Land Report

Number 107, Fall 2013 · The Land Institute

About The Land Institute

MISSION STATEMENT

When people, land and community are as one, all three members prosper; when they relate not as members but as competing interests, all three are exploited. By consulting nature as the source and measure of that membership, The Land Institute seeks to develop an agriculture that will save soil from being lost or poisoned, while promoting a community life at once prosperous and enduring.

OUR WORK

Thousands of new perennial grain plants live year-round at The Land Institute, prototypes we developed in pursuit of a new agriculture that mimics natural ecosystems. Grown in polycultures, perennial crops require less fertilizer, herbicide and pesticide. Their root systems are massive. They manage water better, exchange nutrients more efficiently and hold soil against the erosion of water and wind. This strengthens the plants' resilience to weather extremes, and restores the soil's capacity to hold carbon. Our aim is to make conservation a consequence, not a casualty, of agricultural production.

LAND REPORT

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ELECTRONIC MEDIA

For e-mail news about The Land Institute, write to Carrie Carpenter at carpenter@landinstitute.org, or call. Web site: landinstitute.org.

SUPPORT

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Cover

Greenhouse manager Tiffany Durr waters seedlings of Kernza, a perennial grass that The Land Institute is developing as a grain crop. These progeny are from crosses of select plants. The approximately 15,000 seedlings were moved to the field in mid-November. Scott Bontz photo.

Pheonah Nabukalu seeks the genes for perenniality in sorghum-johnsongrass hybrids. Scott Seirer photo.

Sorghum work for Africa

$650,000 to isolate genes and breed Kansas plants with sub-Saharan varieties

The Land Institute and collaborators won grants to help make grain sorghum both a perennial and a better crop in Africa, where the plant is a major human food grown by small farmers in often marginal soils and tough climate. Improved sorghum should help conserve that soil, along with the richer but eroding soil of the American Plains. It also will make up for the Green Revolution, which dramatically boosted corn, wheat, and rice yields, but overlooked sorghum, which naturally better handles drought and has untapped genetic potential.

A USDA grant for $150,000 will fund a new Land Institute scientist, Pheonah Nabukalu, who comes from Uganda by way of a doctorate from Louisiana State University, to connect results in the field with genetic mapping at the University of Georgia. This two-year project uses 500 sorghum lines developed over the past four years at The Land Institute by crossing annual grain crop plants with a wild perennial relative, johnsongrass. It should help resolve how to precisely breed into the annual crop the overwintering ability of johnsongrass, but exclude unwanted traits. For more than a decade institute breeder Stan Cox has worked with these crosses and selection, developing plants with bigger seed that are increasingly able to survive Kansas winters. But the hybrids are years away from being ready for the farm, and the genes responsible for perenniality remain hidden. Nabukalu will work to find them by associating more than a dozen traits observed in plants and grain with the genetic markers being deciphered by Andrew Paterson, head of the Plant Genome Mapping Laboratory at Georgia.

Paterson also will lead the use of a $5 million grant from the US Agency for International Development, with $500,000 coming to The Land Institute over five years, to get its sorghum strains to Africa, breed them with locally adapted varieties, and test how the offspring perform. Winter-hardiness will not be a problem in Africa, so Cox can send plants selected solely for traits like grain production and development of the underground stems called rhizomes. The rest of the USAID money will pay for the work in Ethiopia, Mali, and South Africa. The collaborator in Ethiopia is Jimma University. Overseeing the other locations is the International Crops Research Institute for the Semi-Arid Tropics, which is based in India, and where Cox once worked.

The diverse but dry and fragile Sahel region between the Sahara and the more humid savannas and woodlands of central Africa is pressured by a population of more than 100 million and annually growing by 2.8 percent. Some get nearly 40 percent of their calories from sorghum. Based on tonnage, sorghum is the fifth most important grain crop, grown in India, China, Brazil, and the US southern Plains. Here it is almost entirely for livestock. Climate change plus increasing population and demand for water will make it more important as human food.

Land Institute shorts

Study to see whether cereal crops can fix nitrogen

The Land Institute has hired a scientist from India, Sivi Damaraju, to study whether bacteria living in some grain crops or wild grasses can pull nitrogen from the air to support their growth. As crops, such plants could help farmers avoid costly synthesized nitrogen, and reduce water pollution and greenhouse gases. (See the feature story about nitrogen on page 10.) Damaraju had been working as a post-doctoral researcher at Kansas State University. He will start here on December 1. Private grants will fund a study expected to last 12 to 18 months.

Farmers long have known that forage legumes such as alfalfa and clover help boost production by crops that follow them in rotations. Bacteria in nodules on legume roots convert atmospheric nitrogen to a form that plants can use to build tissue. In return, plants feed sugars to the bacteria. Scientists recently have explored whether plants other than legumes have similar nitrogen-fixing ability, only in a looser association with the bacteria, which either live between the plants' cells, not at committed nodules, or live free in soil near the roots. This kind of arrangement might explain how for centuries Hopi farmers in Arizona got more protein-building nitrogen from their corn than was contributed by legumes or manure – none – or by lightning – only a little. Sugarcane has been shown to clearly have this ability. The sum of studies of other plants, including corn, sorghum, and the perennials miscanthus and johnsongrass, which gives perenniality to our sorghum, so far are not clear.

The Land Institute seeks to know if any of the plants it is developing as perennial grain crops already fix nitrogen, and whether the trait can be added or improved through selection and breeding.

The Land receives farm near University of Kansas

A former energy executive and his wife donated to The Land Institute their 19th-century stone house and 65 acres of pasture and woodland, valued at $1.2 million and 10 minutes from the University of Kansas. The unexpected gift from Jim and Cindy Haines does not just expand the institute's research space, but also is a boon for collaboration: in recent months, Land Institute researchers have been laying the groundwork for a consortium with KU and Kansas State University to advance perennial-grain breeding and companion ecological study. The aim is more opportunities for study and work, around the world, in this new agriculture. The donated property includes 50 acres of brome grass cropped for hay, which could be devoted to ecology studies and perennial-grain trials.

Jim Haines directed Westar Energy, one of the largest utilities in Kansas. Cindy Haines reviews films for National Public Radio affiliate KCUR in Kansas City and teaches film courses at the University of Kansas. They left their rural house, near the Lecompton interchange of Interstate 70, for a house in Lawrence, home of the university.

After an introductory get-together with neighbors at the site, Managing Director Scott Seirer said, "We've got a lot of friends in Lawrence. They're happy to have us in the neighborhood." Institute Research Director Tim Crews is coordinating the consortium and said, "It's a large undertaking, and a lot of moving parts, but it's under way."

Robert and Helen Gorrill settled on the land in 1872 and hired an Italian-born stonemason to construct the 3,092-square-foot home in the 1880's. The property includes a barn and a granary that has been restored as guest quarters, meeting space, and theater. This will be a site for meetings, promotion of our work, and other gatherings.

Cindy and Jim Haines donated to The Land Institute 65 acres and a 19th century stone house near the University of Kansas. The property will be used for perennial grain and ecology research, meetings, and other functions. For a picture of the house, see the back cover. Photo by Philip Heying, www.philipheying.com.

Gift received of native prairie near Kansas State University

Bill and Irma Lou Hirsch, of the Kansas City area, gave The Land Institute about 16 acres of native tallgrass prairie overlooking Tuttle Creek Reservoir. The land, about 75 miles east of us, and near Kansas State University, will be used for research.

UN's food and farm branch learns about perennial grains

Land Institute scientists joined other researchers in Rome in late August to tell officials of the UN's Food and Agriculture Organization about developing perennial grains. The FAO serves as a "knowledge network" and sharer of policy expertise.

Stan Cox described his work with sorghum, David Van Tassel talked about his plants in the sunflower family, and Lee DeHaan told of Kernza, The Land Institute's trade name for intermediate wheatgrass. Other presentations:

- Work in Sweden to domesticate as an oil crop a plant called field pepperweed, Lepidium campestre, a mustard family biennial that might be made perennial.
- Australian tests of perennial wheat from The Land Institute and Washington State University. (See the fall 2012 Land Report.)
- Italian tests of perennial wheat from The Land Institute and Washington State, by way of the Australian program.
- Australian study of the financial potential of perennial wheat and perennial legumes, and of the engineering and management challenges of changing from annual to perennial crops.
- Pakistani tests of growing cereals amid perennial forage legumes such as clover and alfalfa.
- Examination of apples and grapes, two old perennial crops, for lessons about breeding new ones.
- Work in China, with The Land Institute's help, to develop perennial rice.
- The potential revival of "ratoon" rice – allowing regrowth and harvest after the first crop. Second yields haven't been economical of late, but that might change with Asia's rising labor costs.
- Raising the income of poor farmers by adding tree crops.
- Gains and challenges in making corn a perennial. (See the spring 2011 Land Report.)
- Institutional investments needed to develop perennial grains.
- The promotion at Montana State University of the wild perennial Indian rice grass, *Achnatherum hymenoides*, and seed of the perennial forage crop timothy, *Phleum pratense*, as nutritious though as yet low-yielding grains.
- Work in Malawi to boost soil fertility and corn yields by intercropping with perennial legumes.
- A Dutch study of how conversion from annuals to perennials affects the soil food web.
- Work at the University of Minnesota to save soil and preserve ecosystem benefits with continuous living cover, including perennial grains. (See the spring 2013 Land Report.)

Ken Warren and Sam Evans join board of directors

Sam Evans, a founding member of The Land Institute board who served four years, has returned after a 33-year hiatus. Evans leads fund raising for McCormick Theological Seminary in Chicago. His wife, photographer Terry Evans, served on the board after he left, until last year. Joining the board for the first time is Ken Warren, our former manag-

> "Pluralism, diversity, and tolerance were once native plants in the Middle East – the way the polyculture prairie was in the Middle West."
>
> *New York Times columnist Thomas Friedman*

ing director, a job he held for 16 years until retiring in 2011. He lives where he grew up, in Manhattan, Kansas.

Times columnists Friedman, Bittman cover The Land

The Land Institute was featured by two New York Times columnists, Thomas Friedman and Mark Bittman. Friedman wrote on August 10 under the headline "Kansas and Al Queda." He paralleled how fossil fuels power monocultures both in Midwest agriculture and in Middle East societies, and how these pursuits weaken societies. He presented Wes Jackson's primer on making grain farms work more like diverse prairies, and asked Muslim fundamentalists to remember that as a synthesizer of cultures from the 8th to the 13th centuries, Muslim Arab society became the world's intellectual leader. "Pluralism, diversity, and tolerance were once native plants in the Middle East – the way the polyculture prairie was in the Middle West," he wrote. "Neither ecosystem will be healthy without restoring its diversity." Friedman visited The Land Institute while making a television documentary about how climate and environmental stresses helped trigger the Arab awakening. He interviewed Jackson and other institute scientists. The documentary will appear on Showtime next year.

Food writer Bittman featured The Land Institute in a column published October 23 under the headline "Now this is natural food." The piece is less opinion than a profile of our work, and relies heavily on an interview with Jackson. The Times Web site includes a video of the exchange, and footage from the institute's fields and Prairie Festival, where Bittman was a speaker this year.

Review praises Bill McKibben and The Land Institute's work

Verlyn Klinkenborg, of The New York Times editorial board, recalled his appearance as a speaker at The Land Institute's 2009 Prairie Festival in a portrait of Bill McKibben published in the October 24 issue of The New York Review of Books. Klinkenborg lauds McKibben's latest book, "Oil and Honey: The Education of an Unlikely Activist," and our work. McKibben spoke at the Prairie Festival in 2005.

Land Institute staff will speak in California and Georgia

Land Institute staff members are scheduled to speak January 18 in Grass Valley, California, and March 28 in Athens, Georgia. For more information, call 785-823-5376 or see Calendar at landinstitute.org.

One of the first reactors for synthesizing ammonia now stands as a monument at the German company BASF. The synthesis makes feedstock for fertilizer that has multiplied both the human population and the kind of nitrogen that can alter ecosystems. BASF photo.

N^n

How humans took a nutrient and their population to a new power, and how a new crop population will ease the economic and ecological costs

SCOTT BONTZ

One hundred years ago this fall, along the Rhine River at Oppau, Germany, industrial expansion of a tabletop experiment tapped the atmospheric commons and put to commercial use the most important invention of the 20th century. This invention is not something we drive, fly, program, or watch for entertainment. We explode things with it, but that is a sideline. It disrupts nature, but that is side effect. Its purpose is above all production. Not industrial production, though it requires industry and trainloads of fossil fuel. It is production of the most fundamental kind. And it has enabled us to reproduce like never before, an invention credited as essential to the existence of almost half of humanity.

What the Oppau factory did in 1913 was to take previously unused volumes of nitrogen from the air and synthesize the prime ingredient for nitrogen fertilizers. The process then spread around the world to hundreds of industrial plants. These organisms of tankage and piping distill nitrogen from the other atmospheric gases, split hydrogen from fossil fuels, usually natural gas, and bind the two elements as NH_3, ammonia, under heat to melt lead and pressure to crush submarines. In modern agriculture nitrogen fertilizer is by far the biggest energy sink. Cornell University researcher David Pimentel calculated that for US maize the nitrogen inlay is more than half again as much as for the farm machinery and diesel fuel to run it. World energy consumed to make synthetic fertilizer would power almost half of US gasoline vehicles. Until this synthesis, farmers planted legumes such as clover to replenish soil after they hauled away nitrogen in the protein of annual grains that make most of our food. Synthesized nitrogen curbed millennia-old crop rotations and fostered vast grain monocultures. It also evicted livestock from farms to feedlot: animal contribution to the nitrogen cycle was obsolete. Both shifts from diversity and dispersal to homogeneity and concentration raised risk of pests and disease.

The new, factory nitrogen went on to not only replace homegrown fertilizers, but to double the amount of useable nitrogen coursing through nature. Half of it goes to waste, just as can happen with organic nitrogen sources like manure, at least with the annual crops that monopolize grain agriculture. But now the in-volume is much higher, and so is the outflow. Some waste leaches through the soil and then down the river, leading to asphyxiation of rich sea ecosystems and fisheries. Some goes back to air as a potent greenhouse gas, or to double back in precipitation. We might yet know less of all the eventual effects, but these additions to the nitrogen cycle proportionally are much larger than the carbon infusions that grab climate change headlines.

The other half of the added "reactive" nitrogen, the half that is actually taken up by crops, helped humans to more than quadruple their population in a century, largely through the so-called Green Revolution: wheat, corn, and rice varieties grew less stem and better turned fertilizer into grain. This combination of chemistry and breeding was more fundamentally important to the world than the introduction of airplanes, nuclear energy, space flight, television, and computers, Vaclav Smil wrote in "Enriching the Earth." None of those inventions are critical for our wellbeing. But our building from 1.6 billion people in 1900 to 7.1 billion today came on the back of ammonia synthesis. Figures from the UN's Food and Agriculture Organization show that half of all this fertilizer feedstock has been produced since 1993. The upcurving lines of population and ammonia strongly correlate. Smil wrote in the magazine World Agriculture that with current diets, synthesized nitrogen fertilizers are necessary to secure food for nearly 45 percent of the world population, roughly 3 billion people. He projected that without change in diet or some other part of how we grow, move, store, and use our food, population growth over the next few decades will push that dependence to 60 percent.

Tim Crews said this Faustian share could be driven down, even to near zero. When Crews joined The Land Institute as research director a year ago, he already had explored soil nutrient cycles for more than two decades. He sees independence from ammonia synthesis if our food economy works nearer a natural economy: when it steers the nutrients off of a one-way street, from their origins to the sea, and instead into a circle. Most natural ecosystems consist of perennials of mixed species that cycle nutrients again and again. Tropical rainforests grow on what farmers would consider highly infertile soils, but Crews said they grow more than any other ecosystem on land. They are much tighter and more efficient than annual crops. Likewise are prairies. So The Land Institute works toward agriculture of mixed perennial grains.

Another step to independence would be by eating directly the source of those nutrients, plants, and cutting out the middleman, grain-fed animals. Livestock need several times the protein that they give us in meat. Smil's calculations here are 5:1 for chickens, 10:1 for pork, and 20:1 for beef. Milk is best among animal proteins, at 2.5:1, eggs next, at about 3:1. Crews is not a vegetarian. But he said industrial nations including the US eat more than twice as much protein as the FAO's benchmark, and far exceed it with servings of animal protein alone. North Americans could end the need for synthetic nitrogen to grow their food by scaling back consumption to dietary recommendations, and switching fields from feed grains to food grains and legumes. There are more steps, but even just this one would pull the synthesis plug and still keep us well fed, Crews said. The US and Canada, relatively land-rich and population-light, have that much slack.

Countries like China and Indonesia don't. Their people eat much less meat – though growing with its wealth is China's carnivory. China has about ¾ as much cropland but 4 times as many people as the US, so its farmers use twice as much nitrogen. In

Smil's wording, for such countries the dependence on fertilizer is existential.

Perennial grains will dramatically help curb nitrogen pollution in places like China, but won't solve their existential problem. Farms will send away just as much nitrogen to feed people, and still will not afford the space to restock it with legumes – even soybeans can be net nitrogen exporters. But a century ago the Chinese devoted themselves to repayment of nutrients to farms, sending back food waste and excreta from their homes and animals. If the same dedication were applied to the Green Revolution's high-yielding crops, Crews said, those crops could feed the Green Revolution's larger populations without synthetic fertilizer. The difficulty is that now so many fewer people live on farms, and cities are so much larger and distant from agriculture.

This break in the food circle comes after the food is eaten. The United Nations estimated that $^1/_3$ of harvested food and nutrients don't even reach our mouths. In developing countries more of the waste goes to pests, in developed countries more to garbage. Without these losses, there would be needed that much less cropped land and fertilizer. Smil lamented that for all of the many major institutions working to raise food production, there is none working to cut food waste.

The circle-closer in the field itself, for the soil, would be mixtures of perennials grains. The annual monocultures that have monopolized grain agriculture consume about $^2/_3$ of cropland and provide about $^2/_3$ of human calories. But soil under annual crops may leave that much or more of it unoccupied: their root systems are relatively small when plants live, and in fall are dead and wasting. Soil under a mixture of perennial species is deeply and thoroughly woven with roots that survive winter. In spring perennials sprout leaves earlier to better shield the soil from pelting and erosion, and to turn more sunlight and atmospheric carbon into life and food. Perennials in mixtures of diverse root architecture, together with the soil they build, can soak up 5 times more water than annuals, a study in Journal of Environmental Quality said. Authors led by G. W. Randall also said perennials can capture from the water 35 times more nitrate for building plant tissue, rather than let it slip away to pollute streams and aquifers. Less nitrogen fertilizer sprayed and cast onto fields means less greenhouse gas from burning fossil fuel to make the fertilizer, store it, move it, and use it. It means less fertilizer becoming the greenhouse gas nitrous oxide, and less reverted oxide and ammonia coming back to Earth to skew forest, grassland, and aquatic life.

Ending the need for nitrogen fertilizer before the end of the fossil fuel needed for its manufacture could mean heading off what at minimum would be great hardship. Eating nearer the protein source, cleaning the plate, returning deposits rather than flushing, and covering farmland with perennial grain mixtures that include legumes would lift our food economy much nearer nature's, which produces amply without fossil-fueled subsidies of nitrogen.

If you wanted nitrogen only for filling balloons, there would never be a shortage. The element, made billions of years ago by a star larger and with more fusing power than our sun, constitutes 78 percent of Earth's skin of gas. It is more than 3 times as common as the next component, oxygen. "But none of this huge store of atmospheric nitrogen – not a single atom of it – can nourish any plant or animal," Thomas Hager wrote in "The Alchemy of Air," his story of ammonia synthesis. While atmospheric oxygen readily burns, atmospheric nitrogen hangs tight. It so strongly resists reaction with other elements that scientists long thought it inert. In fact, the stability comes from triple bonding of atoms as N_2. Plants can't break this bond. Until 100 years ago, only 2 things could: lighting, and enzymes of a particular kind of bacteria, which live in, on, or around the roots of legumes and a few other plants, including sugarcane. (To learn of Land Institute research here, see page 6.) Once that bond breaks, small amounts of nitrogen can do big things.

It is carbon that makes up nearly half of living matter, not counting its water. In an adult human body there is only about 2 pounds of nitrogen. But nitrogen is crucial to the workings of every organism's every cell: in the chlorophyll that turns sunlight into the energy of the living, in the nucleotides of nucleic acids, which make the genetic code of DNA and RNA, and in the amino acids that make all proteins, including enzymes, which control biochemistry. When plentiful the element makes for vigorous growth and deep green leaves. It also builds big and protein-packed grain seeds. In "The Uniqueness of Biological Materials," Arthur E. Needham said that every vital phenomenon comes from a change to the nitrogen in a nitrogen compound.

For millennia Chinese, Japanese, and Korean farmers did not put it in these words, but in practice recognized how hard it was to get and keep nitrogen in useful form. They recycled virtually everything. American F. H. King visited and studied this dedicated life in 1909, and wrote about it in "Farmers of Forty Centuries." He saw that Japanese governments granted subsidies to encourage composting, and gave prizes for the best compost heaps. Each day carts hauled human manure from city to country, returning nutrients to farms. Farmers did not just take the "night soil," they paid for it. King said it went back to fields at annual rates up to almost 2 tons per acre. In this and other areas of their living, including energy-conserving dress, eastern Asians impressed the American with their "intense individual economy, extending to the smallest matters." He said that by their extensive use of legumes, their crop rotations for green manure to maintain the humus of soils, and "the almost religious fidelity with which they have returned to their fields every form of waste which can replace plant food removed by the crops, these nations have demonstrated a grasp of essentials and of fundamental principles which may well cause Western nations to pause and reflect."

Until even after World War 2, much of agricultural energy in the West also went to organically attaining and cycling nitrogen. Farmers rotationally planted large portions of their fields to legumes, at the cost of lower yields than with grains, and a more complicated route of getting crop from field to plate. This included hauling stalks to livestock beds for winter, then back to field, enriched, in spring. You can still find antique manure spreaders. But Western farmers didn't return everything, and the plow-up of the New World drew down soil capital while increasing human population. Early in the 19th century American and European farmers began importing fertilizer, from a place as dry, remote, and volatile as Arabian oil fields.

Off the coast of Peru are islands amid waters rich with life. This wealth draws birds, which make guano that packs as much as 30 times more beneficial nitrogen than does barnyard manure. The birds roost on the islands, where there is almost no rain, and at the richest roost, the Chinchas Islands, they piled guano 10 stories high.

Indians paddled from the mainland to collect it for their corn. They ranked it with gold, Hager said, called the islands holy sanctuaries, and made killing a seabird there a capital crime. Then German explorer Alexander von Humboldt brought home a lump. Tests showed it extraordinarily high in phosphates and urea, a nitrogen compound. “If ever a philosopher’s stone, the elixir of life, the infallible Catholicism, the universal solvent, or the perpetual motion were discovered, it is the application of guano in agriculture,” Farmer’s Magazine told American growers. By 1850, acre for acre the Chinchas were the most valuable real estate on Earth. That year President Fillmore’s state of the union to the still largely rural nation addressed guano. Hundreds of thousands of tons annually sailed to the US and Britain. “Farmers, despite steadily rising prices, found it difficult to do without it,” Hager said. A decade later began the powerful and enabling parallel for mined and imported fertilizer: development of oil and natural gas. Meanwhile, guano miners were essentially kidnapped from China and made slaves, working on meager diet in lung-searing dust of excreted ore. For a few years the riches of their labor supplied most of Peru’s national budget. Then, in less than 2 decades of carting off 11 million tons that had accumulated for millennia, the miners in the Chinchas began to hit rock, and the state was practically bankrupt.

“The guano mania of the 1850’s bore an amazing similarity to the situation in the world crude oil market of the 1970’s,” Smil said: rising prices heavily influenced by a few producers, fear of resource exhaustion, attempts at price controls, and US intervention. In 1856 Congress passed the Guano Islands Act, which allowed Americans to claim any unoccupied, nitrogen-rich island. Secretary of State Daniel Webster tried for rocks off Peru, but riots and troops in Lima forced the US to back down. After many fraudulent claims were laid, to islands already occupied, already owned, or nonexistent beyond the minds of drunken sailors, the nation finally staked out under the act 94 dry spots scattered across the Pacific and the Caribbean. None yielded good guano. But some went on to serve military use, and 8 in the Pacific, including Midway, still belong to the US.

What did fill in for Chinchas guano was another dry, desolate, South American deposit. This one contained almost all of the world’s naturally occurring sodium nitrate, in a narrow strip a few hundred miles long at the western edge of the Atacama Desert. The mineral not only made good fertilizer. With chemical tweaking it became compounds for gunpowder and new explosives like nitroglycerine and dynamite. It was valuable enough that over this desert sliver Peru and Chile fought a war. After Chile won, Hager said, “It would be as if, today, a single nation controlled all of the oil wells in the world.”

The US used almost half of its Chilean nitrates for explosives, to build railroads, dig mines, level roads, and cut the Panama Canal. The rest largely went to bolster yields from Manifest Destiny’s waves of grain, amber but still annual and losing soil and nutrients. Nitrate was even more crucial for the long-cropped soils of Europe, and especially for Germany, which lacked coffer-filling colonies like those of Britain. For the nitrate trade Germany built some of the world’s largest, fastest sailing ships, and by 1912 it was the largest nitrate importer, buying twice as much as the US. By then it also was on the cusp of its revolutionary technical effort for agricultural independence, wealth, and power – after dire challenge from a Briton 14 years earlier, and a century

A Land Institute crew plants seeds of wheat crossed with perennial relatives. At left, Sheila Cox takes packets of seed from individual see spreads the seeds in a dispenser. They are planted over a discrete 3-foot span. Each parent plant's offspring then can be evaluated for sel Perennial wheat will transform how that land conserves soil and nutrients, including millions of tons of nitrogen fertilizer, about half of

d heads to feed into the planter. At right, Kevin Kruse ection. Wheat takes more land than any other food crop. which annual crops waste. Scott Bontz photos.

after compatriot Thomas Malthus said humans would outstrip food production and starve.

New land and farming advances had largely put off Malthus's pessimistic forecast. But by 1898, William Crookes, incoming president of the British Academy of Sciences, predicted that in about 3 decades humans would begin dying of hunger in large numbers. He had examined agriculture yields, and found them always lower than with original soil fertility, no matter how good the farming and recycling after a plow opened a natural economy's veins. He saw how population growth during the 19th century from 1 to 1.6 billion was matched by expansion of cultivated land. There was no longer enough virgin field for a 20th century sequel. He saw what had happened with Peruvian guano, and forecast the same for Chilean nitrate. "We are drawing on the earth's capital, and our drafts will not be honored perpetually," he said. Here is a recognition underlying The Land Institute's work. Now the view is much clearer, and clear to many more, than in the days of Crooke's prophesy – even if still not to economists. But The Land Institute seeks a solution working like whole, natural ecosystems. Crookes narrowed his fix to chemistry.

He called for ways to make chemical manures, in factories. He said this was the great challenge of the time. "It is the chemist who must come to the rescue," he said. "Before we are in the grip of actual dearth the chemist will step in and postpone the day of famine to so distant a period that we and our sons and grandsons may legitimately live without undue solicitude for the future." Crookes's idea was not new. People had tried to turn atmospheric nitrogen into ammonia for 100 years. But it was only after his challenge and the turn of the century that knowledge and technical ability were enough for a final, ambitious kick for success. The rescuer was indeed a chemist. But he also saw that for keeping soil fertile, someday nature might show a solution not so crude, and which worked better.

Fritz Haber led an itinerant academic and early professional life, drifting from one mentor and university to another, and then among businesses, including his father's dyestuffs and pigments company.

In 1892, when the younger Haber was 23, a cholera epidemic struck Hamburg. The only treatment found effective was with chloride of lime. Siegfried Haber and Company sold the compound, and Fritz persuaded his father to buy large amounts in anticipation of demand and profit. But the outbreak was confined, and, as Morris Goran wrote in "The Story of Fritz Haber," Siegfried told his son, "Go to a university. You don't belong in business!" Still, son convinced father that natural sources for dyestuffs would be made obsolete by "materials made in test tubes and retorts" – synthetics.

The young scientist finally found a home at Karlsruhe technical college. He became an admired teacher and a pioneering researcher who published not just papers but influential chemistry books. In 1902 the professional Bunsen Society picked him to tour and report on US universities and factories. Goran said Haber saw the training of American chemists as practical and superficial – and that American educators agreed. He found Americans themselves enterprising and courageous.

In Germany, even before Crookes's speech, a large corporation called Badische Anilin- & Soda-Fabrik had begun pursuing ammonia synthesis. Germans feared the British navy could blockade their supply of Chilean nitrate. BASF broke nitrogen's triple bond with the lightning heat of an electric arc like a welder's. But even with relatively inexpensive power from new hydro works, this did not prove economical.

Another synthesis route was tried by Wilhelm Ostwald, the father of physical chemistry, and who had turned down Haber for work. Instead of "burning nitrogen out of the air," as Hager put it, Ostwald tried a chemical method of merging nitrogen and hydrogen with less heat, plus pressure, supplied in his test with a bicycle pump, and with a catalyst, which would encourage a chemical reaction without itself being consumed. Higher pressure brings molecules nearer, increasing the chance of sticking to a catalyst, where they can react. This was in 1900, and Ostwald was a leader in the new field of catalysis. For catalyzing ammonia synthesis he settled on common flower wire. With the right balance of temperature, pressure, and catalyst, and with quick cooling of the result, he got ammonia. Then he won a patent, and offered to sell it for a million marks. BASF sent a young chemist named Carl Bosch to investigate. Bosch concluded that the ammonia resulted from the machine's contamination. Ostwald indignantly attacked the upstart, but finally withdrew his patent.

Haber's role began in 1904 as consultant for an Austrian company. He found that the heat required to break the nitrogen bonds also destroyed the resulting fragile ammonia. Cooling attempts got him no more than a trace. He notified the company and moved on. But as a scientist, he also published results. This brought embarrassment that spurred him to try again.

At the time, Walther Nernst, Ostwald's protege, was developing a theorem that would come to be called the third law of thermodynamics, and help him win a Nobel Prize. Comparing his math with the measurements of other scientists, he found Haber's meager ammonia claim still too high. Nernst entrusted an assistant to replicate the synthesis attempt, though with variation including, for higher ammonia concentration, pressure 50 times that of the atmosphere. Adjustment gave results close to Nernst's theoretical prediction, and only about a quarter of Haber's finding. Nernst told Haber in writing. Haber repeated his effort, again only at atmospheric pressure. This time he had a new assistant masterful at making lab equipment, an Englishman named Robert Le Rossignol. They published corrected results much nearer and supportive of Nernst's theory, though slightly above prediction. This was still too high for Nernst.

At a chemical society meeting in 1907, he publicly attacked Haber for "strongly inaccurate" results and demanded their withdrawal. Smil called this assault puzzling: Haber had publicly corrected his old figures; his new figures agreed with Nernst's theorem even better than did Nernst's own results; and contrary to what Nernst suggested, Haber inferred that ammonia synthesis was not feasible. Whatever the reasons of Nernst, one of the world's most respected chemists, the result was hard on Haber, a newly appointed professor. He felt damage to his reputation. His wife, Clara, wrote of him suffering emotional upset, indigestion, and skin problems.

Haber sought relief through vindication. He and Le Rossignol prepared experiments that were more careful, and this time used a pressure of 30 atmospheres. Results confirmed their previously revised numbers. They also showed the advantage of pressure forcing atoms together: the ammonia yield was 28 times higher. The higher they raised the pressure, the lower they could drop the temperature, and the more ammonia stayed intact. But higher pressure was costly. What they had would not yet pay. They sought a better catalyst to help raise the conversion rate with less energy. They played for the optimum balance of pressure, temperature, and catalyst. They refined and improved their little machine for months, with Le Rossignol making special valves and other gear to handle pressures up to 200 atmospheres. There was no great breakthrough. But through patience and perseverance the small gains added up. In early 1908 the men were happy enough with results, and convincing enough, to make a deal with BASF for more research funding in return for commercial rights that included a cut for Haber.

A year later the scientist and his assistant could shout eureka. They had scavenged from a light bulb element a bit of the metal osmium. Using it as the catalyst, they saw the ammonia yield jump. Haber advised BASF to corner the osmium market. The company didn't even know how much of the scarce element existed, and could not yet tell how long it would last. Executives hopefully thought that more trials would find a better material.

But some were horrified at the pressures Haber required, many times the 7 atmospheres that had recently blown up a BASF autoclave. Haber and Le Rossignol's pressure chamber was drilled from a block of solid quartz that could fit on a lab bench. BASF would need reaction chambers filling a room and fashioned from metal. Nothing near this had been done. BASF consulted Carl Bosch, the chemist who had deflated Ostwald, and who was also expert with tools and knew the German steel industry. He concluded, "It should be risked."

On July 2, 1909, Bosch and another BASF chemist, Alwin Mittasch, went to see Haber demonstrate proof of his claim. The company needed a device that worked reliably 24 hours a day. Its men arrived to find Haber's crew scrambling to fix a leak. A connection had been over tightened – an inopportune mechanical failure that Germans call *Tücke des Objekts* – the spite of things. While repair dragged on, Bosch left for another appointment. Mittasch stayed. After several hours, he finally saw the machinery warm up, pressure and temperature attained, gases flow, and ammonia begin to drip. He is said to have pressed Haber's hand. They watched the accumulation and chatted about chemistry for 5 hours. There was no hitch. With the time late and the men tired, Haber shut down the machine.

They calculated the production rate. Between 6 and 8 percent of the nitrogen that went in one end as N_2 emerged as NH_3, to make half a cup of ammonia per hour. Haber told BASF that catalyst space could be used much more fully and output made much higher. It was – though the economic optimum today still sees in each pass through the reaction chamber only about 15 percent of the nitrogen "fixed," and unreacted gas sent back through.

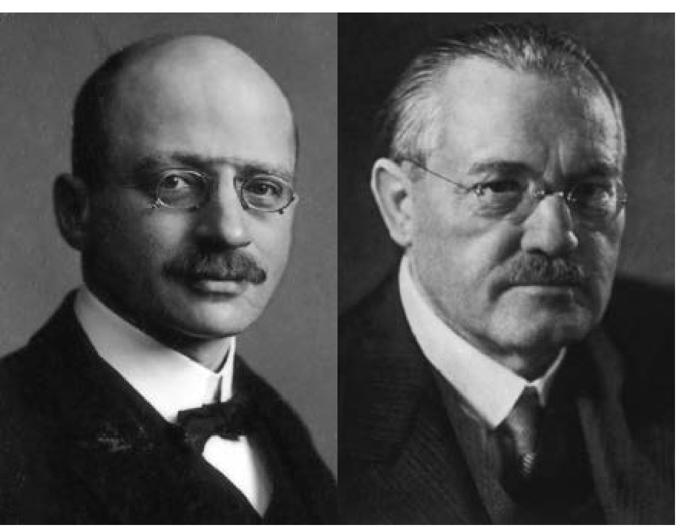
Mittasch returned to BASF convinced that when ramped up Haber's process could compete with nitrate, relieve Germany of dependence on Chile for fertilizer and gunpowder, answer Crookes's challenge, and give BASF dominance of a growing world market. Smil compared the demonstration in Haber's lab to "that special group of discoveries," including Edison's light bulb and the Wright brothers' flight, for which the breakthrough date is pinpointed. Hager wrote, "The demonstration was a small machine producing a small amount of ammonia for a small group of men. But it marked a turning point in human history."

Other chemists could have won claim to invention of the synthesis. Ostwald's misinterpretation of experimental results in 1900, an explosion the next year in the lab of Henry Louis Le Chatelier, and Nernst's opinion that yields were too low to justify development: disappointment led each man to abandon his work. Only Haber – under Nernst's attack – pressed on after early setbacks and finally succeeded. Some scientists might enjoy more credit for a breakthrough, but all build to that point only on the work of others. "Haber was well aware that it was his privilege to take those last few steps on a long path to a major discovery," Smil said. He called modern science "a cooperative enterprise par excellence."

Haber concluded his deal with BASF, emptied his brain for Bosch, and left to him and the company the transformation of lab science into an industry and commercial success. With his reputation much improved, he left the technical college in Karlsruhe to lead chemistry work at a prestigious new institute near Berlin.

Bosch's challenge was arguably bigger than Haber's. He had to be not just a good chemist, metallurgist, and mechanic, but a master coordinator. He had to build a complex flow subject to full arrest with a breakdown at any point. The plant at Oppau had compressors the size of locomotives, miles of pipes, a rail yard, and a research lab with 180 chemists and 1,000 assistants. "Bosch was creating a single machine as big as a town," Hager said. One example of the problems that he faced: months of failure by steel tanks under pressure, and months of metallurgical autopsies. Smil described Bosch's solutions, which included a sacrificial, changeable liner, and small holes to release safe amounts of hydrogen. Hager told how Mittasch ran 20 machines at a time for 20,000 tests of catalysts common and exotic. He found Ostwald had been on the right track with the flower wire: iron complemented with aluminum oxide and calcium worked as well as osmium, and at a fraction of the cost. Haber wrote to Mittasch about this: "But it is remarkable how in the course of things new special features come to light. Here iron, with which Ostwald first worked and which we then tested hundreds of times in its pure state, is now found to function when impure. It strikes me again how one should follow every track to its end."

The books cited here illustrate more of Bosch and Haber's achievements, such as how Bosch not only built on Haber's invention, but also led refinement of extracting hydrogen for the synthesis without producing much dangerous carbon monoxide. Smil's writing is the most technical, but not all academic. Hager, Goran, and Daniel Charles, in "Master Mind," work more as storytellers, and focus on the full but tragic life of Haber: a man born a Jew but above all a German; whose chemist wife shot herself in the heart with his pistol while he pioneered chemical weapons in hopes of shortening World War 1 – a war that his synthesis prolonged by supplying nitrate for gunpowder and explosives; a repeated scientific success though failed in his attempt to extract gold from seawater for payment of Germany's crippling war reparations; a versifying renaissance man; a beloved and esteemed teacher and institute leader; a man whose career was ruined by the Nazis despite his war effort, for which he received the Iron Cross, and despite his invention.



Fritz Haber, left, credited with achieving economical synthesis of ammonia for fertilizer, and Carl Bosch, who brought the process to commercial scale.

A little more than four years after Haber's convincing lab demonstration, 15 months after construction began, and a little more than a month after opening, Bosch's plant at Oppau was producing each day more than 10 metric tons of ammonia. It eventually tripled that output. Now plants can make about 2,000 tons a day, at 4 times the energy return. With these gains has come nitrogen fertilizer use 10 times that of half a century ago. Smil calculated that synthetic ammonia supplies at least 60 percent, and commonly 70-80 percent, of the nitrogen reaching intensively farmed fields.

Haber and Bosch – the synthesis of ammonia is called the Haber-Bosch process – can be credited with saving the lives of millions, and with making possible billions more. The men also are blamed for millions of deaths because their process fed not just fertilizer but weaponry. When, after repeated nominations, in 1919 Haber won the Nobel Prize, French and American winners protested. But the Nobel committee felt the synthesis was a great advance for the world toward plenty and peace, and could not be ignored for political reasons. Twelve years later they honored Bosch for his role. Smil said, "Haber-Bosch synthesis of ammonia removed the limits on nitrogen supply that had constrained all traditional agricultures." It fueled an agriculture that supplies 4 times as much protein as had been possible under the most intensive traditional agriculture – which with its managed legumes already exceeded by 4 times the production from continuously cropped but unfertilized fields. Haber-Bosch also allowed post-war regrowth of forests in Europe and North America. Without it, more forests, grasslands, and wetlands in poor countries might have become grain fields. But these are marginal lands, and sacrificing them to farms would not feed the world.

Nitrogen is essentially unlimited, and conservation of fossil fuels could deliver hydrogen and energy to make ammonia for hundreds of years. But adding so much reactive form of a usually staid element's passage through the planet's soil, air, and water already causes wide damage, and though this cycle's complexity makes precise forecast difficult, raising the nitrogen pileup, or even only sticking to the current rate, will surely spring greater ecological disruption. A study reported in the journal Nature identified reactive nitrogen as one of nine key global pollution threats, and second worst in terms of having already exceeded a maximum "planetary boundary." Smil called it an "unprecedented large-scale experiment."

The nitrogen atoms originally so hard to break up and combine with other elements are after synthesis quick to dump them and find new partners. Only complete "denitrification" of a compound to the original N_2 has no undesirable consequence. Smil calculated that about 30 percent of lost fertilizer nitrogen takes this route. About a quarter erodes with soil.

Some 20 percent leaches away as nitrates, combinations with oxygen that make the nitrogen so useful to plants, but, when accumulated in water, deadly to other life. Enough nitrates in drinking water chokes oxygen from the blood of infants. Governments in the Midwest, America's breadbasket, and the central valley of California, its fruit and vegetable leader, struggle with nitrate treatments that cost millions. Even if farmers stopped all fertilizer use today, the contamination would last decades. Concentration of nitrates in the most affected European rivers, including the Thames and the Rhine, are 100 times as high as the mean of unpolluted streams. Nitrate levels in the Mississippi have quadrupled since 1900. Nitrates at its mouth bring

John Mai prepares hybrid wheat seedlings for a process to double their chromosomes. This allows for more successful crosses with a perennial species that has roots many times better than annual wheat at capturing nutrients including nitrogen. Scott Bontz photo.

blooms of microorganisms and then oxygen starvation over an area as large as New Jersey. Dozens of other coastal areas around the world suffer these "dead zones."

The last quarter of nitrogen lost after synthesis takes to the air as ammonia, nitric oxide, and nitrous oxide, a gas only about one-thousandth as abundant as carbon dioxide, but about 300 times as potent, and now responsible for about 6 percent of anthropogenic greenhouse gas effect. Precipitation also takes some of these reactive gases back to Earth's surface, and here costs so far are less clear.

Known is that the "depositions" are immense. Parts of natural lands in eastern North America, northwestern Europe, and eastern Asia can receive as much nitrogen as what a North Dakota farmer intentionally applies to a crop of spring wheat. For most forests such rates are 10 times higher than preindustrial means got by nitrogen-fixing bacteria and lightning. If this new nitrogen feeds more growth, plants also will use more carbon to build tissue, and reduce global-warming carbon dioxide. The high end of sequestration could balance the carbon losses resulting from modern land use changes, Smil said. But we don't know how long the benefit will last, and plants can fill only so much space with carbon. Eventually supply will pass demand, and then more nitrates will go to water, more nitrous oxide to air. More carbon will stay there. Meanwhile, nitrogen-fixing species will become less competitive and retreat. Trees might become more sensitive to water stress and nutrient deficiency. Soils might acidify. In areas adapted to little nitrogen, the element's rise might favor nitrogen lovers and drive other species or whole plant communities to extinction. Declines of plant diversity already have been seen in North American grasslands and European heathlands and forests.

Farming drove out species from the start. But until Haber-Bosch, or at least until riches like Peruvian guano, farms still needed to home-grow their nitrogen. This demanded crop diversity including forage legumes like alfalfa, and a tight link with livestock. Crews, The Land Institute's research director, said it was typical for farmers to keep a quarter to half of their land in a legume-rich pasture or cover crop. This biologically fixed the nitrogen and slowly built nutrients weathered from plants. But it got farmers few commodities. "The introduction of nitrogen fertilizers presented an alternative to legume rotations that were expensive in both labor and land," Crews and M. B. Peoples wrote in the journal Agriculture, Ecosystems & Environment. Haber-Bosch let farmers ditch the legumes, leave the animals to adoption by feedlots, and plant more staple food crops.

This led to what Smil said might be called "dysfunctional nitrogen cycling." Increasing amounts of fixed nitrogen moved not only within countries, but also around the world. Not just individual farms, but entire regions ceased to sustain themselves as wholes. Though the staple grains could feed more people, unlike the forages they were all annuals, which opened the soil to erosion, and the nitrogen to loss. Crops came to be grown in vast monocultures, often year after year, which exposed them to more disease and pest risk. Similar risk and antibiotic solution came to large animal monocultures, which piled up vast piles and pools of nitrogen too far away for return to the original grain fields.

Human dumping of nitrogen on the living-world market has won little attention compared with the press for how we bring acid rain and climate change by disrupting sulfur and carbon cycles. But while carbon dioxide in the air has climbed about a third above when Watt's steam engines began burning coal, in a fraction of that time the amount of reactive nitrogen lost by plants to air has tripled, and now accounts for about half of all such life-changing nitrogen coursing over the land – twice the natural amount. Some of this volatile exhaust comes from automobiles and power plants. But the player several times greater than each is Haber-Bosch.

Industrial powers have already greatly cut emissions of sulfur dioxide, and technical solutions could reduce them from the current rate to a fraction. With political will, economic and technical means also could vastly cut carbon dioxide emissions. But there is no way to grow crops and human bodies without fixed nitrogen, and no bioengineered substitutes for Haber-Bosch. Japanese scientists are exploring a titanium catalyst for synthesis without high heat and pressure. American scientists are testing a catalyst of industrial diamond. Success would chop the energy bill for ammonia synthesis, now estimated at 1 to 2 percent of human energy consumption. But only 40 percent of the natural gas used in synthesis is to fuel the process. The rest is feedstock for the hydrogen, and that would not change. So the new catalysts would not save us from running out of gas. They also wouldn't address any of the problems of adding to soil, air, water, and natural workings more nitrogen pollution. That will take nitrogen conservation, going after leaks, drawing a circle.

One small step would be to run more soil tests, and then make application of fertilizer more tailored and discreet. But the farmer still won't command rain to fall at the right time and rate to keep nitrogen from wafting or washing away. With the relatively short-lived ground cover and roots of annuals, the most efficient cropping still loses 30 percent of applied nitrogen. Study of 30 systems found 2/3 lost more fertilizer than they used.

Mixtures of perennials, which account for the large majority of natural vegetation, can cut the loss to near nil. "Everything else being equal, leaching from bare, fallow, or freshly ploughed soil is much higher than beneath row crops, which, in turn, is considerably higher than from soils under such dense cover crops as legume-grass mixtures whose roots can take up large amounts of nitrogen," said Smil, who is not working on perennial grain crops and needs no disclaimer. "The single most important land management factor is the presence and quality of ground cover." If we want to cover as much ground as well as possible, we will need perennial grains.

The Nobel Prize Web site lists the 10 most popular laureates in chemistry. Even in the centenary season of their achievement, an Earth-changing event if ever there was one, neither Fritz Haber nor Carl Bosch appears on that list. But their achievement shows each day on your plate. When perennial grains come to that plate, it will be very unlike Haber-Bosch – not a makeshift injection of fossil energy, with an equal serving of waste, much of it ecologically disruptive. It will be by making agriculture work more like a natural, self-sustaining economy. And for this, Haber's Nobel acceptance speech conclusion was remarkably insightful and fitting. "It may be that this solution is not the final one," he said. "Nitrogen bacteria teach us that Nature, with her sophisticated forms of the chemistry of living matter, still understands and utilizes methods which we do not as yet know how to imitate."

Doubt and hope

Prairie Festival thoughts about reinventing the human economy

SCOTT BONTZ

A young man on the edge of a crowd filling a barn-turned-lecture hall asked the speaker to address the prospect of a radical shift in modern history: a generation of people, his generation, facing a lower standard of living than what their parents enjoyed. "Nobody asked for it, but this is what we have," said the woman on the plywood podium, Lisi Krall. "Because you're under 30, you have no choice." Krall is an economist who argued not for capitalism's reform, but its complete replacement with something more far-sighted. She called the market economy bound to fail and, by damage to Earth, already broken. She likened modern humanity's dependence on economic growth to drug addiction, and earlier in her talk at The Land Institute's Prairie Festival she had said, to applause, "Our economic denial is far worse than our climate denial." Krall told the young man that every generation has its historical moment. "And this is yours."

Speakers at the September festival had been asked to talk about meeting human needs in a declining economy. The young man's question later struck speakers enough for them to make off-script references to coming letdowns. But they, and audience members, also were hopeful.

John Fullerton, who succeeded with derivatives on Wall Street before quitting in 2001 to pursue what he calls regenerative capitalism, spoke casually and assuredly, cup of water in hand, until telling of a road trip where he interviewed his aged father about life. Then Fullerton's voice quavered. His father kept talking about his naval service in World War 2. Fullerton thinks this was because the conflict brought to his father a powerful sense of purpose. Fullerton was too young for Vietnam, too old for Iraq, and is now a father of three, all under 30. He said we are headed into the equivalent of war. "Those of you under 30, your sense of purpose is going to change real fast." He thought that this recovered sense would be for the better.

Some of the nearly 800 festival-goers doubted that people will curb their consumption and lower their standard of living, as currently measured, until forced by shortage and collapse. Speakers called for more equitable sharing of world resources, and Kistie Bunsell of Lawrence, Kansas, said this would be ideal. But she also called it almost impossible to persuade a majority to act. Enid Cocke, of Manhattan, Kansas, has lived in progressive, wealthy countries like Denmark, but even from Danes she didn't expect political pre-emption of hardship.

Some in the festival audience looked for dramatic elective change, even if only at a tipping point of collective consciousness. "I don't know how it's going to happen, but I think it's going to happen," said Lane McDonald, a marine biologist from

"The more you talk about wild and crazy things, the more you live into them. And it's not so bad."

Presbyterian minister Martha Murchison

Bonita, California. "I can't believe that we would choose otherwise." Donna Sandberg of Smolon, Kansas, said the forecast of irreversible economic decline did not leave her feeling down, because the festival brings together hundreds of the concerned and like-minded. McDonald, who has been attending Prairie Festivals for a quarter-century, said, "After a revitalizing of spirit we can all return to our respective corners of the country to contribute to the movement toward sanity."

This was Amy Halloran's first Prairie Festival. But she said, in a follow-up e-mail, "The limits of a growth based economy have been obvious for almost a hundred years in my burnt-out industrial city. Troy, New York, started bleeding garment jobs in the 1920's, and the GI housing bill deepened the wound by inviting people to live elsewhere. I've wondered if art or agriculture could rebuild the engine of my city. But rebuilding is not what we need: we need re-vision." She said she had great optimism for social change, based on thoughts of festival speakers: Stan Cox on why rationing is needed and how it could work; Tim Crews on the importance of recognizing how important is not just local food, but local soil nutrients and their recycling; and Sandra Lubarsky on how recognition of beauty could fundamentally change economics.

Festival speakers' radical critique of market capitalism, and even Jeffersonian ideals of individual liberty and property, would have upset Martha Murchison four years ago. The Presbyterian minister in Salina still likes things as a consumer. But she has turned around her understanding of economic good, and now participates in a local group aiming for greater economic resilience – a group whose members at a recent meeting marveled at how even Salina city commissioners had come to see the importance of checking growth. "The more you talk about wild and crazy things, the more you live into them," Murchison said. "And it's not so bad."

Another audience member, Noni Strand, pursues this by pioneering a sustainability minor at Bethany College, a small Lutheran liberal arts school south of The Land Institute. Students must take classes from across a wide range of disciplines, which can include economics, biology, and art, and at the same time attend Strand's four-semester integrative seminar covering cosmology, systems thinking, justice and sustainability, and importance of place. Students also participate in hands-on projects such as whether to install wind turbines on campus. Strand, the school's chaplain, wants students to live more attentively, to make decisions more intentionally, to see Earth as a whole system, and to be agents for change. "We need to rethink our whole existence," she said. Without a new education, "How in the world can we expect them to do anything different?" She promotes the sustainability minor, with seven students in its first full, post-pilot year, as a deep calling. She said, "We cannot not do this."

The energy of young people impresses Julene Bair, of Longmont, Colorado, and author of the upcoming book "The Ogallala Road: A Memoir of Love and Reckoning." Still, she expects ungovernable circumstances to play a big role in revision of humanity's course. We can make many improvements to avoid filling post-fossil fuel gaps with human slavery, as portended by festival speaker Crews, but Bair foresees economic change having human consequences. Including end of travel to the Prairie Festival.

For recordings of the festival talks, see page 29.

Audience at The Land Institute's Prairie Festival listen to Wes Jackson's David-versus-Goliath comparison for changing the economic system. Scott Seirer photo.

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_______	Progress report and artist's talk	Scientists, Philip Heying
_______	Is There a Ration Card in Your Future?	Stan Cox
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_______	Will Becoming Local Here Get Us There?	Tim Crews
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A stone house built in the 1880's is on 65 acres of pasture and woods donated to The Land Institute near the University of Kansas. For more, see page 6. Photo by Philip Heying, www.philipheying.com.