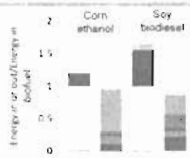
Energy ⟷ Nature

Climate-protective biofuels

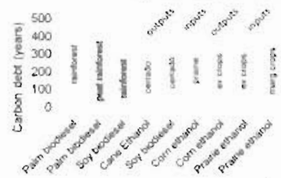
- Grow more plants
  - Without more environmental downsides
- Get more energy per unit of plant biomass
- Figure out where it does and doesn't make sense to produce biofuels

Climate protection issues

- Usable energy out fossil energy in
- Carbon debt – C losses from conversion
- Food security - Indirect conversion



Hill et al PNAS 2006



Fargione et al Science 2008

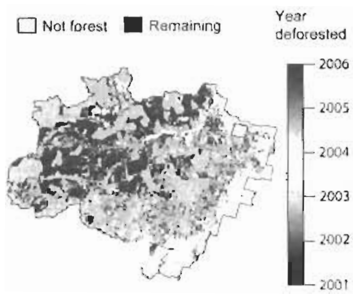
Net energy balance ratio

(biomass energy out/fossil energy in)

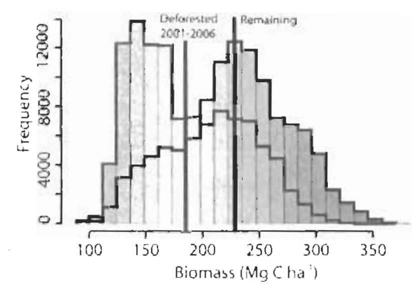
- Corn ethanol ~1.2
- Sugarcane ethanol ~ 8
- Soy biodiesel ~ 2
- Palm biodiesel ~ 9

- Cellulosic ~5(?)

Year-by-year deforestation



Greater biomass in remaining forests



Energy in ag and pastures?

Land Type		Area (Mha)	Mean NPP (ton C/ha/y)	Total NPP (Pg C/y)	Total Energy* (EJ/y)
Global	Crop	1,445	4.6	6.7	119
	Pasture	3,321	3.4	11.3	200
US	Crop	173	5.7	1.0	18
	Pasture	226	3.5	0.8	14

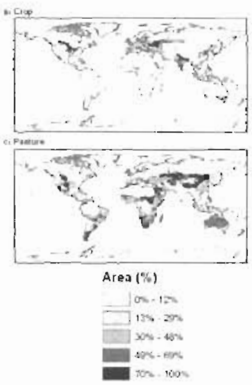
Global Primary Energy = 480 EJ/y

* In ½ biomass (to allow for roots), assume 45% C

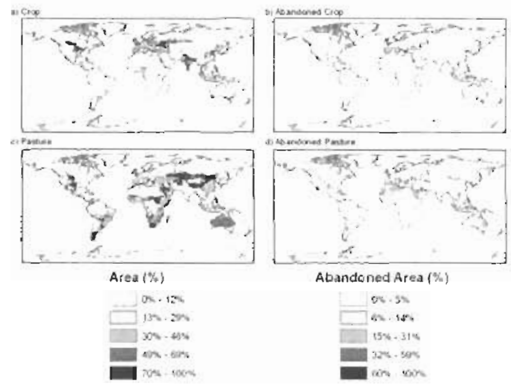
- Ag in relation to natural NPP
  - Ag/NPP -- Globally about 65%

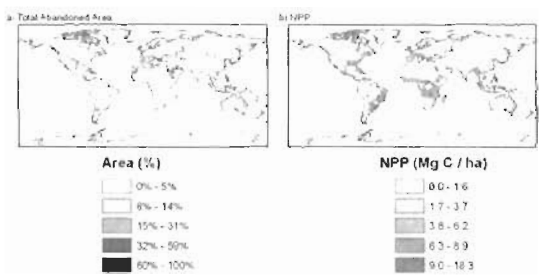
- Global average crop yields unlikely to exceed natural NPP for at least the next several decades

Haberl et al PNAS 2007



Field, Campbell, Lobell TREE 2008





Field et al TREE 2008

Potential from abandoned land

Land Type		Area (Mha)	Mean NPP (ton C / ha / yr)	Total NPP (Pg C / yr)
Global	Crop	1,445	4 6	6 7
	Pasture	3,321	3 4	11 3
	Abandoned	474-579	4 7	2 2-2 7

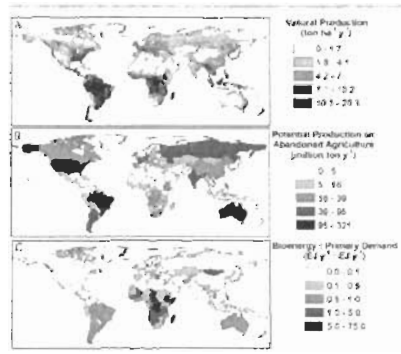
Campbell et al ES&T 2008

From available abandoned land

Land Type		Area (Mha)	Mean NPP (ton C / ha / yr)	Total NPP (Pg C / yr)
Global	Crop	1,445	4 6	6 7
	Pasture	3,321	3 4	11 3
	Abandoned	474-579	4 7	2 2-2 7
	In Forest	72	6 5	0 5
	In Urban	18	5 0	0 1
	In Other	385 472	4 3	1 6-2 1

1 6 – 2 1 Pg C x 2 g Plant/g C x 0 5 g top/g plant x 20 EJ/Pg = 32 - 41 EJ

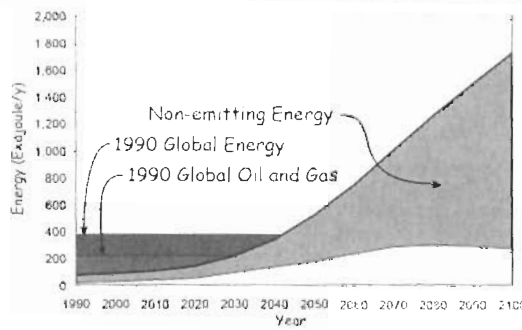
= 7-8% of current global energy system



Bioenergy

- Climate impact depends on pre-existing ecosystem
- Indirect as well as direct paths to carbon loss
- Natural NPP reasonable proxy for potential yield under ag management
- Available land resource limited
  - Quantity and quality
- Big potential in absolute terms
- But a small slice of present or future demand

Future energy needs: Many times current

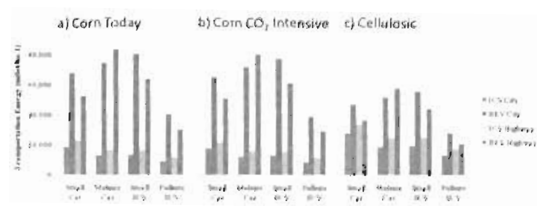


Biomass energy

- Corn $146/ton
- Coal Power River $16/ton
  Central Appalachia $148/ton
- Crude oil $466/ton

Prices 10/24/08

Ferment or burn?



Attachment 3 – Epigenomic Speakers' Biosketches, Abstracts, and Handouts

Dr. Mark Hanson

University of Southampton

Dr. Mark Hanson is a British Heart Foundation Professor of Cardiovascular Science at the University of Southampton and President of the International Society for Developmental Origins of Health and Disease.He has worked in the field of fetal and developmental physiology, and its implications for medicine, for nearly 30 years, establishing a research group at Reading University in 1979, moving to a joint appointment in Obstetrics & Gynaecology and Physiology at UCL in 1990, and founding the Centre for Developmental Origins of Health and Disease at Southampton University in 2000. Early achievements focused on defining neural, hormonal and local mechanisms involved in cardio-respiratory, behavioural and metabolic control in the fetus and neonate, initiating new thinking on fetal adaptations and responsiveness to the prenatal environment. The Centre was the first to make recordings demonstrating unequivocal arterial chemoreceptor function in late gestation, opening avenues for studying fetal reflex responses to hypoxia. This work was extended to the effects of acute and chronic hypoxia in altricial species (e.g. cat) to large precocial species (llama, sheep) to gain insights from differing maturational strategies. The Centre's seminal studies established the concept of postnatal resetting of chemoreceptor sensitivity, explored its mechanisms and relevance to respiratory failure, and developed a test of chemoreflex sensitivity which was applied to human babies, including those at high risk of sudden infant death. Its research simultaneously played a leading role in establishing brainstem processes involved in the characteristic reduction in breathing activity seen in the hypoxic fetus and newborn, and examined interactions between thermoregulation and breathing, e.g. bacterial endotoxin-induced pyrexia. Throughout his career he has collaborated with clinical scientists in developing methods for studying the human fetus, including heart rate variability, Doppler ultrasonic measurement of vascular impedance, cardiac volume imaging and near infrared measurement of tissue oxidative state. This work has contributed to developments in human fetal monitoring. Extending the concept of fetal adaptive responses, his research group was the first to show perturbations in fetal cardiovascular and endocrine function induced by mild nutritional challenges without reductions in fetal growth. It was in the forefront in focusing on the importance of early gestation challenges, and in performing long-term follow up to adulthood of animals in which additional postnatal nutritional challenges were imposed. This demonstrated that prenatal nutrition can condition the animal's later cardiovascular, metabolic and hypothalamo-pituitary adrenal axis responses, relevant to later pathophysiology. This research has now shown that dietary, hormonal and pharmacological interventions can reverse aspects of the phenotype induced in early life, and this may have therapeutic implications. He has conducted detailed investigation of underlying epigenetic mechanisms, showing changes in DNA methylation, histone methylation and acetylation and small non-coding RNAs following a prenatal nutritional challenge and affecting expression of non-imprinted genes in a range of tissues. Recent studies have examined the ways in which epigenetic processes can induce the equivalent of ployphenisms in mammals, and also the effects of endocrine disruptor chemicals. With Peter Gluckman he developed the influential concept of predictive adaptive responses, extending evolutionary and developmental biology concepts to human populations and we have extended this work to champion the field of evolutionary medicine. His recent studies utilise Southampton's human epidemiological cohorts, showing the importance of pre-pregnancy maternal body composition and diet to later fetal cardiovascular function. They will facilitate the translation of mechanistic insights to new early life markers of risk of later chronic disease and to methods of monitoring interventions. In collaboration with organisations such as The World Bank and WHO he is attempting to define the human cost of a poor start to life.

Developmental origins of health and disease – role of epigenetic mechanisms

M.A. Hanson[1], P.D. Gluckman[2], G.C.Burdge[1], K.A. Lillycrop[1], K.M.Godfrey[1]

[1] Division of Developmental Origins of Health & Disease, University of Southampton,
[2] Liggins Institute, University of Auckland

Epidemiological and animal studies show that small changes in the environment during development, e.g. in nutrient provision or balance, induce phenotypic changes which affect an individual's responses to their later environment. These may in turn alter the risk of chronic disease resulting from inadequate responses, e.g. to a rich environment leading to metabolic syndrome or cardiovascular disease. Recent research shows that animals exposed to such a mismatch between pre- and postnatal environment develop obesity, reduced activity, leptin and insulin resistance, elevated blood pressure and vascular endothelial dysfunction. We have found an important role for molecular epigenetic processes in producing such effects, processes which are targeted to promoter regions of specific genes in specific tissues but which also include changes in histone structure and post-transcriptional processes involving miRNAs. Such fine control of gene expression endorses the view that the mechanisms have been retained through evolution as a result of the adaptive advantage which they confer, rather than representing extreme effects of developmental disruption akin to teratogenesis. Moreover there may be adaptive advantage in a developmental cue inducing a phenotypic change in generations beyond the immediately affected pregnancy, and there is now a range of human and animal data which support this concept. Such effects – which might be termed non-genomic inheritance – may be mediated by a range of effects including alterations in maternal adaptations to pregnancy in successive generations or behavioural influences. Recent data however also show that epigenetic effects such as DNA methylation can be passed to successive generations. This suggests that they might persist through meiosis. Environmental toxins, including endocrine disruptors, can play a role in inducing greater risk of chronic disease even at low exposure levels, especially if they act via the normal epigenetic processes involved in developmental plasticity. Current research in this area is important for mechanistic understanding and for developing novel prognostic markers of later disease risk. It also emphasizes the long-term multi-generational effects which appropriate interventions may confer to reduce the risk of chronic disease in subsequent generations.

References

1. Gluckman PD, Hanson MA, Cooper C, Thornburg KL (2008). Effect of in utero and early-life conditions on adult health and disease. New England Journal of Medicine 359:61-73

1. Godfrey KM, Lillycrop KA, Burdge GC, Gluckman PD, Hanson MA (2007). Epigenetic mechanisms and the Mismatch concept of the Developmental Origins of Health and Disease. Pediatric Research 61 (Pt2):5R-10R

3. Burdge GC, Hanson MA, Slater-Jefferies JL, Lillycrop KA (2007). Epigenetic regulation of transcription: a mechanism for inducing variations in phenotype (fetal programming) by differences in nutrition during early life? British Journal of Nutrition 97:1036-1046

MAH and GCB are supported by the British Heart Foundation and PDG by the National Research Centre for Growth and Development

Southampton
School of Medicine

Developmental Origins of Health & Disease - the role of epigenetic mechanisms

Mark Hanson

British Heart Foundation

DOHaD

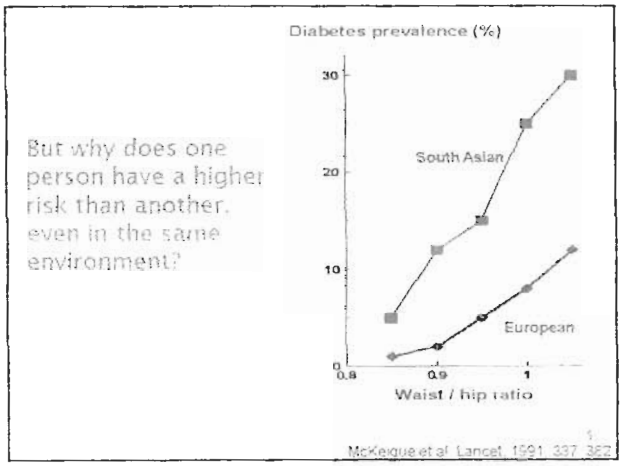
dohadsoc.org

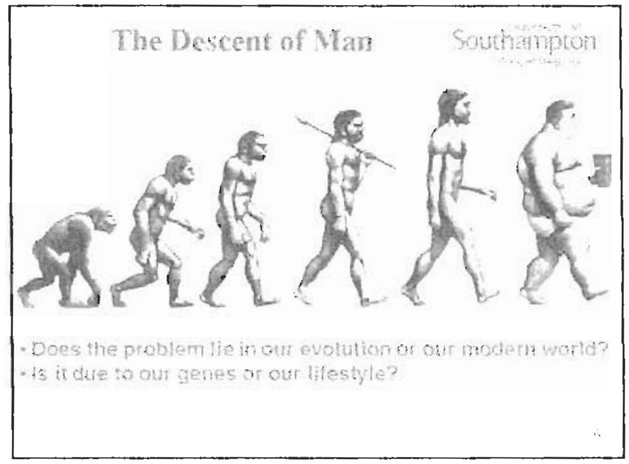
The world map of under-nutrition

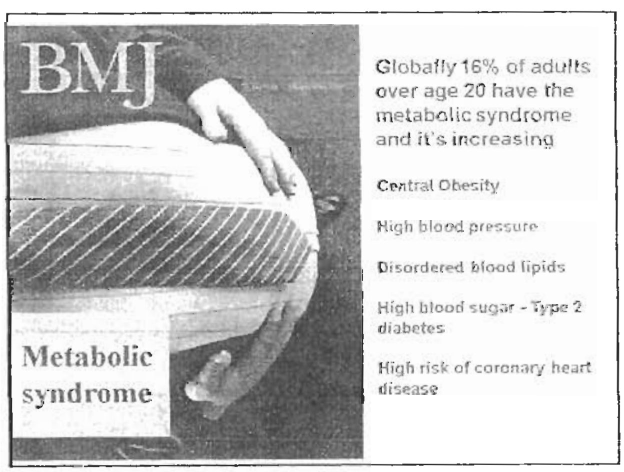
The Epidemic of Diabesity

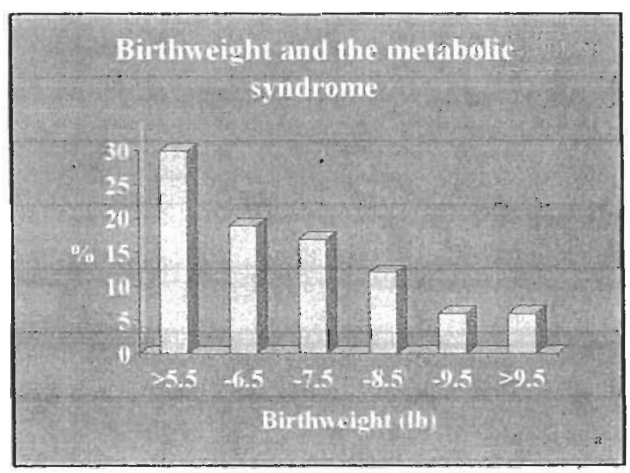
Southampton

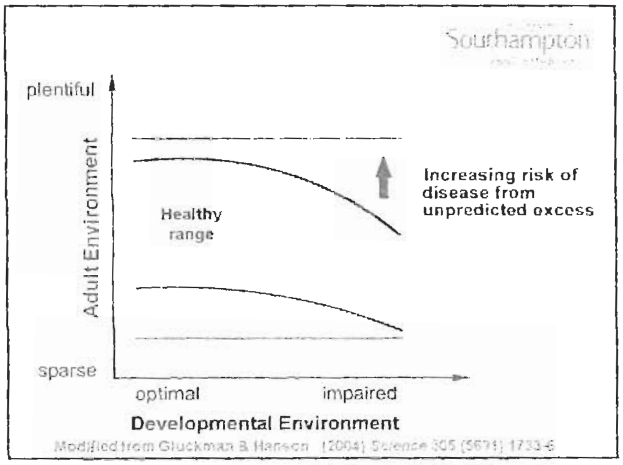
Challenge to humans at least as big as global warming

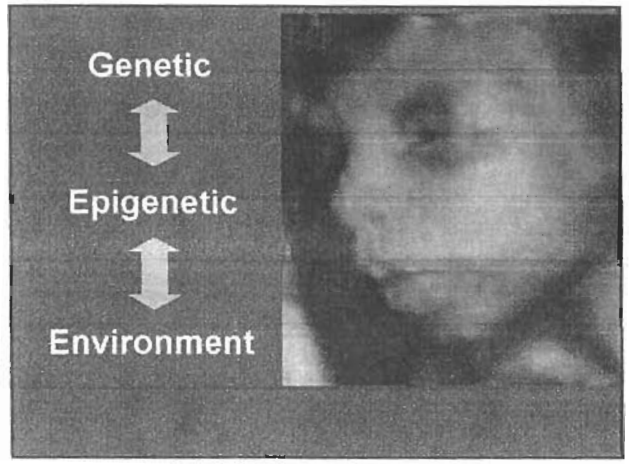

But why does one person have a higher risk than another, even in the same environment?
Diabetes prevalence (%)
30
20
10
0
South Asian
European
0.8
0.9
1
Waist / hip ratio
McKeigue et al Lancet 1991 337 382

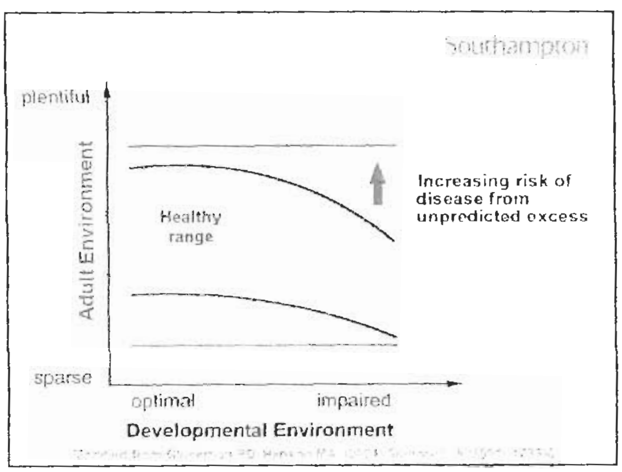

The Descent of Man
Southampton
• Does the problem lie in our evolution or our modern world?
• Is it due to our genes or our lifestyle?


BMJ
Metabolic syndrome
Globally 16% of adults over age 20 have the metabolic syndrome and it's increasing
Central Obesity
High blood pressure
Disordered blood lipids
High blood sugar - Type 2 diabetes
High risk of coronary heart disease


Birthweight and the metabolic syndrome
%
30
25
20
15
10
5
0
>5.5
-6.5
-7.5
-8.5
-9.5
>9.5
Birthweight (lb)



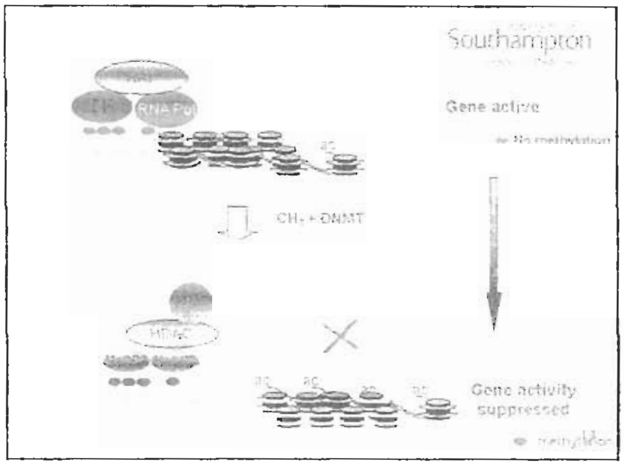


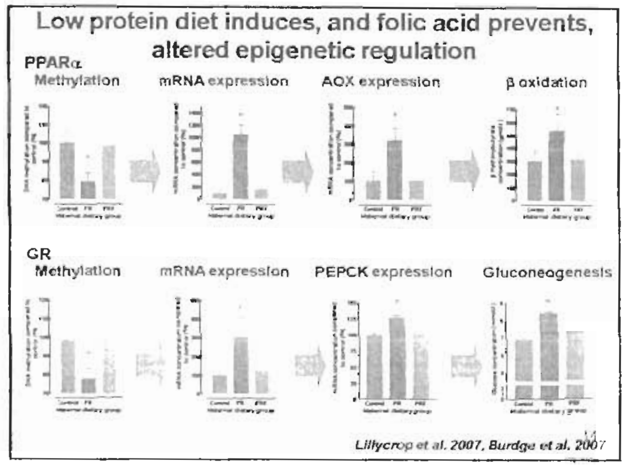


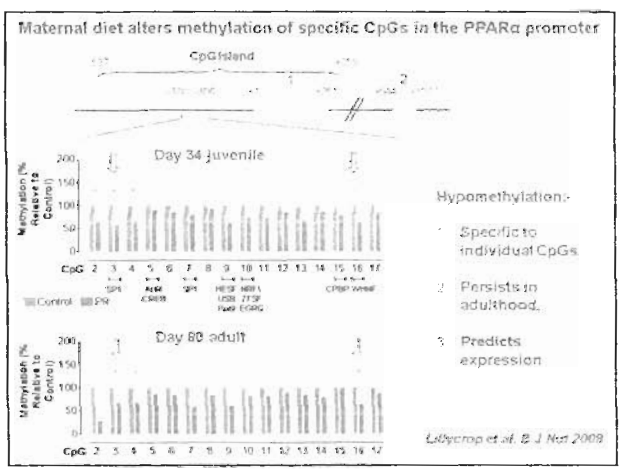
Epigenetic effects

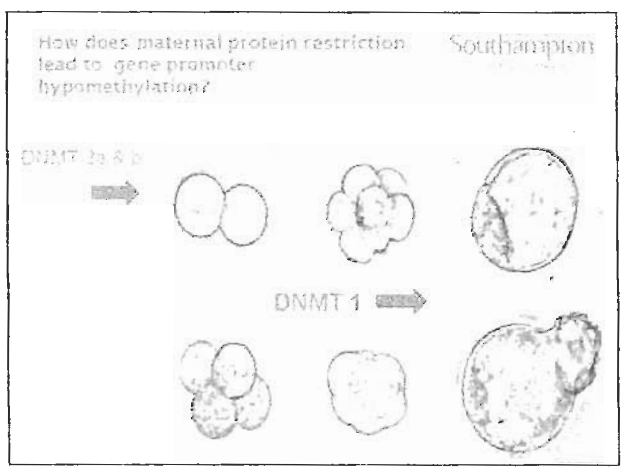
Southampton

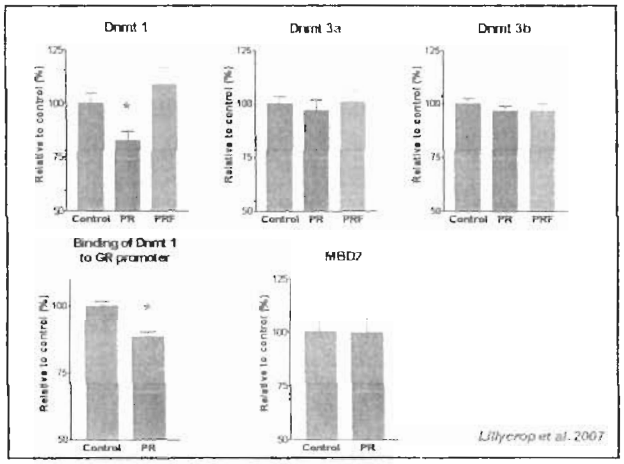
- Allow several phenotypes to be produced from one genotype, depending on the environment
- Affect gene expression without changing genetic code
- Don't just involve imprinted genes
- DNA methylation
- Histone acetylation, phosphorylation, methylation, ubiquitination....
- Small non-coding RNAs

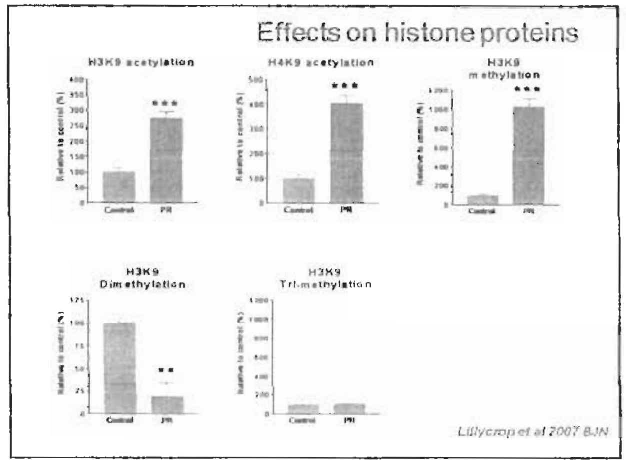

Southampton
Gene active
No methylation
CH3 + DNMT
HDAC
Gene activity suppressed
methylation

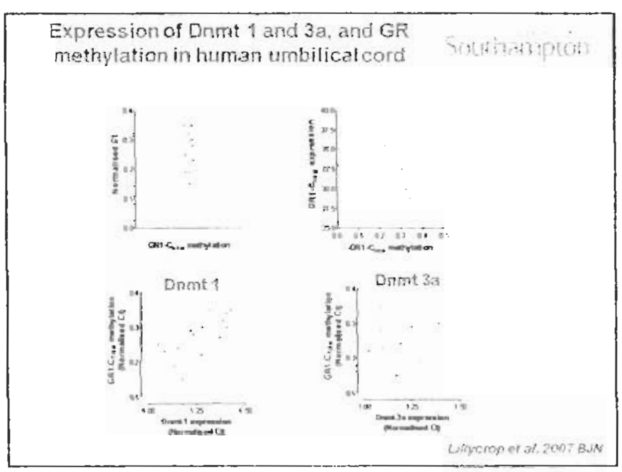

Low protein diet induces, and folic acid prevents, altered epigenetic regulation
PPARα
Methylation
mRNA expression
AOX expression
β oxidation
GR
Methylation
mRNA expression
PEPCK expression
Gluconeogenesis
Lillycrop et al. 2007, Burdge et al. 2007

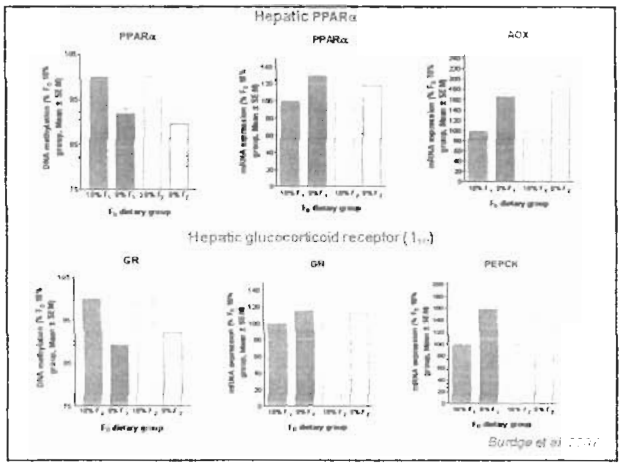

Maternal diet alters methylation of specific CpGs in the PPARα promoter
CpG island
Day 34 juvenile
Day 80 adult
Hypomethylation:-
1 Specific to individual CpGs
2 Persists in adulthood.
3 Predicts expression
Lillycrop et al. B J Nut 2008


How does maternal protein restriction lead to gene promoter hypomethylation?
Southampton
DNMT 1

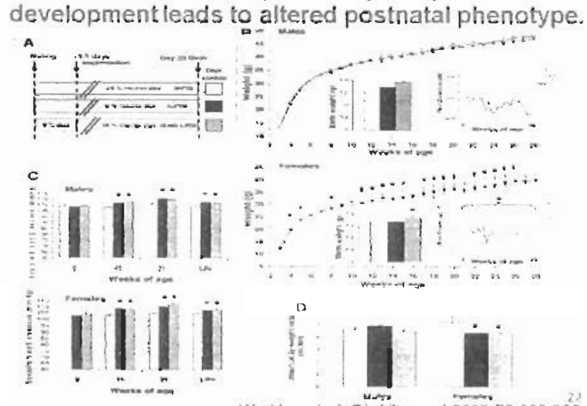

Dnmt 1
Dnmt 3a
Dnmt 3b
Relative to control (%)
Control PR PRF
Binding of Dnmt 1 to GR promoter
MBD2
Control PR
Lillycrop et al. 2007


Effects on histone proteins
H3K9 acetylation
H4K9 acetylation
H3K9 methylation
H3K9 Dimethylation
H3K9 Tri-methylation
Control PR
Lillycrop et al 2007 BJN


Expression of Dnmt 1 and 3a, and GR methylation in human umbilical cord
Southampton
Dnmt 1
Dnmt 3a
Lillycrop et al. 2007 BJN



Maternal diet during mouse preimplantation development leads to altered postnatal phenotype.

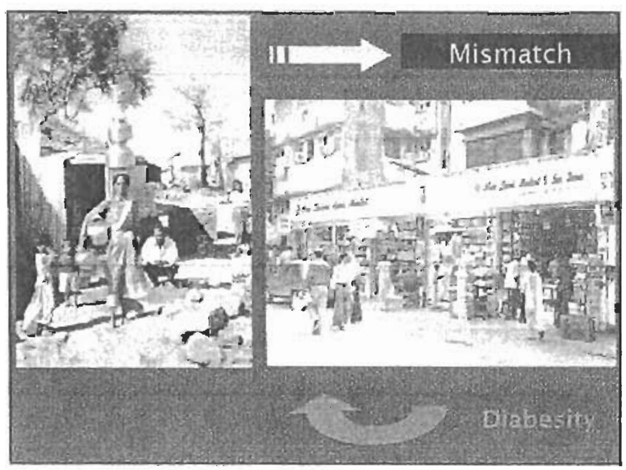


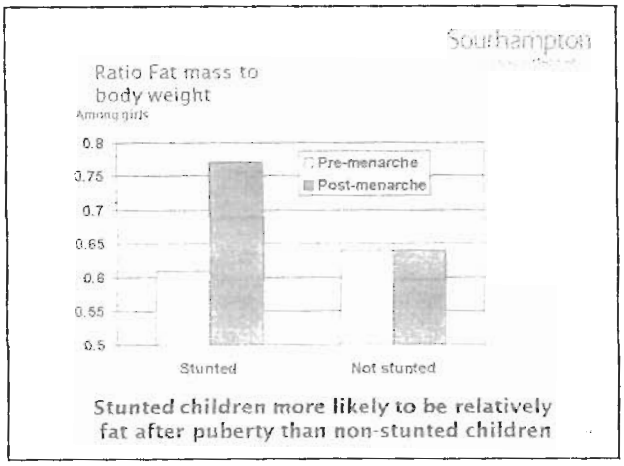
Watkins et al. Biol Reprod 2008;78:299-306

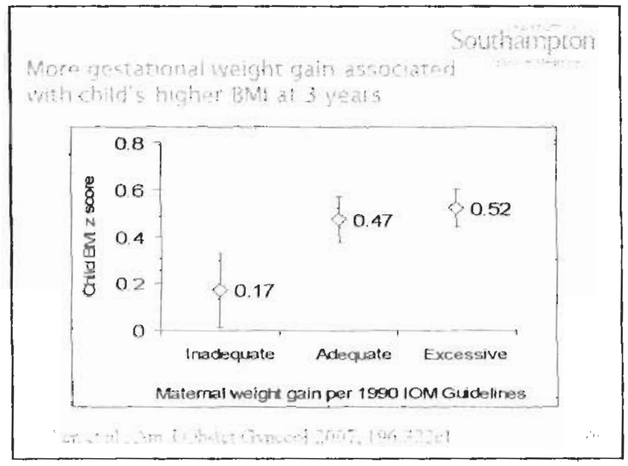
22

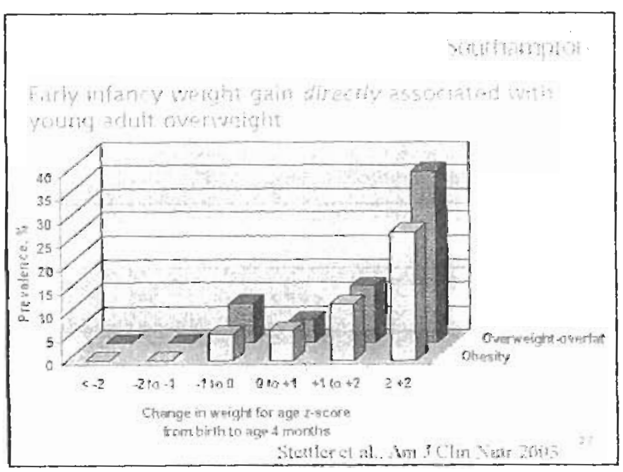
Ceelen M et al *J Endoc Metab.* 2008 May 93(5):1682-8. Cardiometabolic differences in children born after in vitro fertilization: follow-up study.

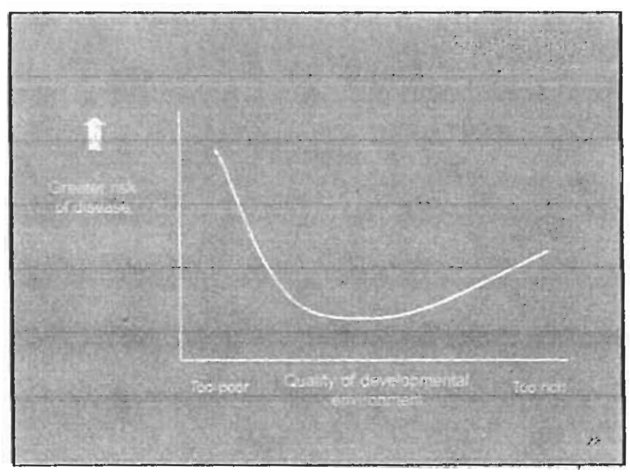
Systolic and diastolic blood pressure levels were higher in 8-18 yr old IVF children than in controls (109+-11 mm Hg vs 105+-10, P<0.001; 61+-7 mm Hg vs 59+-7, P<0.001, respectively). Children born after IVF were also more likely to be in the highest systolic and diastolic blood pressure quartiles (OR= 2.1, 95% CI, 1.4,3.3; OR= 1.9, 95% CI 1.2,3.0 respectively). Furthermore, higher fasting glucose levels were observed in pubertal IVF children (5.0+-0.4 mmol/l vs 4.8+-0.4 in controls, P=0.005). Blood pressure and fasting glucose differences could neither be explained by current body size, birth weight and other early life factors nor by parental characteristics including subfertility cause

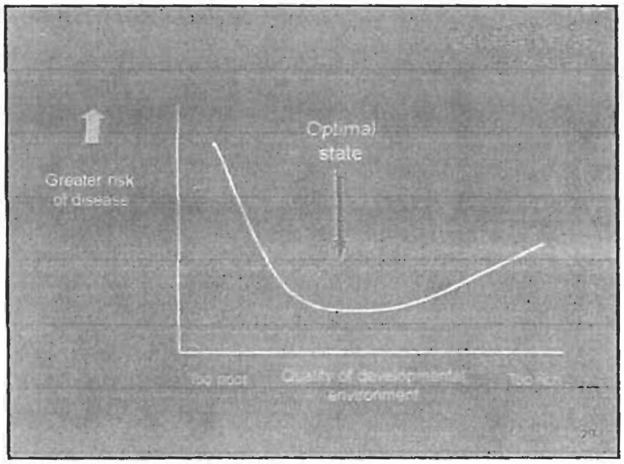


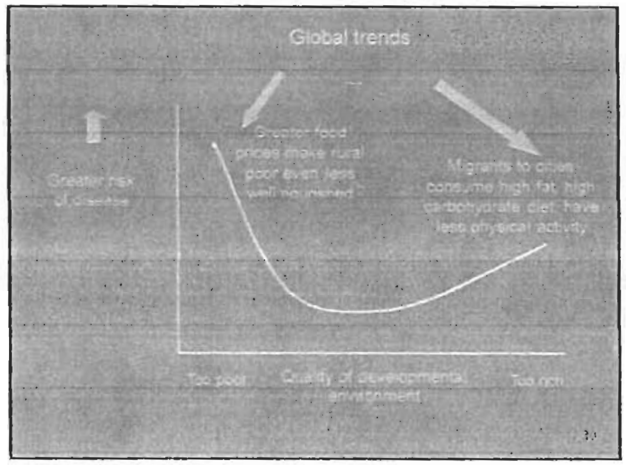

Southampton
Ratio Fat mass to
body weight
Among girls
0.8
0.75
0.7
0.65
0.6
0.55
0.5
Pre-menarche
Post-menarche
Stunted
Not stunted
Stunted children more likely to be relatively
fat after puberty than non-stunted children


Southampton
More gestational weight gain associated
with child's higher BMI at 3 years
0.8
0.6
0.4
0.2
0
Child BMI z score
0.17
0.47
0.52
Inadequate
Adequate
Excessive
Maternal weight gain per 1990 IOM Guidelines


Early infancy weight gain *directly* associated with
young adult overweight
40
35
30
25
20
15
10
5
0
Prevalence, %
< -2
-2 to -1
-1 to 0
0 to +1
+1 to +2
≥ +2
Overweight-overfat
Obesity
Change in weight for age z-score
from birth to age 4 months
Stettler et al., Am J Clin Nutr 2005


Greater risk
of disease
Too poor
Quality of developmental
environment
Too rich

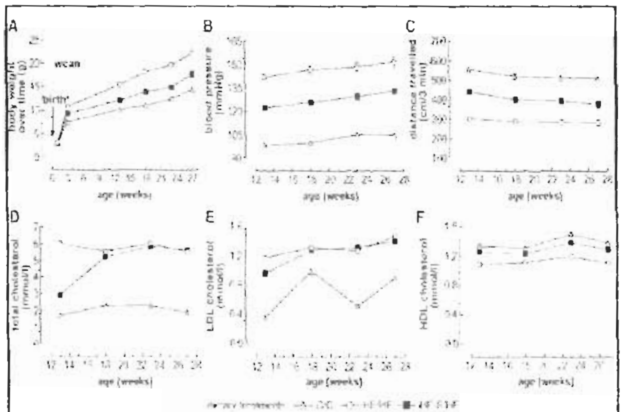




Southampton

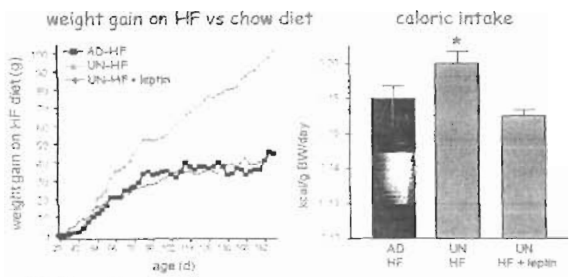
Reversibility?

- Micronutrients - folic acid/ choline
- Statins in late pregnancy (Elahi et al Hypertension 08)
- Neonatal leptin (Gluckman et al PNAS 07)



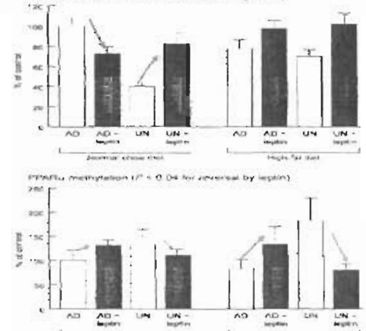
Elahi M et al Hypertension (2008)

Early postnatal leptin treatment alleviate the obesogenic effects of post weaning high fat (HF) diet in rat offspring

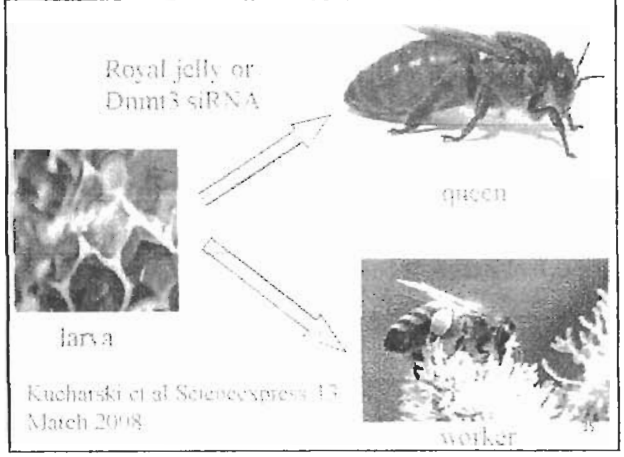


modified from Vickers *et al.* 2005 Endocrinology

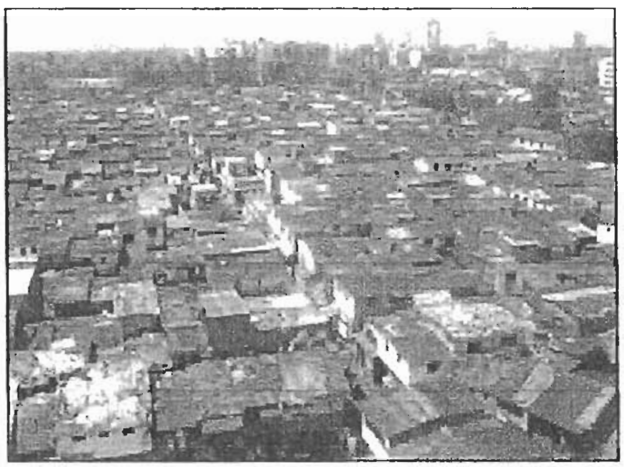
Neonatal leptin effects are directionally dependent on nutrition *in utero* Southampton

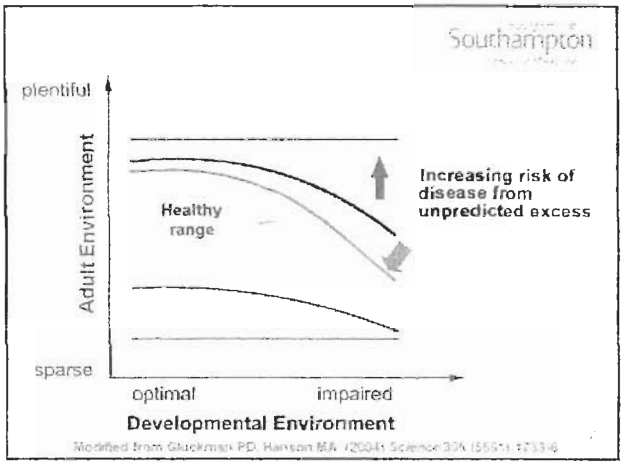


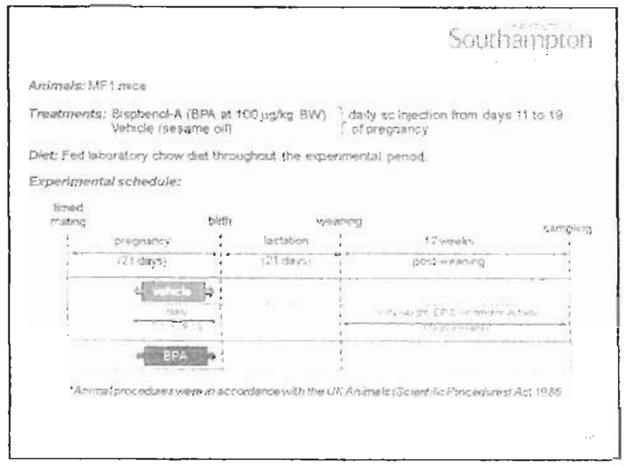
From Gluckman et al. PNAS. 2007;104:12796-800

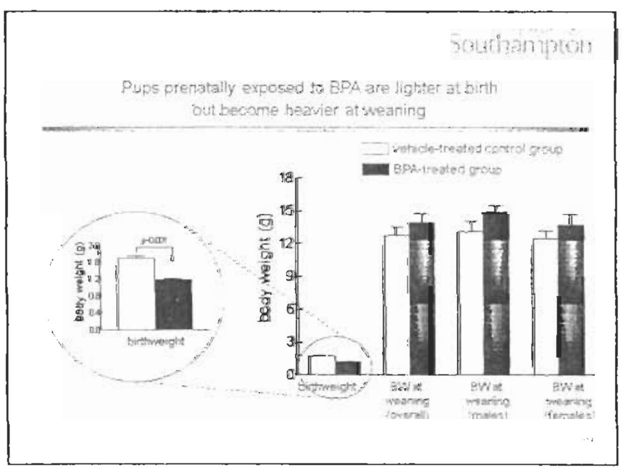


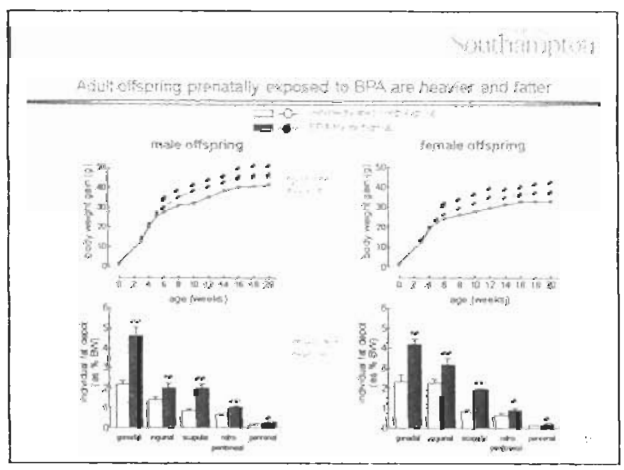
Kucharski et al Scienceexpress 13 March 2008

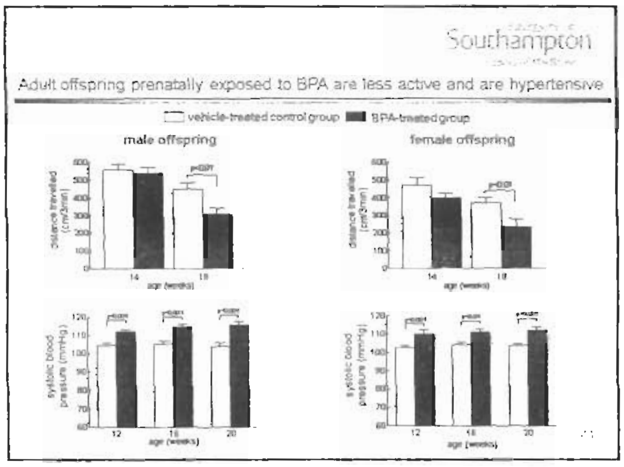


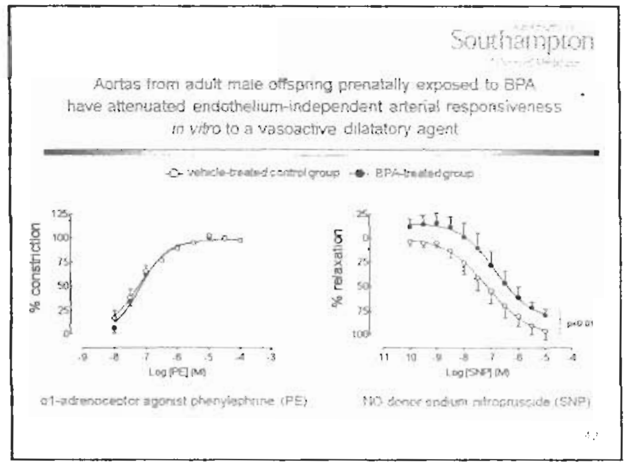

Southampton
plentiful
sparse
Adult Environment
Healthy range
Increasing risk of disease from unpredicted excess
optimal
impaired
Developmental Environment


Southampton
Animals: MF1 mice
Treatments: Bisphenol-A (BPA at 100 µg/kg BW)
Vehicle (sesame oil)
daily sc injection from days 11 to 19 of pregnancy
Diet: Fed laboratory chow diet throughout the experimental period.
Experimental schedule:
timed mating
birth
weaning
sampling
pregnancy
(21 days)
lactation
(21 days)
17 weeks
post-weaning
Vehicle
BPA
*Animal procedures were in accordance with the UK Animals (Scientific Procedures) Act 1986


Southampton
Pups prenatally exposed to BPA are lighter at birth but become heavier at weaning
vehicle-treated control group
BPA-treated group
body weight (g)
birthweight
BW at weaning (overall)
BW at weaning (males)
BW at weaning (females)


Southampton
Adult offspring prenatally exposed to BPA are heavier and fatter
male offspring
female offspring
age (weeks)

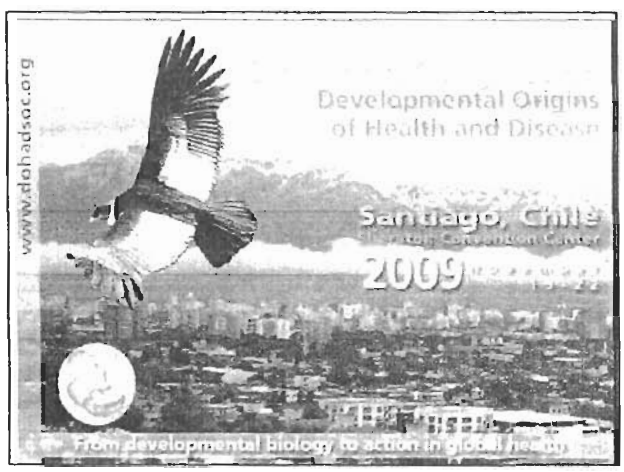


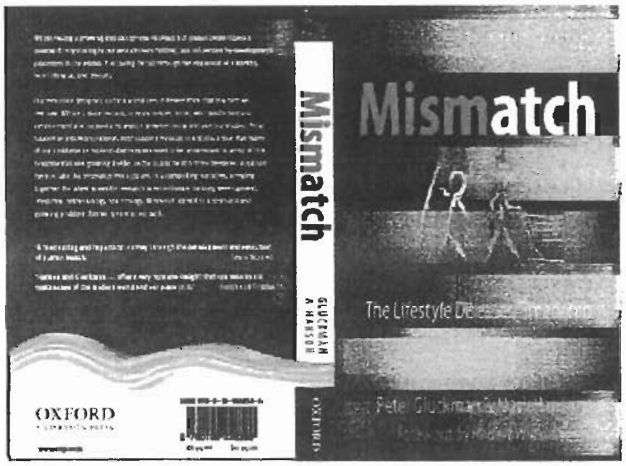


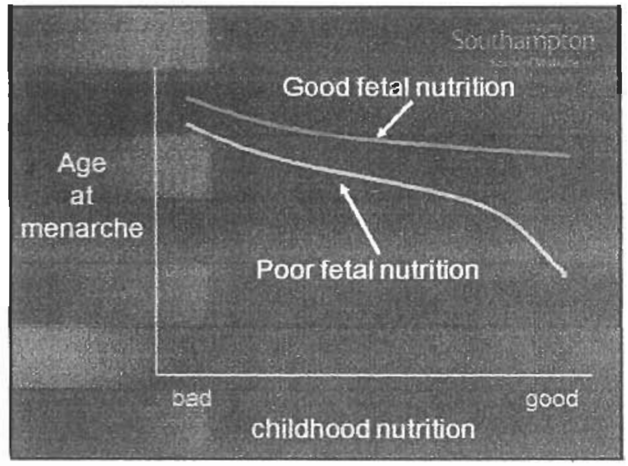
Conclusions

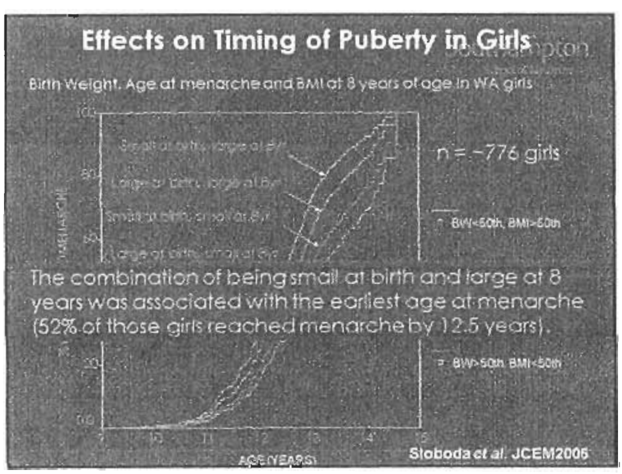
Southampton

- Diseases of developmental origin are a new medical category
- They are reaching epidemic proportions in both developed and developing societies
- Part of the risk of disease is influenced by gene - environment interactions during development
- The underlying epigenetic mechanisms are now becoming understood
- They comprise novel opportunities for prognosis and for intervention
- Research in this area will pay major health and social - - and so economic - dividends




Mismatch
Mismatch
OXFORD


Southampton
Good fetal nutrition
Age
at
menarche
Poor fetal nutrition
bad
good
childhood nutrition


Effects on Timing of Puberty in Girls
Birth Weight, Age at menarche and BMI at 8 years of age in WA girls
n = ~776 girls
The combination of being small at birth and large at 8 years was associated with the earliest age at menarche (52% of those girls reached menarche by 12.5 years).
Sloboda et al. JCEM2006

Dr. Randy Jirtle

Duke University

Dr. Randy L. Jirtle is a professor of radiation oncology and an associate professor of pathology at Duke University, Durham, NC, where he has been a faculty member since 1977. He graduated with a B.S. degree in nuclear engineering in 1970 and a Ph.D. degree in radiation biology in 1976, both from the University of Wisconsin-Madison.Jirtle's research interests are in epigenetics, genomic imprinting, and the fetal origins of disease susceptibility. He identified the imprinted IGF2R as a tumor-suppressor, and showed its inactivation increases tumor resistance to radiotherapy. Jirtle discovered a novel imprinted domain at human 14q32, and identified the Callipyge or beautiful buttocks locus in the homologous region of sheep. He subsequently traced the mammalian origin of genomic imprinting from monotremes to placental mammals. These studies provided the crucial data that allowed him to complete the first genome-wide mapping of human imprinted genes using a bioinformatic approach. The effort yielded candidate imprinted genes in chromosomal regions linked to complex human diseases and neurological disorders. Jirtle also demonstrated that maternal dietary supplementation of Avy mice during pregnancy, with either methyl donors or genistein, decreases adult disease incidence in the offspring by increasing DNA methylation at the Agouti locus. Moreover, these nutritional supplements were shown to block CpG hypomethylation caused by the endocrine disruptor, bisphenol A. Jirtle holds two U.S. patents on imprinted genes and another one is pending approval. He has published more than 160 peer-reviewed articles, including ten publications featured on journal covers. His research has been featured in popular press accounts ranging from American Scientist and Discover to Allure. He was also a featured scientist this past year on the NOVA and ScienceNow television programs on epigenetics, and National Public Radio programs, The People's Pharmacy and The DNA Files. His enthusiasm for promoting the public understanding of epigenomics led him to create the website www.geneimprint.org, which has been designated by the scientific publisher Thomson ISI as an 'Exemplary Website in Genetics.' Jirtle has organized five international meetings and been an invited speaker at dozens of others. He has delivered five endowed lectures, and was invited to present his research at the 2004 Nobel Symposium on Epigenetics. He was honored in 2006 with the Distinguished Achievement Award from the College of Engineering at the University of Wisconsin-Madison. In 2007, Jirtle received an Esther B. O'Keeffe Charitable Foundation Award and capped off the year with a nomination for Time Magazine's "Person of the Year." He was the inaugural recipient of the Epigenetic Medicine Award in 2008.

ABSTRACT

Epigenetics: The New Genetics of Disease Susceptibility

Randy L. Jirtle, Ph.D.
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Duke University Medical Center, Durham, NC USA 27710

Human epidemiological and animal experimental data indicate that the risk of developing adult-onset diseases, such as asthma, diabetes, obesity, and cancer, is influenced by persistent adaptations to prenatal and early postnatal exposure to environmental conditions such as nutritional privation [1]. Moreover, the link between what we are exposed to *in utero* and disease formation in adulthood appears to involve epigenetic modifications like DNA methylation at metastable epiallele and imprinted gene loci.

Genomic imprinting is an epigenetic form of gene regulation that results in monoallelic, parent-of-origin dependent gene expression [2]. Since imprinted genes are functionally haploid, only a single genetic or epigenetic event is needed to dysregulate their function. This vulnerability means that imprinted genes are prime candidates for causative roles in human diseases that have a parental inheritance bias and an environmental component in their etiology. We recently developed computer-learning algorithms that predicted the presence of 600 imprinted genes in mice [3] and 156 imprinted genes in humans [4]. Not only are humans predicted to have fewer imprinted genes than mice, but there is also a mere 30% overlap between their imprinted gene repertoires. By mapping the human candidate imprinted genes onto the landscape of disease risk defined by linkage analysis, we are now poised to determine the importance of imprinting in the etiology of complex human diseases and neurological disorders.

Genes with metastable epialleles have highly variable expression because of stochastic allelic changes in the epigenome rather than mutations in the genome. The viable yellow agouti (A^{vy}) mouse harbors a metastable *Agouti* gene because of an upstream insertion of a transposable element. We have used the A^{vy} mouse to investigate the importance of nutrition in determining the susceptibility of offspring to adult diseases [5,6]. We have shown that maternal dietary supplementation during pregnancy, with either methyl donors (i.e. folic acid, vitamin B_{12}, choline and betaine) [5] or genistein [6], decreases adult disease incidence in the offspring by increasing DNA methylation at the A^{vy} locus. Moreover, these nutritional supplements can counteract the CpG hypomethylation caused by the endocrine disruptor, bisphenol A [7]. (Supported by NIH grants ES13053, ES08823, ES015165 and T32-ES07031, and DOE grant DE-FG02-05ER64101)

References

1. Jirtle, R.L., and Skinner, M.K. Environmental epigenomics and disease susceptibility. *Nat. Rev. Genet*. 8: 253-562, 2007
2. Jirtle, R.L., and Weidman, J.R. Imprinted and more equal. *Am. Sci.* 95: 143-149, 2007.
3. Luedi, P.P., Hartemink, A.J., and Jirtle, R.L. Genome-wide prediction of imprinted murine genes. *Genome Res.* 15: 875-884, 2005.
4. Luedi, P.P., Dietrich, F.S., Weidman, J.R., Bosko, J.M., Jirtle RL, and Hartemink, A.J. Computational and experimental identification of novel human imprinted genes. *Genome Res.* 17: 1723–1730, 2007..
5. Waterland, R.A., and Jirtle, R.L. Transposable elements: targets for early nutritional effects on epigenetic gene regulation. *Cell. Mol. Biol.* 23: 5293-5300, 2003.
6. Dolinoy, D.C., Weidman, J.R., Waterland, R.A., and Jirtle, R.L. Maternal genistein alters coat color and protects A^{vy} mouse offspring from obesity by modifying the fetal epigenome. *Environ. Health Perspect.* 14: 567-572, 2006.
7. Dolinoy, D.C., Huang, D., and Jirtle, R.L. Maternal nutrient supplementation counteracts bisphenol A-induced DNA hypomethylation in early development. *Proc. Natl. Acad. Sci. USA* 104: 13056-13061, 2007.

Epigenetics: The New Genetics of Disease Susceptibility

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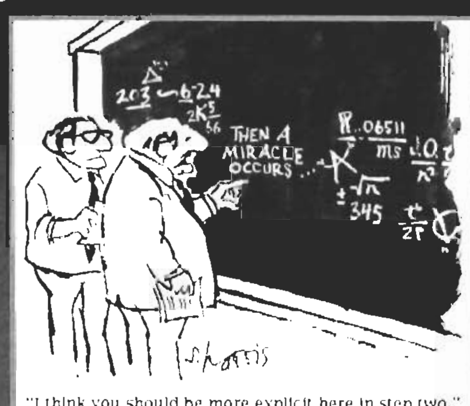
Duke University Medical Center
Durham, NC 27710

Origins
Artist: *Collin Murphy*
Portland, OR

Fetal Origin of Adult Disease Susceptibility

Miracle: Epigenetic Modifications

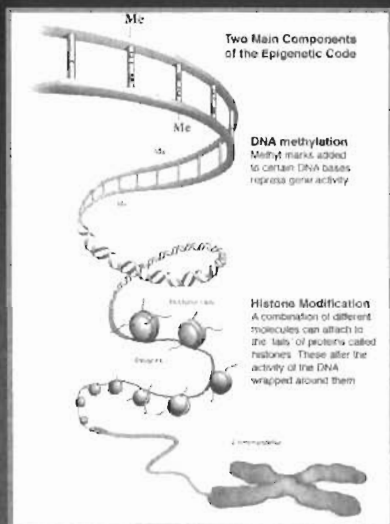


"I think you should be more explicit here in step two."

from *What's so Funny about Science?* by Sidney Harris (1977)

http://www.geneimprint.com

What is Epigenetics?

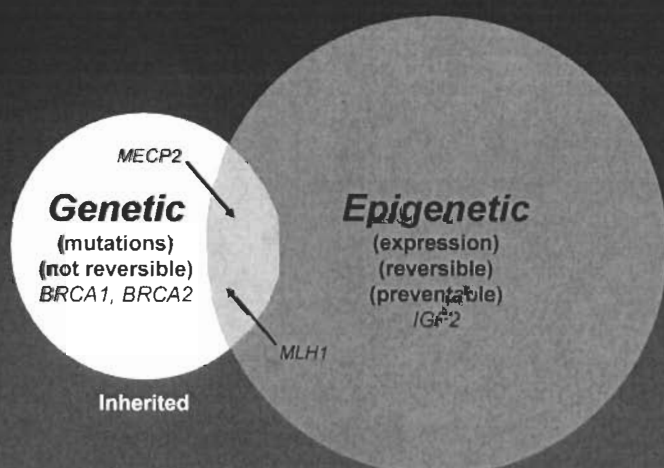


Epi·ge·net·ics - "above genetics"

Epigenetics research is the study of heritable changes in gene function that occur without a change in the sequence of the DNA. (i.e. DNA methylation & chromatin structure)

http://www.geneimprint.com

Cancer Susceptibility



Inherited

Acquired: Pre & Post Natally, Puberty, Old Age

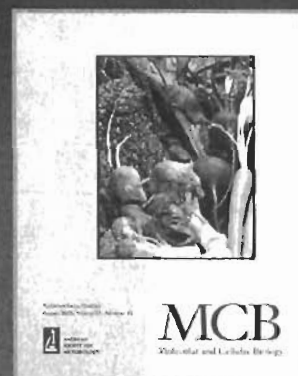
http://www.geneimprint.com

Epigenetically Labile Genes

Artist: *Nancy Jirtle*

Imprinted Genes

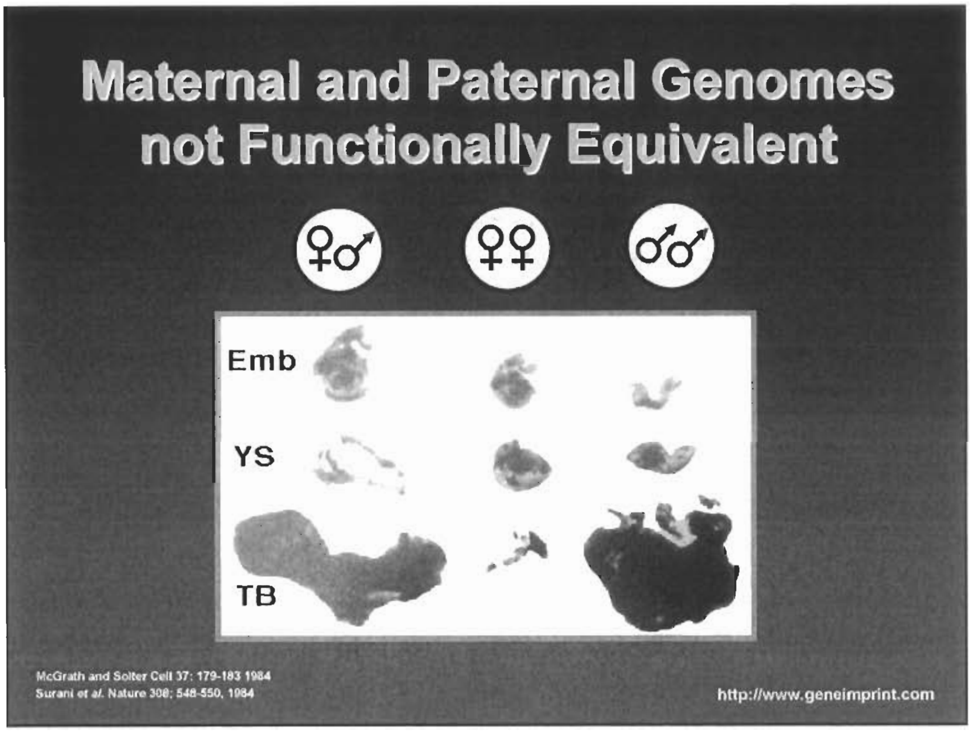
Metastable Epialleles

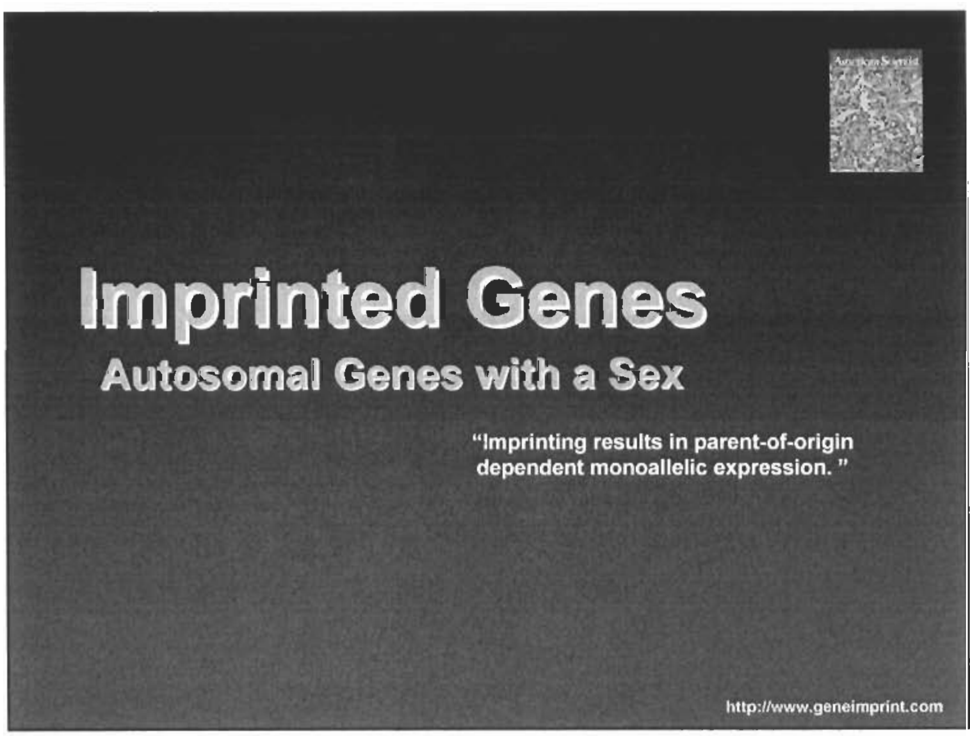


http://www.geneimprint.com

"All animals are equal, But some animals are more equal than others." *George Orwell*

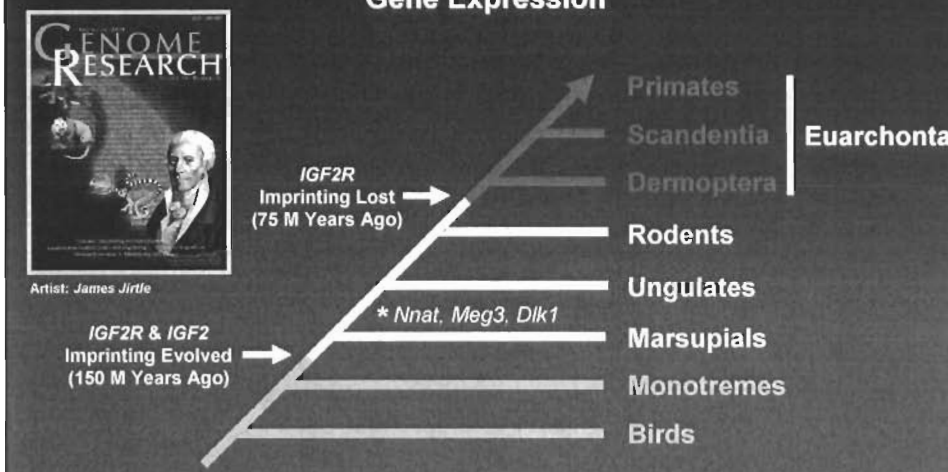
http://www.geneimprint.com


Maternal and Paternal Genomes not Functionally Equivalent
Emb
YS
TB
McGrath and Solter Cell 37: 179-183 1984
Surani et al. Nature 308: 548-550, 1984
http://www.geneimprint.com


Imprinted Genes
Autosomal Genes with a Sex
"Imprinting results in parent-of-origin dependent monoallelic expression."
http://www.geneimprint.com

Imprinting Evolution

Species, Tissue, and Time Dependent Gene Expression



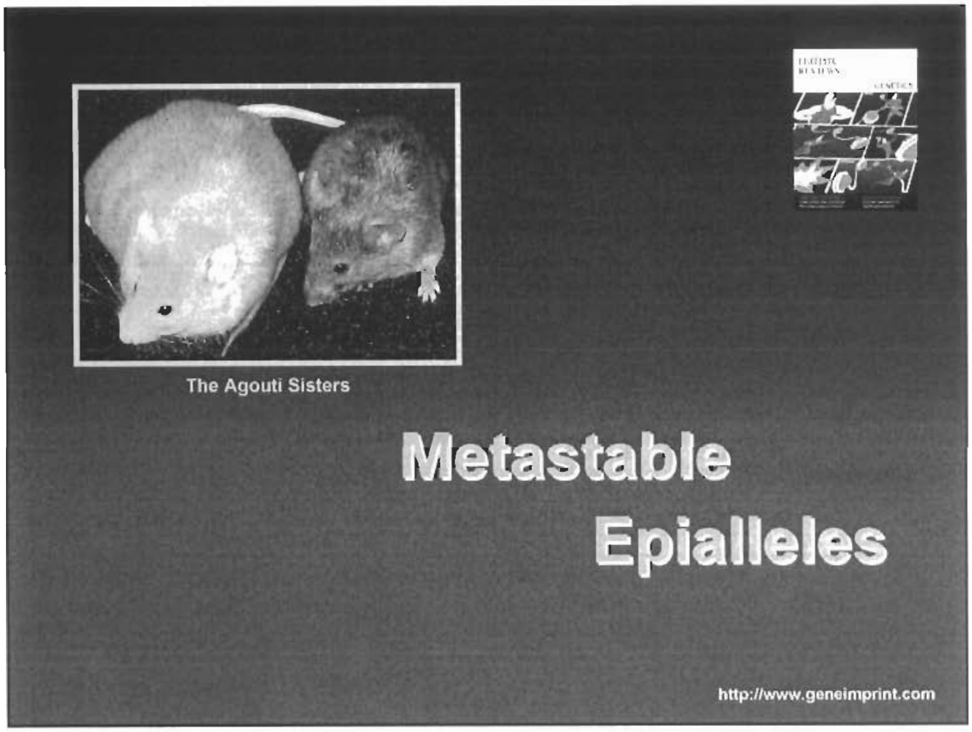
Killian *et al.* Mol. Cell 5: 707-716, 2000
Killian *et al.* Hum. Mol. Genet. 10: 1721-1728, 2001
Evans *et al.* Mol. Biol. Evol. 22: 1740-1748, 2005

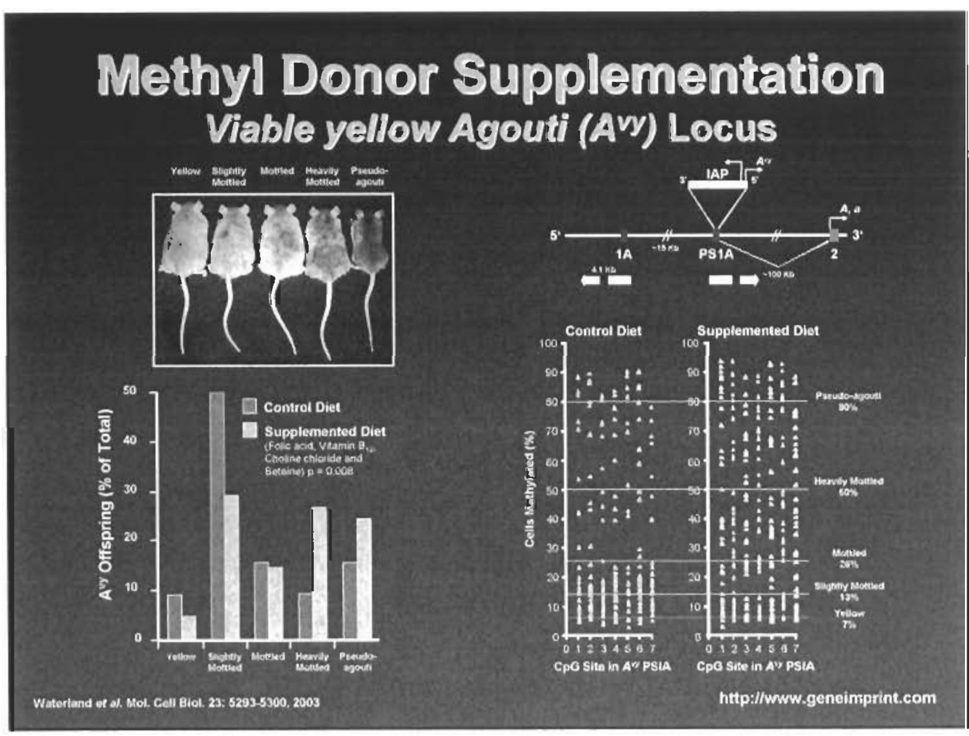
http://www.geneimprint.com

Consequence of Divergent Evolution of Imprinting

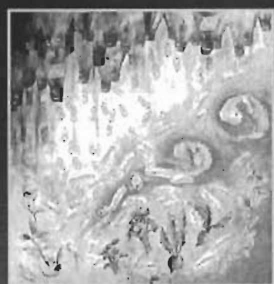
- Biological responses due to imprinting dysregulation will be difficult to extrapolate between species.
- Mice are not humans!

http://www.geneimprint.com


The Agouti Sisters
Metastable
Epialleles
http://www.geneimprint.com

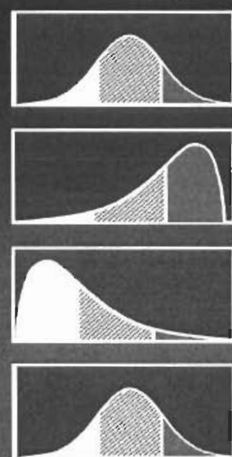

Methyl Donor Supplementation
Viable yellow Agouti (A^{vy}) Locus
Yellow
Slightly Mottled
Mottled
Heavily Mottled
Pseudo-agouti
IAP
1A
PS1A
2
Control Diet
Supplemented Diet
(Folic acid, Vitamin B_{12}, Choline chloride and Betaine) $p = 0.008$
A^{vy} Offspring (% of Total)
Cells Methylated (%)
Pseudo-agouti 80%
Heavily Mottled 50%
Mottled 26%
Slightly Mottled 13%
Yellow 7%
CpG Site in A^{vy} PSIA
Waterland et al. Mol. Cell Biol. 23: 5293-5300, 2003
http://www.geneimprint.com

Food is Medicine!



Artist: *Collin Murphy*

Agouti Coat Color Distribution



- **Control Diet**
- **Methyl Donor or Genistein Supplementation**
- **BPA Exposure**
- **BPA Exposure plus Methyl Donor or Genistein Supplementation**

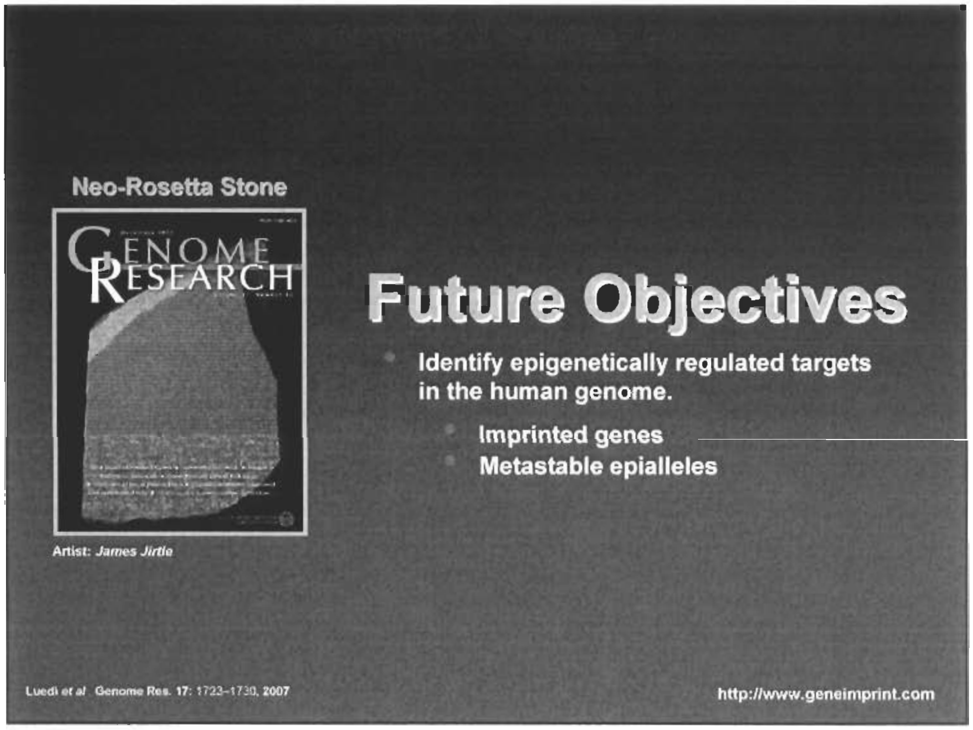
'Let **food** be thy **medicine,** and **medicine** be thy **food**.' *Hippocrates*

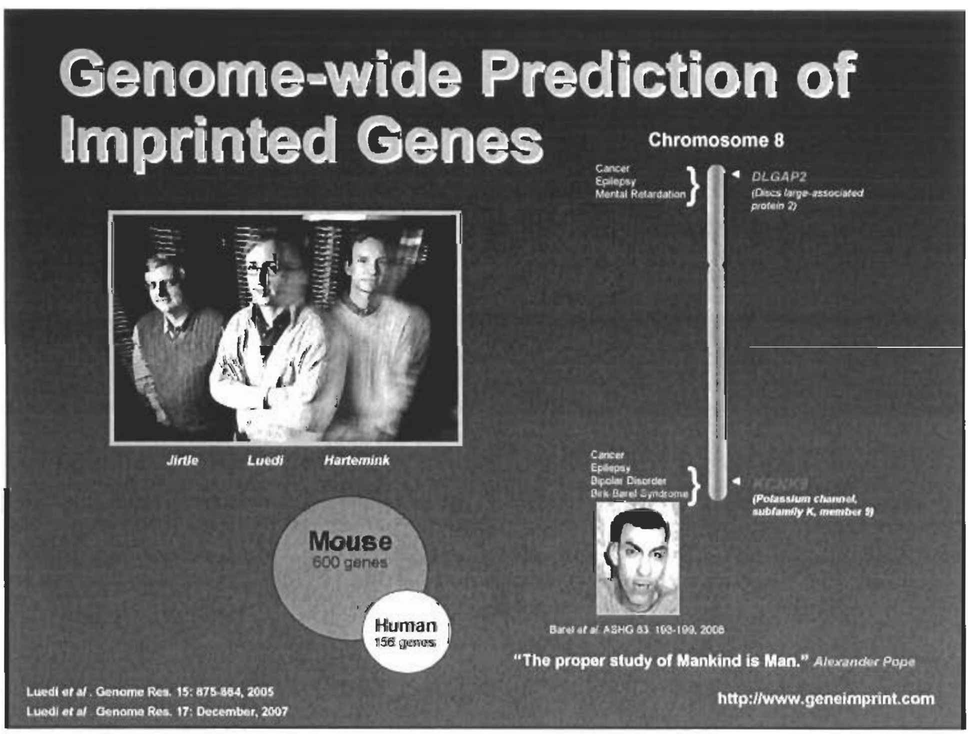
Dolinoy *et al.*, *PNAS* 104: 13056-13061, 2007

http://www.geneimprint.com

You are What You Eat!

http://www.geneimprint.com


Neo-Rosetta Stone
GENOME RESEARCH
Artist: James Jirtle
Future Objectives
Identify epigenetically regulated targets in the human genome.
Imprinted genes
Metastable epialleles
Luedi et al. Genome Res. 17: 1723–1730, 2007
http://www.geneimprint.com


Genome-wide Prediction of Imprinted Genes
Chromosome 8
Cancer
Epilepsy
Mental Retardation
DLGAP2
(Discs large-associated protein 2)
Jirtle
Luedi
Hartemink
Cancer
Epilepsy
Bipolar Disorder
Birk Barel Syndrome
(Potassium channel, subfamily K, member 9)
Mouse
600 genes
Human
156 genes
Barel et al. ASHG 83: 193-199, 2008
"The proper study of Mankind is Man." Alexander Pope
Luedi et al. Genome Res. 15: 875-884, 2005
Luedi et al. Genome Res. 17: December, 2007
http://www.geneimprint.com

Take Home Message

Human risk assessment must be based not only on the ability of an agent to alter the genome, but also the epigenome.

http://www.geneimprint.com

Dr. Michael Skinner

Washington State University

Dr. Michael K. Skinner is Professor and Director of Center for Reproductive Biology at Washington State University. He holds a Ph.D. from Washington State University and a B.A. from Reed College. His primary research addresses on molecular and cellular aspects of reproduction (testis/ovary biology) and transgenerational epigenetic mutagenesis. He has investigaged how different cell types in a tissue interact and communicate to regulate cellular growth and differentiation, with emphasis in the area of reproductive biology. He has initiated an investigation of the effects of environmental toxicants on gonadal development has been initiated and found that the impact of endocrine disruptors on embryonic testis and ovary development demonstrated an epigenetic transgenerational phenotype on adult male fertility. Exposure of the embryonic testis at the time of sex determination caused an epigenetic reprogramming of the male germ-line that causes a variety of disease states in the adult and this phenotype is transferred through the male germ-line to all subsequent generations. His laboratory is investigating the underlying mechanism and phenotype of this epigenetic transgenerational phenomenon.

Epigenetic Transgenerational Actions of Endocrine Disruptors on Reproduction and Disease: The Ghosts in Your Genes

Michael K. Skinner - Center for Reproductive Biology, School of Molecular Biosciences, Washington State University, Pullman, Washington.

Transgenerational effects of environmental toxicants (e.g. endocrine disruptors) significantly amplify the impact and health hazards of these compounds. One of the most sensitive periods to endocrine disruptor exposure is during embryonic gonadal sex determination when the germ line is undergoing epigenetic programming and DNA re-methylation. The model endocrine disruptors tested were vinclozolin, which acts as an anti-androgenic compound, and methoxychlor, that has metabolites that are estrogenic. Previous studies have shown that these endocrine disruptors can effect embryonic testis development to subsequently cause an increase in spermatogenic cell apoptosis in the adult. Interestingly, this spermatogenic defect is transgenerational (F1, F2, F3 and F4 generations) and hypothesized to be due to a permanent altered DNA methylation of the germ-line. This appear to involve the induction of new imprinted-like DNA methylation sites that regulate transcription distally. The expression of over 200 genes were found to be altered in the embryonic testis and surprisingly this altered transcriptome was similar for all generations (F1-F3). In addition to detection of the male testis disorder, as the animals age transgenerational effects on other disease states were observed including tumor development, prostate disease, kidney disease and immune abnormlities. Recent observations suggest transgenerational effects on behaviors such as sexual selection and anxiety. Therefore, the transgenerational epigenetic mechanism appears to involve the actions of an environmental compound at the time of sex determination to alter the epigenetic (i.e DNA methylation) programming of the germ line that then alters the transcriptomes of developing organs to induce disease development transgenerationally. The suggestion that environmental factors can reprogram the germ line to induce epigenetic transgenerational disease is a new paradigm in disease etiology not previously considered.

Anway M, Cupp AS, Uzumcu M and MK Skinner (2005) Epigenetic transgenerational actions of endocrine disruptors and male fertility. Science 308:1466-1469.

Anway MD, Leathers C and MK Skinner (2006) Endocrine Disruptor Vinclozolin Induced Epigenetic Transgenerataional Adult Onset Disease. Endocrinology 147:5515-5523.

Crews D, Gore AC, Hsu TS, Dangleben NL, Spinetta M, Schallert T, Anway MD, Skinner MK (2007) Transgenerational epigenetic imprints on mate preference. Proceedings of the National Academy of Sciences of the United States of America. 3;104(14):5942-6.

Anway MD, Rekow SS, and MK Skinner (2008) Transgenerational epigenetic programming of the testis transcriptome by endocrine disruptor exposure at sex determination. Genomics 91:30-40.