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Impact of Logging and El Niño on the Forests of Indonesia

Introduction:

The trees in Malaysian Borneo do a very odd thing: over thousands of hectares, trees of different species all drop their seeds at the same time. This strategy overwhelms the ability the forest animals to feed on the seeds, allowing enough to survive and provide the next generation of trees for the forest. However, since 1991 there has been no recruitment of new trees to the forests, even in the areas protected from logging. We spoke with Lisa Curran about her article in *Science* magazine and her work on the forest ecosystems of Indonesian Borneo[1].

ER: Professor Curran what is your job?

LC: I have a joint faculty position at the University of Michigan: one appointment is with the School of Natural Resources and Environment, and the other is with South and Southeast Asian Studies. It's unusual for a big research institution to see the need to cross boundaries and disciplines, so it's pretty progressive.

I started out as an undergraduate at Harvard University where I majored in anthropology, and then spent eight or nine years in the tropics in Borneo where I worked on establishing a research site and conducting ecological research with applied aims. I have worked throughout the region conducting scientific research, and training aspiring Asian scientists and managers for UNESCO- Man in the Biosphere Program, working with several nongovernmental organizations and later with the U.S. Agency for International Development on environmental science and policy. I then completed a Masters and Ph.D. in ecology at Princeton, including post graduate work in resource economics and development. So I have an interdisciplinary background.

ER: Where is Borneo?

LC: Borneo is northwest of Australia and south of Singapore; Borneo is the third largest island in the world. Greenland is the largest, and Papua New Guinea or Irian/Jaya is the second. The area where I work is on the equator in the southwest part of Borneo. Indonesian Borneo is called Kalimantan; three quarters of the island is controlled by Indonesia.

ER: When did you first go to Borneo?

LC: I often tell my students, be careful what you sign onto when you're young and energetic. I went out there as a young undergraduate just finishing at Harvard, I volunteered for a couple years to assist Dr. Mark Leighton in the establishment of an ecological research site monitoring vertebrate responses to forest fruit production. I spent the next eight years in the field site. Because I worked on surveys or management plans of all three of the national parks in West Kalimantan, I was able to maintain my close ties to the Gunung Palung National Park and nearby village communities. Thus, I found myself somehow returning to West Kalimantan every year for the last fifteen years.

ER: When did we first find out about mast fruiting in these forests?

LC: A seminal paper was written by Dan Janzen in which he described mast fruiting in the dipterocarp family of plants and predicted why it occurs. Dan had only been briefly out to the northern part of Borneo, Sarawak, and never had really seen a mast fruiting event. I was privileged to meet him last year and give him one of these

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dipterocarp seeds as a thank you for blazing the trail for us.

I went out there to monitor the rhythms of fruiting and flowering in the forest, so my focus emphasized the responses of seed predators to fruit production. We witnessed a mast fruiting event when we were out there and I stayed on an extra two years to quantify the phenomenon. Masting is a fascinating system. It's one of these ecosystem processes that occurs nowhere else in the world with this strength and magnitude.

ER: What is masting?

LC: In the Borneo forest masting is the synchronized production of fruit or seed on multi-year cycles. It's a boom and bust cycle: there are some years where a lot of seed is produced, and then several years pass where there are smaller crops or no fruiting at all.

The term masting comes from crop seed or beech and acorns where farmers were describing boom periods with a lot of seed on the ground, for instance during oak tree masts. But the difference between oaks and dipterocarps is that oaks have dispersal agents. Oaks have these boom years where in one year there's a superabundance of seed and the squirrels are hoarding or burying the seeds and forgetting some. So one of the reasons for that pulse of seeds is to have successful dispersal.

ER: But masting was not really known in these dipterocarp dominated woods.

LC: No one really had measured it or monitored it, even though people had talked about it. Certainly local villagers would say the pigs migrate in search of these seeds and that they themselves collected seeds for oil and butter. In addition, the common lore of foresters and anthropologists working in the region reported widespread and irregular cycles of canopy tree reproduction or wild boar movement. A number of these reports had been compiled by Janzen and later by Peter Ashton, but nobody had quantified seed production or if and how predators responded to this seed availability.

Rather, some of the leading tropical ecologists working in Southeast Asia had written that dipterocarps are not food for animals because these trees possess wind dispersed fruits, not fleshy ones that reward animals for dispersing their seeds. Yet, even referring to seeds, small scale studies in Peninsular Malaysia did not observe any animals eating the seeds. So this was a great mystery because supposedly nobody eats these and no Western scientists had quantified mast fruiting. Why does it occur? And if it does occur, at what scale?

This had dangerous environmental policy implications because commercial loggers used this in defense of their activities remarking that harvesting dipterocarp timber trees would have little effect on the forest community. Nothing could be so far from the ecological reality however.

ER: How do you go about measuring or documenting masting?

LC: You have to be nuts, as we say in this business, to measure mast fruiting because it happens in a short period of time, it's intense. You drink excessive amounts of coffee and stay up around the clock because it only occurs during a brief window, on relatively irregular and until recently unpredictable cycles. It is a major challenge to mobilize teams, obtain funding and receive visa clearance before the cycle is exhausted.

You need to measure on large spatial scales over long periods of time, and at the same time monitor the

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activities of the animals, the seed predators, and the plants, the seeds and how the seeds are produced and when they fall. Although tough to do, it was incredibly fun; full of that pure joy of discovery that one rarely encounters.

ER: Why all this excitement about masting if it's common in oak and other systems?

LC: The differences with oak communities is that usually it's one or two species of trees involved and the species are on different cycles. But in Borneo there are hundreds of tree species, and all these different species synchronize their fruiting and drop their seeds within a few weeks. No vertebrates have been observed to disperse the seeds. They only eat and destroy seeds.

So when we monitored these forests we saw that there was no seed produced at all for many, many years, and then all dipterocarp species joined forces as a union of trees if you will, that synchronized their production and dropped their seed in six to ten weeks.

ER: How many mastings have you seen?

LC: We have documented five different masting events. A minor mast occurred in 1986 where 23 to 30 percent of the trees in a number of species fruited. That year we saw massive migrations of jungle fowl and bearded pigs, wild boar, and orangutan and parakeets and all these other animals that were eating the seeds.

That case was instructive because during a major mast event, the entire landscape is fruited and the trees are overwhelming the seed predators. But when masting only occurred in a localized valley, which is still a relatively large area — we were monitoring an area of eight square miles — every single seed on the ground was destroyed. We wouldn't see wild boar for months, and then when the fruit started dropping we'd see fifty or sixty pigs a day. The forest floor would be shaking with these wild boar moving. So mast fruiting is an effective means of swamping out the seed predators, but it has to occur over a large area. As soon as the seeds were exhausted, the animals would leave.

Figure 11. *Shorea pinanga*. Left: first, opposite seedling leaf; center: seedling; right: later leaf. Horizontal scale bar for leaves, vertical scale bar for seedling.

ER: What were your main results?

LC: First, we documented that there were many seed predators that could eat dipterocarp seeds, and they were generalists, they ate the fruit of all these different species. The trees were working together because they had common predators. If the predators only ate one tree's seed and not another's it wouldn't be useful to join forces.

The trees are in an arms race with the seed predators, they're dropping all their seeds at once, which then germinate immediately. As soon as they germinate, these predators are no longer interested in feeding on them.

ER: So the seedlings must have some chemical defenses.

LC: Yes, there's very little herbivory. We have monitored seedling mortality and herbivory. There can be a hundred thousand seedlings per hectare with many different tree species represented; it's a carpet of seedlings across the forest floor. But very few animals browse the seedlings or chew on the leaf.

ER: I'm having trouble understanding how thousands of trees decided to fruit in unison.

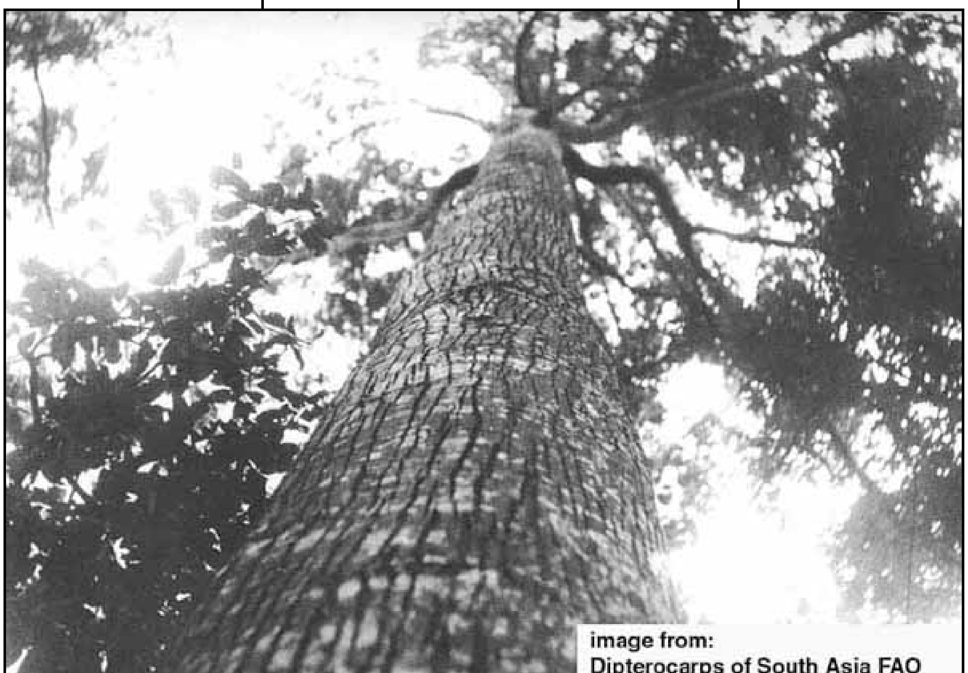
LC: One scenario how masting may have evolved would be where dipterocarps invaded the island of Borneo and became common, and once a tree gets to be common, predators can build up their numbers and feed on it. So we could imagine how the fruiting rhythms could become entrained if a few individuals fruited together, so that per capita losses of seed were much lower. That could quickly entrain the population, but they needed a cue. They need something that's going to be a trigger that all the trees would experience or cue into, and it turns out it's some factor associated with El Niño climatic cycles.

If you talk to local farmers or forest village communities and even scientists, what happens in West Kalimantan is there is an extreme drought in June, July, and August preceding the flowering. So there are fewer clouds, reduced cloud cover, with perhaps lowered temperature, but it occurs over the entire region. But most of this is still correlation not causation.

ER: This drought occurs before the El Niño?

LC: Yes. It starts when the El Niño is about to occur. In West Kalimantan June, July, and August was very dry, less than 100 millimeters of rain. In this last 1997-98 El Niño it went on through September and October, many months without rainfall. This is highly unusual because this region typically experiences 4,500 millimeters of rainfall annually. So going below 100 millimeters of rainfall in any particular month, let alone for three consecutive months is a considerable decline.

Then early in September the flowering starts, and the flowering is staggered over a four or five month period. So from September to mid December we still have flowering of all the different tree species.



It is a cathedral-like forest. It's quite striking. One of these trees can be worth $3,000.

ER: So they're flowering and getting fertilized over several months, but they all drop their fruit together?

LC: Correct. They all synchronize. Those trees that flower later in the season are either smaller seeded or they speed up the maturation of fruit, and they all hit that fruit drop window in early February. Some of the largest seeded trees flower earlier because they require more time to mature fruits.

ER: How long does it take to drop their seeds?

LC: Ninety-three percent of the seeds fell within six weeks, and that is about 180 kilos of seed per hectare. Twenty-five to thirty kilos of seed a week drops. This is why you don't sleep. You spend all your time chasing wild boar in the evenings, parakeets in the morning, and counting seeds and seedlings all day long.

ER: What does the forest in the park look like?

LC: It is a cathedral-like forest. It's quite striking, and it's very low turnover. You see these trees die standing in old age, it's kind of like looking at old-growth forests. That's not to say that edge effects don't occur, and fires do escape and move into the graded logged sites and then on to natural forest. So some of the protected areas have been decimated by fire. That's why this park is one of the few that has lowland tropical forests remaining. Most of the protected areas that are remaining are only upper hill forest and montane.

ER: What does logging outside the park have to do with what happens inside it?

LC: All across this province, say, 150,000 square kilometers would fruit together. By logging vast tracts of it, first you take out the midstory trees and the logged forest, but then you fragment the landscape with patches of clearcut or logged-over forest, so you don't have that contiguous sea of fruiting dipterocarps that you had even ten years ago. So that matrix is degraded into these little remaining islands or pockets of forest.

ER: There's been no recruitment to the stand since 1991?

LC: Not really. We're monitoring these areas, and I think there's hope. We don't know if it will change. We'll have another chance at the next El Niño. This last was an extremely severe El Niño. And there have been some miscues and problems. I think this is this is the wake up call for potential catastrophic change. We hope foresters would see this. I'm on a tropical forest foundation board, where some more traditional foresters or even ecologists might remark, Oh, there's plenty of trees. Well we know from Chuck Cannon's work there are trees in the understory that are saplings or what we'd say midstory trees that can grow in, but if they are re-logging those and then clearcutting for oil palm plantations, we won't have that regrowth capacity either. The area that Chuck and I worked in was clearcut and turned into an oil palm plantation. So even though he had a hopeful paper in the sense that it has the potential for recovery, it's not being allowed to go in that trajectory. But I'd also say it's not as degraded as say, Central America. There's forest still remaining.

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In these lowland forests dipterocarps can comprise 40 to 80 percent of the canopy trees, so there's a rich, dense source of timber. Unlike, say, in African or in the neotropics like Amazonia, where only one or two trees per hectare would be commercial, like mahogany. In Indonesia they would only be leaving less than one or two undamaged trees per hectare and taking ten to twenty-five trees. These are dense stands, very lucrative.

So Indonesia has become the world's largest exporter of tropical plywood; it supplies about 80 percent of the plywood for the U.S. construction industry. At first all the dipterocarps were supplied by the Philippines, but they were extracted early in the sixties. Then the industry moved across peninsular Malaysia and northern Borneo. Then Indonesia with extensive forest land area as well as favorable political and economic conditions for rapid exploitation, became the world's largest exporter of tropical timber. More tropical timber is exported from the island of Borneo than all of Latin American and Africa combined.

Indonesia became the world's largest exporter of tropical plywood; it supplies about 80 percent of the plywood used in the U.S. construction industry.

Early on we did some studies in logged-over forests. I was working in a different capacity for the U.S. Agency for International Development for several years surveying different practices and using case studies of a few concessions occupying about 3 million hectares of forest. By working in the region and knowing the foresters, we could observe first hand how forestry concessions operated without the site managers being on their best behavior. They did not suspect we were inspecting them as official teams on a site visit. We had the backing of Dr. Herman Haeruman from the central national planning agency. He and USAID economists and policy advisors sought to understand how central government policy was translated in practice at the local level and what the ecological and economic impacts of these policies were. We worked quietly from the inside providing confidential memoranda to those who were in a position to influence events.

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ER: So there was some progressive effort within the government even then?

LC: Yes. Many Indonesians at all levels were concerned about unscrupulous resource extraction but when it's so directly linked to high ranking military and even the president, it was at best difficult if not dangerous and even naive to push for substantive change. Part of our work was trying to understand what was going on in the field because concerned people in the central government weren't getting good information.

This was big money. One of these trees can be worth $3,000. These companies were making incredible profits. This was all about power and resources and who controls access to policy leaders. As a guest in Indonesia, I provide my technical skills and assistance with training to provide information to Indonesians. They are the ones who need to push for changes.

ER: The impression I got from the statistics in your paper was that it looks pretty damn bad.

LC: It is. For me, one of the most devastating and disheartening activities was surveying after those forest fires and seeing what was happening to both local village communities and the natural ecosystems.

With the forest fires, the political crisis and the economic crisis, coupled with the IMF structural adjustment policies, we saw a complete dismantling of protection and pushing for clearcutting and plantations. Hundreds of thousands of hectares were given over to clearcutting for plantations and to clear these areas of the remaining wood for the use of the plywood industry and to put in oil palm plantations.

Illegal logging is now rampant because the local communities are strapped for cash and the plywood mills are strapped for logs. Illegal logging is threatening the remaining lowland areas, and protected forests generally.

ER: So logging outside the park is hurting the ability of the trees inside the park to reproduce?

LC: One of the most disturbing things about this paper is the offsite ecosystem effects of logging and land use. We were all surprised when we saw that there was no real recruitment occurring across all of these tree species, even within a protected area. I think it was picked up as a lot more doomsday than I wanted it to be — I think that sells papers sometimes — but I think this could be an ecological threshold. We are seeing reductions in seed dispersal and seedling recruitment in the forest twenty to thirty kilometers from a logging site. These protected areas had become islands to which seed predators fled because they contained relatively high densities of fruiting dipterocarps, in contrast to the surrounding logged landscape.

There was no real recruitment occurring across all of these tree species, even within the protected area.

What most researchers have measured initially was direct effects within a logging concession. How does removing logs affect seed production, seed dispersal? Indirect effects of logging have been more elusive and more difficult to measure. Scientists are now asking, What are the indirect effects of human activities on natural or ecosystem processes? The indirect effects were surprising here, and they were at first counterintuitive.

First of all, if you're having large-scale logging outside the park, you're changing local weather patterns. You'll have changes in rainfall and soil conditions, more drying. By logging the canopy and reducing evapo-transpiration by the trees you're changing moisture levels in an entire region.

Another consequence of logging is that much more debris and wood waste is created than natural forest dynamics of tree and limbfalls. This debris serves as tinder. Coupled with more severe drying conditions, as well as more tinder in these forests, and with people lighting fires to clear land for plantations, industrial agricultural and swidden farming, human-caused forest fires have raged out of control.

Forest fires have spread across these regions in El Niño years, and fires are not naturally occurring in these forests. Unlike boreal forests and what we know in the temperate zone, fires don't normally occur in equatorial, ever-wet rainforest.

ER: So the big fires we read about last year were not natural?

LC: That's right. Lightning strikes may occur occasionally but, these are very old, slow-growing trees that have been there for half a millennium. And as we're seeing drying conditions, the trees are experiencing more drought stress, they're dropping their leaves, they're not producing as much fruit.

ER: This is within the logging areas?

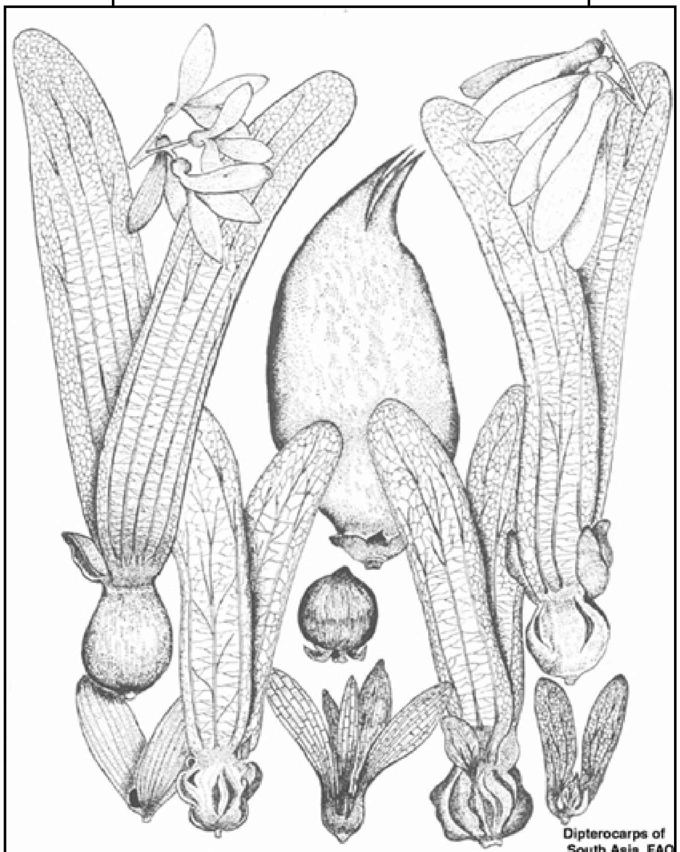
LC: Within the concessions but we're also seeing these off-site effects within the protected area. So even though the trees are supposed to be flowering, they're producing fewer flowers. Seventy-three percent of the trees attempted to mature fruit, but only a few species managed to produce enough seed crops. And those that did produce seed crops, lost them to the seed predators that moved into the national park. And of the few seeds that actually could germinate, they dried out from the severe conditions. There were no seedlings that we could find of forty-eight species that in previous years had hundreds of thousands of seedlings. We went from 195 kilos of seed to 18 kilos of seed, and of that 18 kilos of seed almost all was eaten by seed predators.

ER: What's going to happen to the animals that eat the seeds?

LC: We don't know. We may have a dying off of some of these seed predators. We may see orangutans or other animals that need these bloom periods; that's when they reproduce. For instance, the pigs and the jungle fowl and the parakeets, the seed production is critical for their reproduction as well.

ER: Can these cut over forests come back?

LC: A logged-over forest matrix can recover, but not if it is clearcut, burned, and converted to non-native plantations. Over a million and a half hectares have or are scheduled to be converted to plantations. The structural adjustment programs through the International Monetary Fund was 42 billion dollars in loans. The Indonesian government must increase export revenues to pay off their debts. So there is a direct link between ecological conditions and economic conditions. Labor is cheap in Indonesia and Kalimantan's land is practically given away. So the true ecological cost of what these forests are providing are not valued well. Large tracts are owned by Malaysian or other companies, and oil palm is relatively inexpensive to grow given the wage labor in Indonesia, so that route was actively pursued as the means of generating export revenue. The financial crisis coupled with instability and the IMF's structural adjustment program provide perverse incentives for forest conservation and management.



Various fruits of trees in the dipterocarp family of plants.

ER: What can be done to save what's left?

LC: I think that we need political pressure on all governments especially the U.S., that these are important issues and that reduced impact harvesting, cutting back on the volumes, and providing the training and assistance to reassess what is left out there and determine its condition. That's why many of us believe coordinated interdisciplinary partnerships across jurisdictional boundaries working on an island-wide scale are necessary. We're starting an initiative with different agencies to address these problems on a broad ecosystem scale; that requires new approaches and ways of coordinating resource use across the entire island. For one example, the University of Michigan's International Institute has supported these non-traditional efforts that a research university would not have even approached a decade ago.

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Investing in Innovation: Energy R&D Policy

Introduction:

An article in *Science* magazine points out that research and development funding for energy technology has declined significantly during the last two decades throughout the industrial world[1]. The R&D intensity of the U.S. energy sector is extremely low and recent cutbacks in energy R&D are likely to reduce our capacity to innovate and to respond to emerging risks such as global climate change. We spoke with one of the authors of the report, Daniel Kammen, about our energy policies and their implications for our future.

ER: Professor Kammen, what is your training?

DK: My undergraduate training was at Cornell in physics, my graduate degrees were at Harvard in Physics, and after that I was a postdoc at California Institute of Technology. I started off in biology at Caltech because I was working on theoretical physics models of the brain, but I was also in engineering, and during my three years there I was also added into the Division of the Humanities. That's the point that I began to make a more formal transition into energy and environmental issues. From Caltech I returned to Harvard for a year as a lecturer in global change science, and did some more work on energy policy both in the physics department and at the Kennedy School of Government, and then found my way to Princeton as a junior faculty

At Princeton I was in the Woodrow Wilson School of Public and International Affairs, which is primarily populated by policy-interested economists and political scientists. I was brought in to help expand the program. While I was program Chair, the name changed to Science, Technology, and Environmental Policy (STEP) and we built up a Ph.D. program of which the first batches are graduating now. I had a great time at Princeton more or less trying to emulate the exciting mix of faculty-student collaborative research and activism that was taking place at the University of California Berkeley in the Energy and Resources Group. They've been around since the 1970s and are quite famous.

After six years at Princeton, the Energy and Resources Group (ERG) had an opening when John Holdren left for Harvard. So, now I'm a professor in ERG. ERG has always had a focus on energy, and I'm one of the handful of core faculty. The faculty interests range from climate change, to ecology to biodiversity, to pollution management to new visions of ethical and ecological economics, to the social implications of technology and environmental sociology. It is dream come true to be able to interact with this remarkable group on a day-to-day basis.

ER: Does ERG have faculty from other departments?

DK: Yes. We're multidisciplinary, interdisciplinary, transdisciplinary, whatever you want to call it, in a couple ways. I mentioned the faculty, but the students are truly the crown-jewel. There are about sixty remarkable students who bring a diverse set of backgrounds and a shared commitment to doing analysis and engaging in the public policy and activist process to build sustainable local and global societies. Their focus is on everything from species conservation to environmental racism to the politics of climate change to risk policy to renewable and clean energy science and policy.

We also have a group of around 100 faculty affiliates and they are in basically every school and division at Berkeley: the law school; the business school; geography, politics, natural resources, engineering, and biology. They advise students, collaborate with and advise us, and generally build a cross-campus network. That's why for me, even though I loved Princeton, it was such a pleasure to be able to come here. The academic community is so big and so interesting and so diverse that one day I can be at a meeting talking about the political economy of wood use and biodiversity in Zimbabwe, and the next at a meeting on ways to clean up pollutant emissions from a power plant in California or Kenya. This is a special environment. I work on energy policy, both in the U.S. and overseas, focusing on efforts to dramatically reduce our impact on the global environment through policies for reduced carbon emissions, decreased use of natural resources, improved energy services through decentralized and locally managed renewable energy systems, and through studies of the interactions between energy, human and ecological health.

ER: What is the connection between your training as a physicist and working on energy policy?

DK: Actually a number of physicists have made these types of career shifts – including Holdren, and von Hippel, that I've already mentioned, but also a number of others in academia, non-profit groups, think-tanks, and federal agencies. Physicists tend to think, rightly or wrongly, that they can look at many different problems in new ways and use analytic thinking. But the primary thing that I think that physicists have had to learn is humility, and often that's a little bit tricky road for them. The second thing they have to learn is that the social science and the humanistic aspects of the problems and the economics really matter, and in many cases dominate these issues. The physicist's view is often, I can bring clarity to a problem. So it's trying to de-learn a bit of arrogance and begin to appreciate the equal or greater importance of other fields. That is an important transition that some make well and where others utterly fail. There are people who have said, Oh, there's an interesting problem out there, be it improving fuel efficiency dramatically or solving global winter. I can work on that as a summer study problem. That mentality invariably makes things worse off than better.

So the main thing I learned was humility and that there are significant theoretical and practical results in other fields out there that one has to learn about. The thing that was the most interesting and intriguing for me was that the more social a problem is, the less people are willing or able to dig down and find what are the real clarifying and unifying truths. Not to say there's a basic theory of all or even most social and policy concerns and issues, but there are often design principles, issues of feedback, issues of scale, issues of the interaction of technical and social questions that if you think hard about and, if you are willing to be more of an empiricist than a theorist, you can make some important interesting headway. This in turn often leads to theoretical – understanding, advancing the field of policy science.

ER: Our lack of research on energy is obviously important yet nobody seems to be noticing or caring.

DK: Well, fortunately there are some groups that are beginning to notice and care. But let me start with the basic summary of what the findings are. One is that we do not have very good tools for evaluating the impact of research and development. That's not surprising because R&D is inherently not a simple, linear, process. If you put money on a given project, how do you trace all the various tendrils and leads that come out of that to try to get some realistic measure of what was produced?

Some money put on R&D may produce a patent, a paper and then a patent directly and maybe a company, and it's a pretty easy chain. But other research may produce some well-trained graduate students who then change fields and then talk to a policy maker in D.C., and the route is very tenuous and it's hard to trace.

So to evaluate R&D in the paper, we looked at one tried-and-true measure that Sven Griliches, a professor of Economics at Harvard who recently passed away developed in the fifties and sixties. He used patents as a measure of productivity; we were following in his tradition on that.

We looked at patents in the energy field because we had a hunch, based on some numbers that had been published in a report by the President's Committee of Advisors on science Technology. They noted that there had been stark declines in R&D funding in the energy field since the eighties; the declines were dramatic in the U.S., almost 60 percent decline, in the U.K., almost 90 percent.

First patents are an imperfect but still useful measure of the product of science. If you look across the U.S. economy overall, the amount of R&D funding and the number of patents correlates quite well. When you look at the energy field, you see an equally strong correlation, but instead of a growth trend it's falling off a precipice, a dramatic decline in R&D funding. That's depressing result number one.

Result number two is that several other measures also show that the energy field is under-investing compared to other fields. We looked at the energy intensity; that is, the percentage of the profits in a given field that are put back into R&D. Medicine, biotech, and scientific instruments have reinvestment levels over 10 percent, reasonable rates of reinvestment. In energy we see reinvestment rates that are less than half a percent, maybe even two-tenths of a percent. Orders of magnitude lower.

Now there's all kinds of ways you can quibble about those numbers. You

Medicine, biotech, and scientific instruments have reinvestment levels over 10 percent... In energy we see reinvestment rates that are less than half a percent, maybe even two-tenths of a percent.

can say well, electricity has a very small margin. You're selling it at a couple cents per kilowatt hour, and so percentage returns may not be a good measure. But no matter what you do, with any correction you want to test, you discover the reinvestment numbers for energy are shockingly very low.

ER: Is it because of the capital-intensive nature of energy production?

DK: Some of it's due to that. You have to be a big player to put big money into energy. But I think in the eighties and nineties we've had such low oil prices that people have not looked at the wider implications of fossil-fuel dependence. Until recently we had energy monopolies in the U.S. that had no incentive to invest much in the future. There were some R&D investments, and some of it was very good, but they didn't invest overly heavily because they were unchallenged. Beginning a few years ago the energy industry has seen looming deregulation, and so the investments they have done have been more in the way of process and distribution and building markets, and very little in the way of new insights into better modes of primary generation.

Utilities certainly needed to learn lessons about how to service their customers better to provide energy services and not just produce more electricity. Learning about the demand side and how to manage that, and how to more efficiently manage their service is certainly a good thing. But to neglect research on the generation side is close to criminal.

There's an industry consortium in the energy field called EPRI, the Electric Power Research Institute, that pools research money from utilities and invests it. When you look at their funding levels, you see dramatic shifts in where the research money is going. Money is being redirected out of generation into the management side. That also means we're cutting back on learning about new technologies.

Even more alarming, 80 to 95 percent of global R&D is done in the developed countries. But most of new energy-generating capacity is being installed today in developing countries, and by 2020 or so, more energy will be being produced and consumed in the developing world than in the developed world. This is a dramatic shift. So there is a double whammy, limiting our options through lack of R&D is bad for us, and it's also bad for developing countries.

> ... by 2020 more energy will be produced and consumed in the developing world than in the developed world.

These dramatic cuts in R&D funding are giving me an overall sense that we're not looking at many interesting options for countries that critically need ways to reduce the environmental footprint. When you install a new power plant today, you're going to live with that decision for decades. So bad or dirty investments now make it harder for us to clean up our environmental act down the road.

ER: Is the lack of research because energy technologies are mature?

DK: When you see installed capacity, be it power plants or be it urban works and plumbing, you tend to have a feeling that, it's installed, it's the way things are. But it's dramatic how quickly things *can* change when there is some signal, and we tend to forget that. Before the oil crisis in the seventies, there was almost a theorem, in the *Scientific American* it appeared as a law, that the amount of gross national product was directly proportional to the amount of energy it used; that was the mantra. Then when the oil crisis hit and GNP and energy decoupled, we suddenly realized that this view was wrong, and that a world of other energy futures was possible. Another physicist, Amory Lovins wrote a beautiful book, *Soft Energy Paths* (1977) that focused attention on this. For example, five or six years ago the big auto manufacturers were saying the fuel-cell powered cars, those that run on electrochemical reactions and not combustion, are an interesting item that we will see some decades from now. But among other things California pushed the low and the zero emission vehicle standards, technical advances in fuel cells occurred, and those same industry executives who were saying this is a long way off suddenly changed their tune and said fuel cell technology is going to be available in 2003, 2004. It's a remarkable turnaround spurred by clever policy.

Another related revelation is that until recently, climate change had been seen as a process that was generally slow, occurring over centuries, millennia, or more. Well, over the last few years researchers have been finding in the historical record abrupt climate events that happened in just a few years. This is a revolution in our realization of how fast things can change and a complete eye-opener. We see that same kind of revolution going on in our understanding of energy: you can have countries with one set of installed technologies and if properly motivated, can implement a relatively quick shift to others.

I for example can envision the U.S. closing down the vast majority of power plants in the country and replacing them with a decentralized distributed system of renewable energy systems here and there, with some remaining baseload capacity for gas turbines to run, which do produce carbon, although far less than coal or oil. We can have wind farms, and fuel cells in people's basements and people's cars, photovoltaic panels in the lobbies of buildings and on rooftops, and we don't have the old model of power plants. Instead we have a distributed grid and the utilities make their money by managing that product in the grid more so than by primary generation. Individuals and companies can all make, buy and sell power.

That vision can only be realized if we make the investment, something we are not seeing today. We need to research, build, and install those technologies to test them out so that they can be used in this new distributed system. I can imagine that happening in the next several decades. It would not be that difficult technologically or economically, but we would have to commit to exploring the options. Right now we're not very progressive in exploring those options because our R&D base is low and because the existing energy monopoly is largely happy and unmotivated by policy measures or public outcry for the need to change.

ER: What would a better R&D program look like if you were made the energy czar?

DK: That would be fun. I often envision being such a czar, and I write papers pretending I am. I think the first thing we need to do is not to say that there is a given solution. I and others have said a carbon tax is needed, or this and that is needed, and those things are all true.

But, I think we need to decide first where we want to be and state it clearly. For me that is a world were we use energy wisely, and cleanly. We then need to be willing and not afraid to say that that protecting the environment is good for us, not just because we're granola crunching Birkenstock wearing do-gooders, but because we think it's better for our overall interests. We have ample evidence that with sound policies, research, and collective action consuming less is better because you can live better that way.

> To me the real story is that we have equated consumption with happiness. Well, there are equally valid alternative models.

I think if we said those things and articulated them more clearly, the public would be supportive. I think we could do much more economically and environmentally with a lot less impact on the planet, and I think we need to articulate that vision of the future first and then say, Okay, what do we need to do to get there?

We are going to find out along the way that there are a multitude of unrealized ways to improve the human and environmental condition with a far smaller ecological footprint. We need to ramp up our clean energy production. We need to be thinking about a low carbon economy instead of only saying, Oh, it's a tragedy that the funding levels for energy research have fallen. To get to this cleaner situation, we need the following resources: we need to couple our thinking about energy with ideas about consumption and with health. From there we can develop and implement new proposals for R&D activities and policy action like the clean car efforts that accelerated electric vehicle and fuel-cell car development.

Conservatives and liberals, Democrats and Republicans, all admit that R&D takes time. You're not going to decide on September 1, 1999 that you want fuel cells, invest a lot of money, do a 'cold start' from nothing, work hard for one or two or three years and have it. You've got to invest in R&D over time. You've got to send signals to companies that it's worth investing, to universities that training people in those areas is important and that there will be jobs and there will be careers for them making a difference in those areas.

One way to do that would be to set bigger targets for cleaning up the environment and improving our health and improving our economy because then we would be able to tell proponents and opponents what our goals were and not every year have to fight the small-scale budget fight. The Apollo program was dramatic because we thought big and had a longer-term view. Aiming all ones efforts for a 5 cents per gallon gas tax, then retreating when the going gets tough is a strategy for failure. A national vision of a 50 percent cut in carbon emissions with increased economic activity over several decades is the right sort of vision.

Another start is to look for international partnerships, not unequal big-brother relationships. It is critical to build capacity in developing countries so they can make their own decisions and they can do things in cooperation and not just be clients or the research subjects for interesting energy studies by academics from the North. As it is, we do not value energy resources globally at their true environmental and social costs.

ER: What is an example of a hidden cost?

DK: The cutest and entirely accurate example is that I'm sitting here drinking a bottle of water while I'm talking to you. That bottle of water was pumped out of the ground probably less than forty miles from here. Yet it costs more than does an equivalent quantity of a certain liquid that gets pumped out of the ground in the Middle East, held in tanks, transported on huge ocean vessels, refined, pumped through refining stations here in California, and brought to my automobile which I then burn as gasoline. The carbon in that gas then goes into the atmosphere, where about half of it stays up there for about a century causing global warming. That's a ridiculous situation. That says that somewhere a lot of the true costs of that gasoline are being hidden.

Lets say gasoline costs $1.50 a gallon. However, add to that the environmental costs, from illness and environmental damage that are estimated to add another 30 to 60 percent to that gallon of gasoline. If you tend to be more anti-establishment in that analysis and you add in the costs of wars fought to protect oil sources, you can increase those numbers so that the implicit subsidies for gasoline are huge. It depends very much on who you ask, but some people will certainly say, and have the calculations to back it up, that the true cost of gasoline is several *times* what we're charging in the U.S. That means there are subsidies of several hundred percent, and that's just one graphic example.

On one level I think that's an intellectual argument. Adding up the numbers is important. But I think the other one that's more visceral to me, and I think equally telling, is that we see all around us not only the harmful impacts of using fossil fuels in terms of health, in terms of smog and accidents, poor quality of life for people who commute hours a day alone in cars, and so forth. But, the U.S. has cleaned up its act considerably since the fifties, all measures of the major pollutants with the exception of nitrogen oxides are down dramatically. This was achieved over the objections of the conservative and pro-industry lobbies, and low and behold, we have now found that everyone benefits from a cleaner environment, and despite the gloom-and-doom calls, the economy has blossomed. Investing in clean energy use is good business. It's kind of a funny process: whatever technology and infrastructure we have at a given point in time, some fraction of people are going to argue that change from this, whatever "this" is, is so costly we can't do it. People were saying that the change from leaded gasoline is impossible because the economy will collapse. Well, we find out that (a) it was pretty easy to change, and (b) the benefits from it far outweigh the costs.

Then we were saying that phasing out chlorofluorocarbons was going to be so costly we couldn't do it. Well, now everyone looks back and says, Oh, that was easy to do. Well, before we did it, it wasn't easy; afterwards, the big companies that were making CFCs discovered they saved money.

We need to be willing to say that protecting the environment is good for us... because it's better for our overall interests.

People are now saying we can't do anything about climate change because it's going to cost us a lot of money. Well, we haven't tried to fix it yet and so it's a little bit like putting a blind eye to history to keep saying over and over again, if you change it, we'll all go broke. Every time we've changed these things, we've done better.

ER: In Germany gasoline costs considerably more. Have they gotten any benefit from that?

DK: Certainly. Gasoline prices are much higher in all of Europe; in Italy it's five times higher than the U.S. Yes, there are benefits because the amount of driving per person in Europe in general is far less than in the U.S. It is also, however, true that driving is increasing. Europe is becoming more like America in terms of miles driven and in terms of restructuring cities. Without a new vision, affluence breeds over-consumption with little quality of life to show for it. The point is that we only find benefits if we are willing to invest a little in looking at problems in a new way, as opportunities.

To me, the real story is that we have equated consumption with happiness. Well, there are equally valid alternative models: we could equate lack of busywork with happiness, and if we tried to design our energy systems and our other systems around things like that, we would do far better, and I think we would make more money.

Paul Hawken, Hunter and Amory Lovins have a new book out called *Natural Capitalism* which makes a compelling argument and has a long list of areas in which you can do good and do well, in the sense that you can make a lot of money for your company or yourself by making better choices for the environment.

Their argument — people tend to discount because it sounds too good to be true — is that you can make more money while being greener. If people really believed it, they should be doing these things all the time, but they tend to believe, again, because of the status quo, that's not likely. Whereas we keep discovering it often is the case. We just have to be willing to take the first step. My work has been to do the research to demonstrate that renewable energy systems are examples where you get this double-benefit: better living and environment, and better economic activity too.

ER: In your article you mentioned the problems of betting on technologies. What have been some of our bets?

DK: Examples of betting on losers that have been real tragedies are the clean coal and the synthetic fuels initiative in the U.S. We put billions into it in the late seventies, and it may bear some fruit down the road. But that was the dominant chunk of the energy R&D budget for some time and it didn't go anywhere. The problem was not these specific technologies, but that we fixated on a *technology*, and not on a diverse R&D portfolio that supported and rewarded solutions. I am confronted all the time by federal funding agencies that are locked-in to funding iterative improvements on inherently dirty technologies.

The U.S. photovoltaics program in the seventies had another type of problem and that was that funding levels that are higher obviously make things easier to get things done, but you have to plan your increases carefully. You can't rocket them up and down. Volatile funding levels are as bad as just chronically low levels.

All those are examples of areas where, through policy action or through betting on certain companies, as opposed to rewarding production, we misplaced incentives. There's a classic example where it was possible in the late seventies in California under certain tax schemes to purchase and install a windmill and to put it up but never connect to your house or the grid -- never make it a real power producer. But because the policy incentives at the time (subsidies) rewarded construction and not power sales this happened a lot and the industry suffered.

A few years ago auto manufacturers were saying fuel-cell cars are interesting, we will see them some decades from now. But California pushed the air standards and those same executives changed their tune and said fuel cell technology is going to be available in 2003.

ER: Ethanol fuel comes to mind.

DK: Right. We're still subsidizing ethanol at several billion a year. Whereas the Brazilian ethanol program, which is not without its problems, has seen consistent decreases in product cost accompanied by increases in quality, and it is now a dominant fuel in the market there.
We were not able to follow the Brazilian model. Well, when you look at the U.S. program, when you strip away the hype, the reason for the ethanol program in the U.S. was to subsidize farmers, not to produce the fuel. So you've got to pick your signals, and that was not a case where fuels were picked properly.

ER: Are there examples of winners?

DK: Not only do examples come to mind of winners, but we're now finishing up a Special Report that's going to be published by the Intergovernment Panel on Climate

Change. It's a report on technology transfer that includes thirty case studies from a list of almost 100 that we compiled. Some of these winners have been dramatic: improved efficiency cook stoves, for example, that are more energy efficient and produce far less pollutants that are the biggest source of illness in most countries went from a few hundred thousand at most, installed in China to 150 million units. The Chinese did it through an intelligent program of setting up regional competitions for the best design. By design I don't just mean the engineering the device but also better marketing plans and better support networks and all the kinds of things you need to sustain an industry. They did it at an incredibly small cost. That's one international example.

Inner Mongolia went from none to 150,000 windmills providing power on individual rooftops. In Kenya the number of photovoltaic systems, the number of improved cook stoves, have each just shot through the roof.

In the U.S., one success story is the U. S. EPA's Green Lights program that encouraged the installation of more efficient light bulbs; not just the light bulb, but also the ballast. That was a program that was very inexpensive and didn't provide very much in terms of hardware resources. It provided companies with educational materials and performance evaluations; this is called the soft subsidy, meaning don't just subsidize the hardware. In this case it means don't even subsidize the hardware because you would like the actual gadget to reflect and be sensitive to market forces.

Through the U.S. this particular efficiency gain really took off, and you see the number of these bulbs being installed dramatically shooting up, so much so that as the number of these improved efficiency bulbs were installed, another effect kicked in, and that effect is called the learning curve.

We observed the following effect in many cases: the more of a given widget that you build and sell, the more the price drops, which makes sense. As you are learning more efficient ways to build, sell, and market it we observe a strikingly regular relationship, and that is every time you double the number of units built, the price drops by around 20 percent. Obviously it's easy to get those doublings when you're building your first few units. The first few fuel cells are very expensive, but that thousandth one made on a production line is far cheaper, so you see these drops there. The first bunch of gas turbines were quite expensive, then the price really came down.

When you see installed capacity be it power plants or plumbing, you tend to think that's the way things are. But it's dramatic how quickly things can change...

This learning curve tends to hold when the technology or the process that you're installing is one that can be standardized. So you tend not to see such dramatic learning, for example, in nuclear reactors. Not just because of the environmental regulations and their problems, but because they don't tend to be knockoffs, each one is basically hand built at the site. But things like portable photovoltaic panels and windmills and fuel cells and things that you can mass produce once you get good models, dramatically come down that learning curve.

In this Green Lights case the effect of the program was so strong, people were putting so many in, that we began to see more and more cost decreases due to the feedback. The more units that are installed because this program supports it, more units are therefore being built. The people building them learn more and bring down the price, and now you have a positive feedback loop that has helped to draw down the price even more.

A similar analysis was the basis for a World Bank sponsored program to install photovoltaic systems in Kenya, in Morocco, and in India where the effect of the program itself is to install systems, but then to get these feedback groups going.

One question is, Under what range of cases do these learning curve results hold and in what cases do they not? That is another line of our current research in the Renewable and Appropriate Energy Laboratory at Berkeley.

Another one is recognizing and supporting the entire of chain of events from good idea to installed, working, commercially sustainable and viable technology. This holistic approach does not stop when the first few units are sold. We often strongly under-invest in all of the training and learning and after-market issues. We support a company to build photovoltaic panels that then get sold in the U.S. and overseas, but we don't at the same time support it – or potential customers – though training or through programs to the people who are then going to go out there and provide the after-sales industry, the servicing, the upgrading of systems, the warranties.

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ER: Where do you see us going from here? Take look back from the future.

DK: Without being considered to be a hopeless optimist or greenie, which I guess I am, I can see a dramatic change in the landscape. Thirty years from now we will look back and scratch our heads as to why we ever had such an entrenched system of big centralized fossil fuel power plants. It's not the thing we need. Right now we could replace it with a decentralized low-impact energy system, and make a lot of money doing it. This would put the energy where people are, reduce the social and environmental impacts of big energy infrastructure.

We're going to need more and more energy in the future in various forms, whether it's just higher quality energy, more locally placed energy, or just simply more raw energy. But I can see doing it with dramatically lowered environmental impacts.

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