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The Future of Agriculture and Society in Iowa: Four Scenarios

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Abstract

Iowa is a leader in crop and livestock production, but high productivity has had concomitant negative environmental and societal impacts and large requirements for fossil-fuel derived inputs. Maintaining agricultural productivity, economic prosperity, and environmental integrity will become increasingly challenging as the global demand for agricultural products increases and the fossil-fuel resources needed to produce those products becomes increasingly limited. Here we present four possible scenarios for Iowa in 2100 based on combinations of differing goals of the economy (high material throughput versus improvement of human and environmental welfare) and differing energy availability and cost (high versus low). In scenarios with a focus on high material throughput, environmental degradation will be exacerbated and social unrest will increase. In scenarios with a focus on human and environmental welfare, current environmental damage will be ameliorated and societal happiness will increase. Movement towards a society focused on human and environmental welfare will require changes in the goals of the economy in addition to complementary governmental policies, whereas no major changes will be needed to continue to focus on high throughput as an economic goal. When energy sources are readily available and inexpensive, the goals of the economy will be more easily met, whereas energy limitations will restrict on the options available to agriculture and society. Our scenarios are not predictions of the future, but can be used as tools to inform people about choices that must be made to reach more desirable futures for Iowa and similar agricultural regions.

Key words: agricultural productivity; ecosystem services; energy availability; Genuine Progress Indicator; scenario planning; systems thinking

One of the most pressing challenges for agriculture in the 21st century is the need to produce adequate amounts of food and farm income while protecting environmental quality and the health of rural communities. This challenge is especially apparent in Iowa, which lies in the heart of the United States Corn Belt. With fertile soils, adequate rainfall, abundant agricultural technology, and 85% of the state's land area devoted to farming, Iowa leads the United States in the production of corn, soybean, ethanol, eggs, and hogs[1]. Sales of billions of bushels of grain, billions of gallons of ethanol, billions of cartons of eggs, and millions of pounds of pork generated nearly $25 billion in farm revenue within the state in 2008[1,2].

Concomitantly, Iowa also ranks high nationally in the number of surface waters impaired by excessive concentrations of nutrients, pathogens, pesticides, and soil sediment, and its croplands are major contributors to the hypoxic zone in the Gulf of Mexico[3-5]. Iowa ranks last among the 50 states in the amount of original vegetation still remaining, and not surprisingly, the diversity and richness of the native flora and fauna have been greatly reduced[6]. Despite abundant production of crops and livestock, Iowa farmers received $3.8 billion in federal commodity program payments during 2003-2005[7]. Seventy-five of Iowa's 99 counties lost population between 2000 and 2008[8], and 42 of its counties have per capita income levels <80% of the national average[9].

The challenge of maintaining high levels of agricultural productivity, economic prosperity, and environmental quality is likely to become more difficult in Iowa in coming decades as volatility in the price and supply of fossil fuels increases. Conventional, industrial farming in the Midwestern United States is heavily reliant on fossil-fuel inputs embodied in synthetic fertilizer, machinery fuel, and natural gas used for grain drying[10-12]. Prices of these inputs have become increasingly volatile as the market for petrochemicals has become less stable, and over the longer term they are expected to rise. This rise threatens farm profitability, but it has also increased interest in and production of alternative sources of energy, including wind and biomass, for on- and off-farm use.

Using Scenario Planning for Iowa

Iowa thus presents the opportunity to develop a case study of the interactions among high agricultural productivity, environmental conservation, and societal wellbeing. In order to examine the interactions among agriculture, the environment, and society, we used scenario planning, which is part of a branch of science known as "futures studies"[13-17]. In scenario planning, scenarios are developed that are "… plausible, challenging, and relevant stories about how the future might unfold, which can be told in both words and numbers. Scenarios are not forecasts, projections, predictions, or recommendations. They are about envisioning future pathways and accounting for critical uncertainties"[18]. Scenario planning allows integrated pictures of plausible futures to be created in order to better understand the choices available to society. In this study we created four alternative scenarios for the agricultural landscapes of central Iowa as a way to frame and explore choices and trade-offs.

The four scenarios were created to illustrate how the intersection of two different key factors, the availability and cost of energy and the way the economy is framed, has the potential to lead us towards very different futures. Agriculture and society in general rely heavily on inexpensive and readily available energy, and major disruptions in energy supplies have can have dramatic effects, such as the oil crisis in the United States in the 1970s[19]. Understanding the way that the economy is framed includes understanding both the explicit goals and implicit assumptions of the economy. One explicit goal of the current United States economy is to have continuous economic growth, as measured by the gross domestic product (GDP). Implicit in this goal is that continuous economic growth is possible. In order for continuous economic growth to be possible, the material resources for the production of goods and the storage or elimination of wastes must be unlimited or completely substitutable[20]. An alternative goal of the economy is to increase human wellbeing through increased development without having the economy expand beyond the Earth's capacity to provide material resources and store or eliminate wastes[21]. An assumption in this goal for the economy is that the Earth is a closed system, and as the human population and economy grow we are extracting resources and producing wastes at a rate greater than can be continued indefinitely[22].

Here we present four plausible scenarios for Iowa in 2100 based on combinations of differing economic goals and energy availability and cost (Figure 1). In Scenarios 1 and 2, the goals and structure of the economy are organized to emphasize and facilitate high material throughput, which is the extraction of natural resources, their transformation into market goods by production, and their disposal as waste. However, in the first scenario, energy is available and low cost; in the second scenario, the energy supply is constrained and is high cost. In Scenarios 3 and 4, the goals and structure of the economy are transformed to emphasize and facilitate bringing about human and environmental welfare. Again, we envision the effect of energy availability and cost by contrasting the third scenario, where energy is readily obtainable and inexpensive, with the fourth scenario, where energy is limited and expensive.

Focal Area of Analysis

We focused our scenarios on three counties in central Iowa (41-42°N and 93°W): Hamilton, Story, and Polk Counties (Figure 2), because these three counties are representative of Iowa more broadly, and contain a range of land uses from agricultural to urban. At approximately 1,500 km^2 each, all three counties are nearly of equal size[23]. Virtually all of the landscape in Hamilton and Story Counties is dedicated to agriculture, 94% and 96%, respectively, whereas, 66% of Polk County is used for agricultural purposes[24-26]. Hamilton County is a rural county with 15,000 residents[23]. Story County has a population of 87,000, with most of the residents living in the Ames metropolitan area[23]. Polk County is the most populated county in Iowa with 425,000 residents, most of whom live in the Des Moines metropolitan area[23].

The importance of agriculture to the economies of Hamilton, Story, and Polk Counties also differs greatly. One indication of the importance of agriculture to the counties is livestock density. The livestock populations in these three counties, which are primarily hogs and cattle, are inversely related to the population densities. More than 1.12 million livestock were sold in Hamilton County in 2007, making the livestock to person ratio 73:1[24]. In Story County there were twice as many livestock sold in 2007 as county residents[25], whereas in Polk County there are 7.6 times more people than livestock[26]. Crop and animal agriculture is a central component of the Hamilton County economy; 20% of the jobs in Hamilton County are related to agriculture[23]. In Story and Polk Counties, agricultural jobs comprise 11% and 3% of the total workforce, respectively[25,26].

Methods for Evaluating Scenarios

Land use maps and photorealistic visualizations of farm landscapes were constructed to aid in the evaluation of the scenarios (Figures 2 and 3). The land use maps compare the major land uses among the scenarios and compare the envisioned land uses to present and historical land uses. The photorealistic visualizations are based on an actual central Iowa landscape and are bounded by the biogeographical attributes of that landscape. In the forefront of each visualization is a farmstead whose structure and function illustrate how the adjacent agricultural systems are organized. Waterways and wetlands are present to indicate the role of water in each scenario. In addition to using visualizations to compare the scenarios, we compare the specific agricultural and social characteristics of each scenario as it relates to agricultural productivity, ecosystem services, socioeconomic outcomes, and policy.

Agricultural Productivity

The definition of what is considered productive will differ among the scenarios. When ecosystem services provided by agricultural systems are valued – as they will be in Scenarios 3 and 4 – the concept of productivity will expand to include a broader suite of saleable goods as well as services provided by the system. In this section, however, we restrict the definition of productivity to include only saleable goods provided by agricultural systems to make comparisons between goods produced in all scenarios. These goods primarily include grain, livestock, fruits and vegetables, and energy crops.

In 2009, almost 65% of Iowa's landscape was used to produce commodity grains of corn and soybean (Figure 2)[27,28]. In Scenarios 1 and 2, commodity grain production will increase, whereas, the reverse will occur in Scenarios 3 and 4. Due to intense investment in molecular corn and soybean breeding technology in Scenario 1, corn and soybean yields will increase at 3.4% and 2.4% annually, respectively, which is double of the historic increases in yields[29]. Large annual harvests will provide sufficient corn and soybean for livestock feed, energy production, and human food. Corn and soybean will be grown in Scenario 2, but crop breeding programs will focus on developing crops that use energy more efficiently, such as increased nitrogen-use efficiency, increased pest resistance, and increased performance under no-till conditions, which will maintain yields at levels similar to those of 2010. In Scenarios 3 and 4, multiple grain crops will be grown and cropping systems will be designed to enhance ecosystem services and system resilience. For example, perennial species and cover crops will be integrated into grain production systems[30]. In Scenario 4, grain production will be further integrated into diversified systems designed to persist with low external inputs and environmental uncertainty.

In 2008, Iowa was the national leader in swine[31] and egg production[32]. In Scenario 1, demand for animal products will steadily increase. Concentrated animal feeding operations (CAFOs) will continue to function, and the environmental and social consequences of these systems, such as environmental pollution and obesity-related human diseases, will continue to be externalized (Figure 3). In Scenario 2, these issues will be of less concern due to a general decrease in demand for animal products globally. What remains in this scenario of industrialized livestock production will be heavily subsidized by government payments. In Scenario 3 there will be sufficient energy to make animal products available to those who want them. However, meat consumption of Iowans will decrease from current levels of over 100 kg meat/person·yr to 1950's levels of 65 kg meat/person·yr[33] due to increased costs as animal welfare and environmental issues are internalized into the cost of animal-product production. In Scenario 4, livestock will be managed as tools to maintain ecosystem health; including recycling nutrients, maintaining desired ground cover, and maintaining wildlife habitat; as well as human food (Figure 3)[34,35]. Grazing systems that manage for drought reserves and grass banking will be necessary as insurance policies against environmental unpredictability[36].

In 2007, fruit and vegetable farms in Iowa covered less than 5,000 ha – less than 0.04% of Iowa's land area[37]. Approximately 10% of the fruits and vegetables that Iowans consumed came from Iowa farms[38]. In Scenarios 1 and 2, the production of fruits and vegetables in Iowa will decline to less than 1% of the food consumed in Iowa because of the continued focus on commodity grain crop production. In contrast, fruit and vegetable production will increase in Iowa in Scenarios 3 and 4. In Scenario 3, approximately 50% of the fruits and vegetables consumed by Iowans will be produced in Iowa on moderate-sized (3 – 7 ha) farms, which rely heavily on both outdoor and greenhouse food production (Figure 3). In Scenario 4, fruit and vegetable production will occur primarily in urban areas in home, rooftop, and neighborhood gardens, and more than 90% of the population will participate in some form of gardening or food production (Figure 2). Permaculture methods will be heavily employed such as inter- and multi-cropping.

In 2008, the United States produced approximately 38 GL of biofuels. Ninety-three percent of these fuels were ethanol from corn grain[39], which required approximately 30% of Iowa's corn crop[40]. In each scenario, bioenergy will be produced from plant biomass, but the form of biomass and energy produced will differ among the scenarios. Biofuels will be the primary bioenergy produced in Scenarios 1 and 2. Corn grain and stover will continue to be the primary biofuel feedstock in Scenario 1, whereas soybean will be the primary feedstock in Scenario 2. Multiple forms of bioenergy, such as heat, electricity, and biofuels, will be produced from biomass in Scenarios 3 and 4. High-yielding perennial plants that are environmentally beneficial, such as prairies, will be grown for biomass in Scenario 3 (Figure 3)[41]. In Scenario 4, "waste" materials, such as crop residues, municipal waste, and tree thinnings, will be the primary feedstocks for bioenergy production[42].

Ecosystem Services

Ecosystem services refer to the natural processes by which ecosystems support and sustain human life[43,44]. How agricultural systems and the broader landscape are managed greatly affect the quantity and quality of the ecosystem services provided. Because natural resources will be viewed as unlimited and readily interchangeable in Scenarios 1 and 2, ecosystem services will not be economically valued. Natural resources will be viewed as finite and not interchangeable in Scenarios 3 and 4, however, and the services provided by ecosystems will be valued[21]. In Scenario 3, many environmental resources and the services that they provide will become part of an expanding commons sector that is collectively managed and "propertized" (i.e. assigned value) but not owned (Figure 3). In Scenario 4, all urban and agricultural land will be managed for multifunctionality, which will include ecosystem services[45]. We compare the provisioning of these ecosystem services related to water, biota, soil, air, and culture among the four scenarios.

Water Regulation

The total quantity of precipitation in Iowa is expected to increase in the coming century, and the timing and intensity of that precipitation is expected to become more infrequent and severe[46,47]. The management of the landscape in the scenarios will have a dramatic impact on both water quantity and quality. More of Iowa's landscape will be devoted to row-crop production in Scenarios 1 and 2, which will increase the amount and rate of water leaving the landscape (Figure 2). The amount of water stored in the soil is lower under row-crop systems than perennial systems[48], and water infiltration rates are five times lower under row-crop systems than under multi-species perennial systems[49], which means that more water will leave the field as surface-water runoff. This will be more exacerbated in Scenario 2 than in Scenario 1 because the perennial vegetation in fencerows and buffers will be removed to increase field sizes (Figure 3). Because the landscape in Scenarios 3 and 4 will have large amounts of perennial vegetation, surface-water runoff will be greatly reduced.

Subsurface water flow will also differ among the scenarios. Iowa is part of the prairie pothole region, which is characterized by numerous, small, depressional wetlands across the landscape[50]. Although wetlands perform critical ecosystem services such as slowing water movement across the landscape, mitigating floods and droughts, purifying water, and providing animal habitat, approximately 99% of the wetlands have been drained in Iowa for conversion into agriculture[51]. In order to drain the wetlands, subsurface drainage tiles have been installed under approximately 25% of Iowa's landscape[52]. Subsurface drainage tiles allow water to move more quickly from uplands into water bodies[53]. In order to accommodate the increased row-crop production in Scenarios 1 and 2, more subsurface drainage tiles will be installed, and Iowa's prairie potholes will be virtually eliminated (Figure 3). This will result in increased subsurface water flow and increased flooding frequency and severity in Scenarios 1 and 2[54]. Wetlands will be reincorporated into the landscape in Scenarios 3 and 4 by breaking subsurface drainage tiles and allowing natural hydrologic patterns to reestablish (Figure 3). This will reduce the volume of subsurface water flow and reduce the frequency and severity of flooding[55].

In addition to changes in the quantity of water moving across the landscape, water quality is affected by how the landscape is managed. Section 303 of the Clean Water Act sets standards for water quality, and those water bodies that have substandard water quality are classified as "impaired waters"[56]. Less than 20% of Iowa's water bodies are classified as not impaired and more than 25% are classified as impaired (the remaining water bodies have not been sufficiently tested to determine if they are impaired)[57]. The main causes of impairment are bacterial contamination, excess nutrients, and increased turbidity[57]. The increases in row-crop production and CAFOs in Scenario 1 will increase potential for decreased water quality due to bacterial, nutrient, and soil pollution[50]. Water quality in Scenario 2 will be similar to water quality in 2010 due to the offsetting changes in agricultural production of reductions in tillage, reductions in nutrient applications, reductions in the number of CAFOs, elimination of wetlands, and elimination of buffers around water bodies (Figure 3). Water quality will increase in Scenarios 3 and 4 because more of the landscape will be in perennial vegetation and animal production will not be concentrated in CAFOs. A major factor in increasing water quality, however, will be the reestablishment of wetlands. One effect of reestablishing prairie pothole wetlands is that water flow will become more localized around individual wetlands with fewer large linear networks, which reduces the sphere of influence for any polluting activity[50].

Biotic Resources

Pest regulation, pollination, and wildlife habitat provisioning are three important biotic ecosystem services that will differ among the scenarios. Scenarios 1 and 2 will rely heavily on therapeutic measures for pest regulation, whereas agricultural systems will be designed to intrinsically limit major pest outbreaks in Scenarios 3 and 4 through the use of longer rotations, more complex landscape structure, polycultures of crops, and planned refugia for natural pest enemies[58]. Scenario 2 will be especially susceptible to crop failures because no-till cropping systems often require higher rates of herbicide use[59], but the high costs of herbicides in Scenario 2 will limit their availability. Higher ambient levels of pests will be tolerated in Scenarios 3 and 4 before intervention is considered because repeated interventions with high, but not complete, efficacy can lead to increased reliance on pesticides as the pests become resistant to the intervention[58].

Pollinators require sufficient food resources and habitat throughout the year in order to thrive. Wind-pollinated plants, such as corn, do not provide appropriate food resources for pollinators, and annually-harvested plants, such as corn and soybean, generally do not provide sufficient pollinator habitat. Many native prairie forbs are excellent food sources for pollinators in addition to some non-native forbs, and standing vegetation throughout the year provides sufficient habitat[60,61]. Pollinator populations will decline in Scenarios 1 and 2 because of the expansion of annual row crops and reductions in patches of native vegetation, whereas pollinator populations will increase in Scenarios 3 and 4 because the landscape will become more heterogeneous and native vegetation will be reestablished (Figure 2).

Wildlife habitat is loosely included under the ecosystem services umbrella because wildlife benefit from this service more than humans – and ecosystem services are defined based on the benefits that humans obtain. Wildlife habitat will decrease in Scenarios 1 and 2, but some habitat will remain in Scenario 1 because wealthy individuals will pay to conserve game-animal habitat to use for hunting[62]. In Scenario 2, hunting as a recreational activity will decline due to insufficient money available for recreational activities and for the removal of land from agricultural production. In Scenarios 3 and 4, however, people will recognize the value of maintaining wildlife on the landscape. In Scenario 3, wildlife habitat will be actively managed. For example, every county will have at least one large prairie restoration in addition to multiple satellite prairie patches (Figure 2). In Scenario 4, wildlife habitat will primarily occur in the land that is farthest from cities and towns because this landscape will not be heavily managed by people due to the lack of resources needed to manage the land. Species such as prairie chickens, bison, and wolves, which all need large areas of land to thrive, will be more common in Scenario 4 (Figure 2)[63-65].

Soil Quality and Nutrient Cycling

Soil quality will decrease in Scenarios 1 and 2 due to increases in soil erosion without the utilization of farming practices that increase soil formation rates, whereas soil quality will increase in Scenarios 3 and 4 due to decreased soil erosion rates and increased soil formation rates. Soil erosion rates will be greater than soil formation rates in Scenarios 1 and 2. In

Scenario 1 soil erosion rates will increase as soil conservation practices are abandoned. Although no-till crop production will be adopted in Scenario 2, soil erosion rates will increase because marginal and highly erodible land will be put into row-crop production[66]. Scenarios 3 and 4 will include more perennial vegetation and cover crops which will reduce erosion rates[67,68]. Soil formation rates will increase more in Scenario 4 than in Scenario 3, however, because the availability of large amounts of human labor will allow agricultural practices such as intensive rotational grazing to be used.

Nutrient cycling and waste treatment greatly affect soil and water quality. In Scenarios 1 and 2 there will not be a focus on enhancing soil and water quality. Because surface and subsurface runoff will increase in Scenarios 1 and 2, high concentrations of nutrients will continue to be transported out of Iowa and will be deposited into large water bodies such as the Mississippi River and eventually the Gulf of Mexico[69,70]. These lost nutrients will have to be replaced continuously. In Scenario 1, nitrogen fertilizers will continue to be derived from petroleum-based sources, whereas those sources will be too expensive in Scenario 2, and farmers will rely heavily upon biological sources, such as microbial nitrogen fixation. Re-incorporation of perennial vegetation, biotic diversity, and wetlands into the landscape in Scenarios 3 and 4 will improve soil quality and water retention which will reduce the long distance transport of nutrients (Figure 3)[67,71,72]. In Scenario 4, there will be a heavy emphasis put on tightly cycling nutrients and energy. Diverse plant populations will be selected to fill multiple niches necessary to capture energy and nutrients at different times of year and at different levels of the soil profile. Animal and human wastes will be composted and otherwise transformed into nutrient-rich soil amendments.

Atmospheric Gas Regulation

The structure and functioning of the landscape affects the global climate. In Iowa, the management of agricultural landscapes is a major source of greenhouse gas emissions[73]. Scenario 1 will have extensive subsurface drainage, tillage, application of fertilizer, and CAFOs which will result in increased emissions of carbon dioxide, methane, and nitrous oxide[74-77]. These emissions will be less in Scenario 2 than in Scenario 1 because tillage, fertilizer, and animal agriculture will become too expensive to use extensively. Scenarios 3 and 4 will both offer opportunities to sequester carbon through increased perennial vegetation[76,78]. Decreased greenhouse gas emissions will also result from decreases in the overall consumption of animal products in Scenarios 3 and 4. In Scenario 3, greenhouse gas emissions from animals will be further reduced because ruminants will be bred to reduce the amount of methane that they emit[79].

Cultural Resources

Ecosystems provide numerous cultural resources such as aesthetic, spiritual, and recreational opportunities. The cultural resources provided by ecosystems will not be heavily valued in Scenarios 1 and 2 because these resources do not contribute to the overarching goal of high material throughput. Cultural resources will be valued in both Scenarios 3 and 4, however. In Scenario 3, people will have large amounts of leisure time and will have some monetary resources to spend on the cultural resources that are of the most value to them. For example, ecotourism to the large prairie reserves will be common (Figure 2). In Scenario 4, people will have less leisure time and fewer monetary resources to spend on cultural resources, but because they will be directly involved in obtaining their resources, people will develop deep spiritual connections to the land such as the "land ethic" described by Aldo Leopold[80].

Socioeconomic Outcomes

For each of the four scenarios, we analyzed the impact on society using two measurement tools: the GDP and the Genuine Progress Indicator (GPI). GDP uses only economic measures without regard for issues of equity or quality of life. GPI attempts to measure both economic and social progress, and the degree to which benefits are dispersed throughout society. GPI is used as a means of quantifying human well-being in terms of health, environmental integrity, and access to basic services, such as housing, education, clean water, and health care[81-82].

The GPI is a constructed number created by adjustments based on value judgments. Although this makes the measurement dependent upon the analysts' values, most values are derived from known data and predicted trends[83,84]. As a means of comparing among the scenarios, we constructed relative GPIs for the four scenarios (Table 1) [85]. Using the current social, economic, and physical environment as our baseline (a score of "0"), each measurement was scored on a scale of -2 to 2, with negative numbers representing a decrease in GPI and positive numbers representing an increase. Final scores provide a relative ranking in changes in GPI across the scenarios.

In **Scenario 1**, agricultural production will continue to become more energy intensive and focus on short-term profits will continue to externalize the health and environmental costs of the system (↑GDP, ↓GPI). Labor will continue to become less skilled and more interchangeable with mechanization until it is completely replaced with computerized or remote technology. The trend towards vertical integration of agricultural production will continue. These downward pressures on wages drive people to urban centers in search of opportunity. Urban areas will continue to expand into the agricultural areas (Figure 2) because residential uses out compete land rents for agriculture (↑GDP, ↓GPI)[86]. Additionally, GPI will decline due to the cumulative effects of long-term environmental damage from the continuation of production-oriented agriculture and urban sprawl.

The population will enter a situation where increasing work hours are expected to maintain a static quality of life (↓GPI). Longer commutes and telecommutes will be made possible by increased use of personal automobiles and communication devices, respectively[87]. The old center cities will not be redeveloped because people with wealth (hence capital) will be free to flee the cities[88,89]. Poorer populations will cluster in areas with insufficient amenities and deteriorating infrastructure (↓GPI). In sum, GDP will continue to increase over the next 90 years although the quality of life will decrease, resulting in a relative GPI score of -7 (Table 1).

In **Scenario 2,** agricultural production will be one of society's highest priorities and will command a disproportionate amount of the available, expensive energy (↓GDP). This will make it possible for current agricultural practices to continue as in Scenario 1, despite burgeoning energy costs. Day to day work will be done by low skilled and interchangeable labor, and management will center on a few highly paid administrators overseeing large tracts of land (↓GPI; Figure 2). Overproduction and dependence on high-input systems will negatively affect the market and will ultimately result in economic decline (↓GDP). These same factors will also decrease environmental quality and will result in poorer human health and a decrease in quality of life (↓GPI). The consolidation of economic power will increase inequity and will exacerbate the exploitation of labor, further reducing GPI.

The decline of rural and suburban economic opportunities will increase the relative attractiveness of urban areas and spur the migration of rural populaces to urban areas[90]. Automobile usage, which requires a substantial amount of energy, will nearly cease due to energy restrictions (↓GDP). To compensate, a shift in behavior towards public transport in the urban areas will ultimately result[87]. In sum, GDP will decline due to increasing energy costs and limits on production, and the GPI will decline, a relative score of -9, due to the exploitation of resources and labor (Table 1).

In **Scenario 3**, higher levels of technology and innovation maintain low energy prices and create new opportunities for rural areas (↑GDP, ↑GPI). The proliferation of renewable-energy technologies and a new variety of agricultural enterprises will create numerous career opportunities for both agriculturalists and engineers (↑GDP, ↑GPI). Technology will allow for efficient use of natural resources, which will enhance economic development and quality of life (↑GPI), but enforceable governmental policies will prevent increased consumption as efficiencies increase (i.e. Jevons' Paradox). Energy and resources will be successfully invested in technological advancements that benefit the whole of society and enhance environmental integrity.

Access to information will be recognized as a necessity for equitable knowledge, and publicly-funded broadband internet will be available to everyone. Many individuals will be able to work online, which will drive the increase in the population of small Iowa towns (Figure 2). As rural towns are revitalized, schools, grocery stores, convenience stores, and clinics are reestablished providing access to health care, goods and services, and economic opportunities (↑GDP, ↑GPI). Increased community vitality leads to increased societal participation in the political process and better urban planning (↑GPI). Politicians will become genuine public servants with vantage points longer than 2- to 4-year electoral cycles, and legislation will be passed to reform campaign finance to 100% public support. In sum, there will be an increase in both GDP and GPI, with a relative GPI score of +12 (Table 1).

Scenario 4, expensive energy will make current energy-intensive cropping systems unfeasible. The optimal mix of labor, capital, and energy will also change, leading to more farming and labor opportunities for the general population. These jobs will be characterized by higher skill levels and non-interchangeability (↑GPI). Workers will have control over both their methods of production and the goods that they produce. Higher energy costs will lead to an overall decrease in production and consumption (↓GDP). Health care expenditures overall will be reduced as human health improves due to decreases in the consumption of industrial foods, decreases in toxins released into the environment, increases in human activity, and greater emphases placed on overall wellbeing (↓GDP, ↑GPI).

Urban and rural populations will organize around localized clusters, thus achieving significant reductions in energy use (Figure 3)[91]. Because energy consumption is negatively correlated with inner-area employment, settlement will concentrate around areas of opportunity[92]. Small towns will grow or repopulate to meet the day to day consumption needs of the expanding rural labor force (↑GDP, ↑GPI). Throughout, smart growth plans will be implemented to lessen the monetary and energy costs of infrastructure maintenance (↑GPI)[93]. Despite a stark reduction in GDP, a reallocation of resources with a priority on human and ecological wellbeing will result in an increase in GPI, a relative score of +8, due to reductions in income disparity, increased human health, and improved environmental quality (Table 1).

Policy: How do we get there?

Policy at all levels of government will significantly influence the ways in which we meet the agricultural, environmental, and quality of life challenges of the next 90 years. Policy is a strong mechanism by which a society drives changes in behavior and the landscape, and it reflects the goals of the society and economy in which it is embedded[94]. Policy provides positive and negative stimuli, such as subsidies (incentives) and taxes (disincentives), that can influence the decisions individuals and groups make. The absence of policy can have an equally dramatic effect on decision-making.

Our policy assessment starts by asking several basic questions: Who has the power to wield policy? Who are the main political actors? Who benefits from policy? Who pays? In Scenarios 1 and 2, the power to make policy will be held by entities with the financial and political means to influence the policy process. Often the resulting policies will reflect their best interests, and this will often be with externalized expenses to other individuals, groups, and the natural world. In contrast, in Scenario 3 and 4, the public will be critically engaged in the political process because institutional roadblocks that inhibit citizen participation and democratic structures, which currently exist, will be removed. The resulting policies will be specifically targeted to positively enhance societal and environmental welfare.

Another key area where policy will differ dramatically between Scenarios 1-2 and 3-4 is in how the local and global ecological commons will be envisioned and valued. In the former, the commons will be an exploitable resource pool and sink, and will be managed best when it is privatized. In the latter, the commons will be assets to be protected in perpetuity, to be utilized sustainably by society[95]. The change in valuation and concomitant policy focus will be central to the vision of society and economy in Scenarios 3-4. This fundamental change will create the matrix for a coherent environmental policy, rather than a piecemeal approach that tends to oversimplify and opt for simpler “silver bullet” solutions.

Policies that currently exist will continue in **Scenario 1**. These include heavy subsidization of commodity crop production, marketing and export, and subsidization of energy including access to oil-producing lands, tax breaks for refiners and transportation, and infrastructure that will promote energy use such as the federal highway system and pipeline production. There will be continued disincentives for non-commodity crop and food production. Campaign finance policy will continue to allow for the concentration of undue political influence, wealth, and power. Frequently, policy decisions will be influenced by past promises or future hopes of monies donated for campaign financing. Because the economy prioritizes throughput of any sort, private entities and corporations will largely drive research, development, and innovation. Correspondingly, environmental laws seen as impeding and adding costs to production will continue to be weaker than other developed countries and will be poorly enforced. In order to maintain material throughput, policies will continue to encourage high levels of consumption and short turnover of disposable goods. Although tensions will build between urban and rural interests, suburban sprawl will continue to overtake fertile soil due to lack of appropriate land use policy and the ability of suburban developers to pay higher prices for agricultural land (Figure 2).

In **Scenario 2,** burgeoning energy costs will add energy subsidies to the continuing commodity-crop subsidies to facilitate continued commodity-crop production. This influx of funds to the agricultural sector, in contrast to struggling urban sectors, will further focus political power and policy more on agricultural interests dominated by large commodity groups and consolidated agricultural and energy corporations. Commodity and energy markets will be battered by volatility in reaction to climatic and economic events, driving agricultural interests to demand policies to protect agriculture. Environmental policies will be viewed as adding additional costs without corresponding economic benefits and will stagnate in the face of powerful political adversaries. Regulatory bodies will be eliminated as budgets are downsized in response to increasing energy costs. Food prices will rise with increases in energy costs, and consumers will be vocal in their demands for policy relief as real incomes shrink.

In **Scenario 3**, a societal shift toward valuing human wellbeing and ecosystem functioning will significantly impact policy decisions. Environmental policy will come to the forefront of society's concern; it will be merged with economic and agricultural policy in a new system-wide paradigm. Governmental policy at the federal and state levels, in terms of incentives, subsidies, and grant dollars, will nurture the research and development of new technologies to support this integrated environmental/economic/agricultural paradigm, and all government-funded research will be published in an open access format, as property of the commons. These technologies will be developed and deployed within the constraints of the precautionary principle. Market and political power will be decentralized across the value chain of agricultural goods, which for Iowa will result in the rise of stronger local and regional economies. Iowa's development will be further supported by an increase in income to farmers and landowners in the form of payments for ecosystem services, both from functioning markets for these services and taxpayer supported targeted mitigation. To help reduce overconsumption, goods will be taxed based on product durability and a greater proportion of the government's general revenues will be collected in the form of luxury sales taxes. Steep, progressive income taxation and incentives prompts citizens to work less than forty hours of paid labor each week and to then turn their attention to social and community activities, and other interests and means for self-fulfillment.

In **Scenario 4**, given the reality of limited energy and its contracting effect on the economy and incomes, many issues tied to the consumption of inexpensive fossil fuels (from over fertilizing to over shopping) will be self limiting and will not likely require policy to change behavior. Policy will be more focused on the invention and dissemination of energy-efficient technologies, fostering innovation within the re-formed economic reality, making existing knowledge widely available, conserving the natural resource base, and mitigating the detrimental environmental impacts of previous land uses. Current policies that hinder local-food processing and distribution will be amended to accommodate alternative methods and multiple scales of production (Figure 3). Some decision making will be decentralized and communities and regional economies will sort out a new set of rules both inside and outside of policy in an effort to simply exist. Groups of citizens with common interests will band together in cohesive voting blocs and will drive place-based policy initiatives. Reliance on adaptive solutions will create a positive feedback loop for a resurgence in local and regional participation in policy making and in the political process[96].

Conclusions

Iowa is currently situated as a leader in crop and livestock production in the United States. Achieving that high level of agricultural productivity has been subsidized by fossil-fuel-derived inputs and environmental degradation whose costs have been externalized. The role that Iowa will play in meeting future agricultural demands is uncertain. We presented four scenarios of possible futures for Iowa in 2100 based on combinations of differing goals of the economy (high material throughput versus improvement of human and environmental welfare) and differing energy availability and cost (high versus low). The scenarios are not predictions of the future; they are useful tools that highlight how specific changes can have dramatic outcomes for the future. Envisioning scenarios derived from situations that are likely to occur in the future provides guidance for how to get to more desirable futures.

The availability and cost of energy is a major determining factor of human actions in the early 21st century, and it is likely to remain a major factor at the turn of the 22nd century. As a society we can choose to continue to consume large quantities of energy and rely on fossil-energy sources, or we can choose to reduce our energy consumption through conservation and increased efficiency and transition to renewable sources of energy. In addition to the cost and availability of energy, we must also choose how to manage the waste products that result from the production of goods. The onset of global climate change is a dramatic sign that the waste products from human activities can have strong impacts on the environment.

Limitations in energy and the production of wastes are physical realities of the world around us, but the explicit goals and implicit assumptions of the economy are not tangible. The current metric of a nation's health is the GDP. GDP is effective at measuring the growth in material wealth of a country, but it is relatively ineffective at measuring the welfare of its citizens and the environment in developed countries. In order to move to a system where human and environmental welfare are valued above material wealth, such as in Scenarios 3 and 4, numerous changes will have to occur including individual choices and governmental policies and laws. It is difficult to know whether technological advances will occur in the future that will ameliorate energy limitations, but transitioning from a material-wealth-focused society to a welfare-focused society will require significant changes to how our society is organized and functions.

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The Future of Agriculture and Society in Iowa: Four Scenarios

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Figure 1. Scenario descriptions based on differing economic goals and energy availability and cost. Economic goals are high material throughput versus increased human and environmental welfare. Energy availability and cost are readily available and inexpensive energy versus expensive energy that has constrained availability.

Figure 2. Land use maps of Hamilton, Story, and Polk counties in Iowa for Scenarios 1 – 4 (top row), 2009, and pre-1850s (bottom row). In **Scenario 1** field sizes will increase (average field is 250 ha) and become dominated by corn production. Urban and suburban regions will expand, whereas small towns will become abandoned. In **Scenario 2** corn and soybean will be grown on dramatically larger fields (average field is 3,000 ha). Urban regions will contract and small towns will be converted to agricultural production. The landscape will be diversified in **Scenario 3** through the use of more crops and re-incorporating livestock onto the land. Field sizes will be smaller (average field size will be less than 100 ha), and urban will have condensed. Small towns will be repopulated. In **Scenario 4**, most of the land will be in grasslands for either livestock grazing or conservation. Agricultural production will be concentrated near urban area to minimize distances that agricultural products must travel to consumers. Data source for the 2009 land use map was Iowa NRGIS Library (http://www.igsb.uiowa.edu/webapps/nrgislibx/). The pre-1850 map was derived from the General Land Office surveyor field notes and township plat maps.

Figure 3. Photorealistic depiction of the Iowa countryside for each scenario, seen from 150m above ground with 60° FOV. **Scenario 1** is a countryside dedicated to agricultural productivity, fields of annual row crops dominate although suburbia is encroaching on the horizon. A concentrated animal feeding operation and a large machine shed have replaced a previous farmstead. Conservation practices are used only where it is economically beneficial. In **Scenario 2** soybeans must be grown for their nitrogen fixation, but deep gullies result from soil erosion on even moderate grades. The crops in low-lying areas have been lost to flash flooding, abetted by extensive subsurface drainage. The farmstead has been abandoned and invasive Eastern Red Cedar has established. In the distance a refinery produces biodiesel for local distribution. In **Scenario 3** field crop production consists of a variety of annual and perennial grain and biomass crops as well as a mosaic of warm- and cool-season grasses used for forage and biomass. Vegetable crops are grown outside in the summer and year round inside large climate-controlled greenhouses. Native prairies, interspersed with hybrid tree plantations, form a riparian buffer network along every watercourse. Reconstructed wetlands with associated upland habitat are managed as part of the commons sector for multiple benefits including human recreation, wildlife habitat, flood mitigation, and nutrient transformation. On-farm energy generation facilitates a large single-family dwelling and a highly machine dependant farm operation. On the horizon there is a densely populated city center. In **Scenario 4** much of the countryside has been replanted or reverted to perennial vegetation. Integrated crop and livestock systems rely heavily on human ingenuity and labor to maintain tight nutrient cycles. The farmstead is home to multiple families living in modest sized dwellings and acts as the hub for numerous farm enterprises (including, cattle, hog, sheep, and poultry production; fruit, nut,

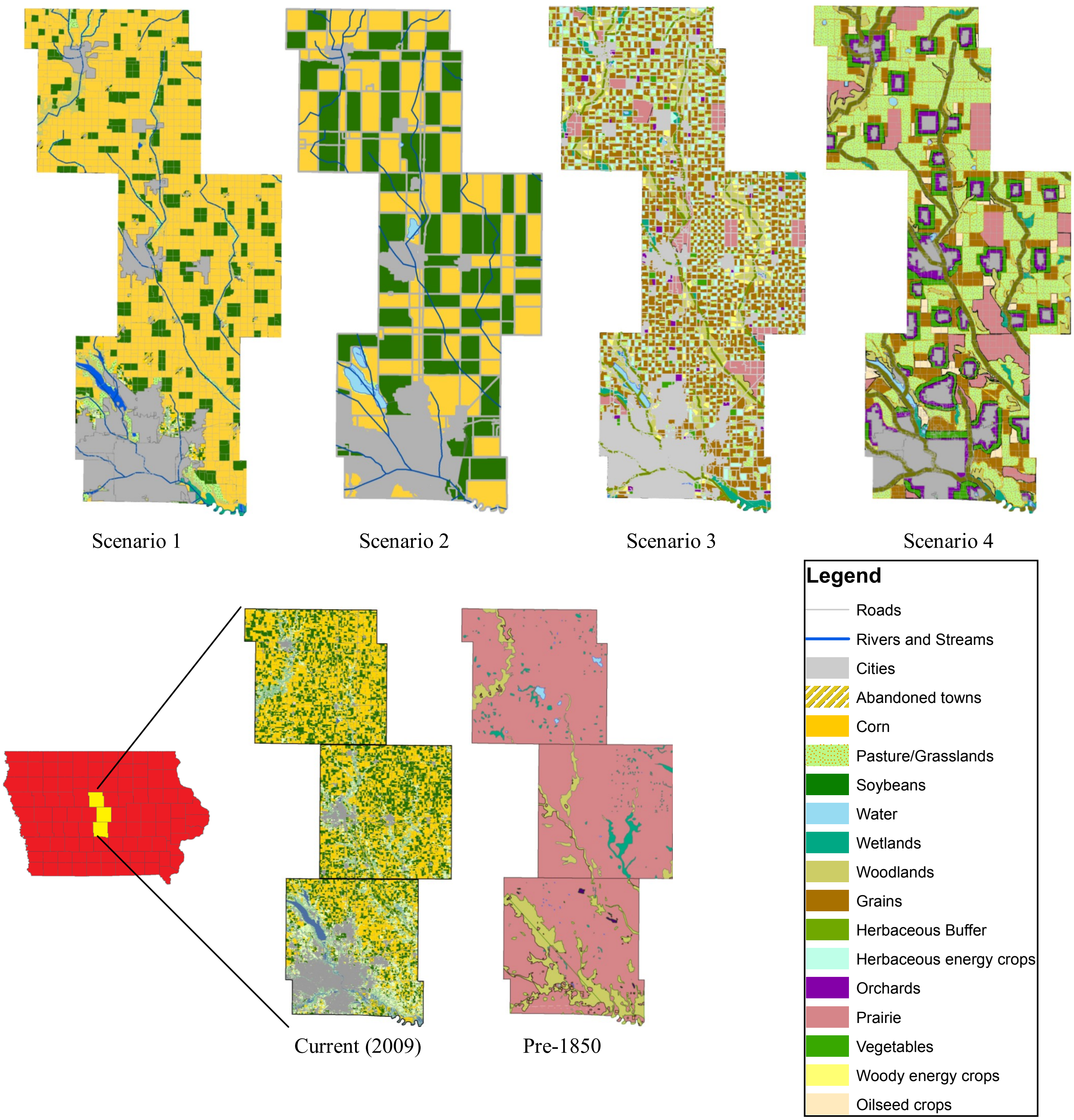
and fuel-tree production; and vegetable and fiber production). Riparian buffers and wetlands protect the water supply as well as serve as a forage reserve in case of drought. Images created with Visual Nature Studio 3 (3D Nature) by D. Larsen, Landscape Ecology and Sustainable Ecosystem Modeling Lab, Iowa State University.

Table 1. Relative quality of life scores for Scenarios 1 – 4 for selected categories from the Genuine Progress Indicator (GPI). Five of the ten GPI categories are shown below to demonstrate how scores were determined. Scores were assigned from -2 to 2 for each scenario in each category to represent the relative changes in that category compared to conditions in Iowa in 2010. Negative values represent a decrease in GPI, whereas positive values represent an increase in GPI. The text in the boxes describes the factors that most strongly affected the relative GPI score.

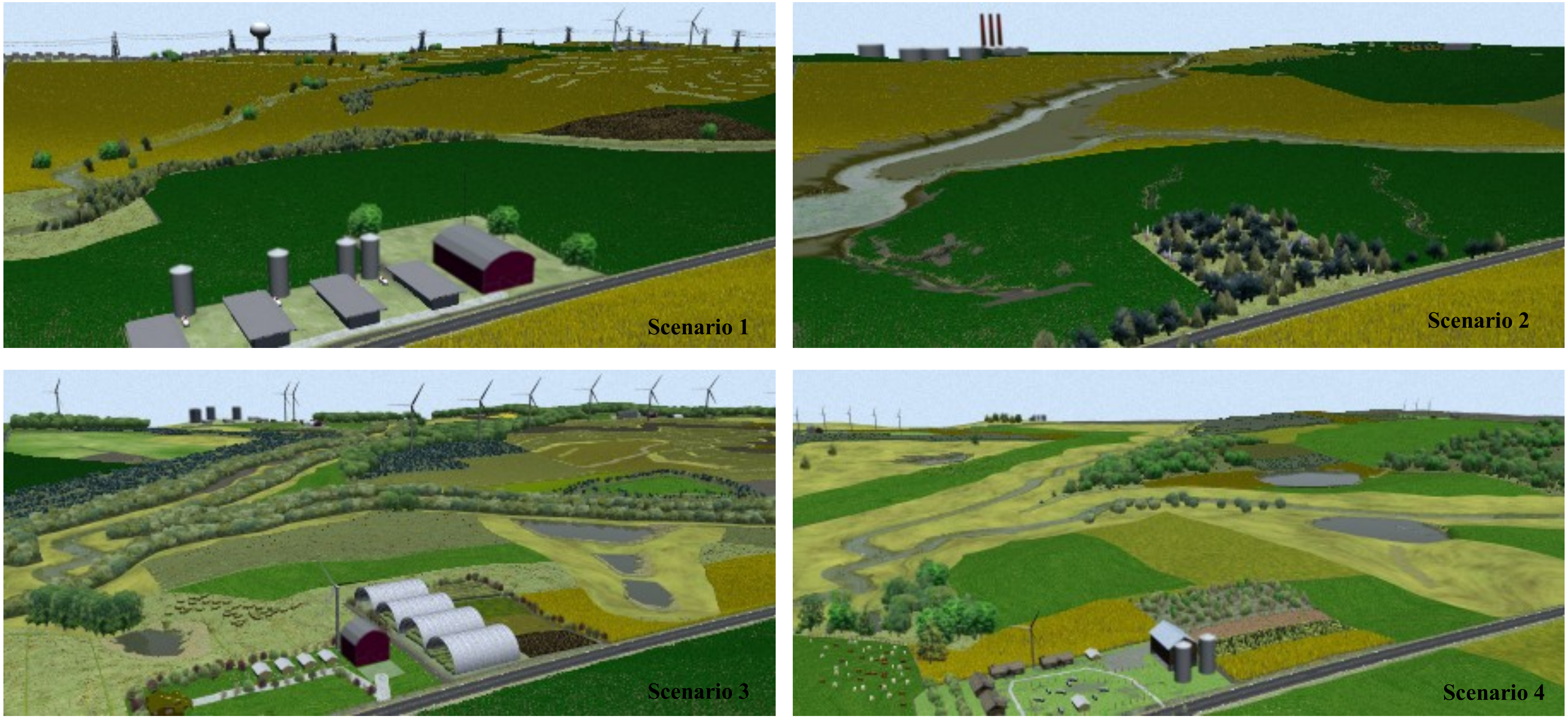
Figure

Economy \ Energy		
	Scenario 1 High material throughput Energy is available and inexpensive	**Scenario 2** High material throughput Energy is expensive and availability is constrained
	Scenario 3 Human and environmental welfare Energy is available and inexpensive	**Scenario 4** Human and environmental welfare Energy is expensive and availability is constrained

Figure


Scenario 1
Scenario 2
Scenario 3
Scenario 4
Legend
Roads
Rivers and Streams
Cities
Abandoned towns
Corn
Pasture/Grasslands
Soybeans
Water
Wetlands
Woodlands
Grains
Herbaceous Buffer
Herbaceous energy crops
Orchards
Prairie
Vegetables
Woody energy crops
Oilseed crops
Current (2009)
Pre-1850

Figure



Table

GPI Indicators	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Income distribution	Differences in income will be maintained by profit motive and relatively inexpensive energy	Disparity between the rich and poor will increase as those with access to energy profit more than those without access to energy	Quality of life priorities will lead to a democratic decision to adjust taxation to minimize income disparity	Incomes will be equalized due to high costs for basic needs; taxation will redistribute wealth to address quality of life priorities
Crime	Crime will remain stable as the cost of living is maintained and most immediate needs are met	Increased disparity between wealthy and poor will create social unrest and crime will increase	Technology will drastically improve law enforcement; crime will be low because people have basic needs met	Prioritizing quality of life will result in increased support for social programs, reducing social tension and crime
Resource depletion	Resources will be depleted at little monetary cost to Iowa's population	The drive for profit will deplete most valuable resources, although complete extraction of resources will not be economically feasible	Most of the energy will be derived from renewable sources and will result in little resource depletion	Resource depletion will be slowed by an awareness of consequences
Long-term environmental damage	Focus on immediate short-term profit will create irreversible long-term environmental damage	Prioritizing profits over environmental welfare will result in irreversible environmental damage	Long-term environmental damage will not be tolerated and previous damage will be reversed	Long-term environmental damage will not be tolerated, but some past damage will remain
Changes in leisure time	Leisure time will be limited by focus on money-making activities, but labor-saving, high-energy devices will make work more efficient	Leisure time will be rare; working hours will increase time and lower classes will be exploited to substitute for energy	Leisure time will be highly valued and technology will ease work loads	Leisure time will be important but limited by the need for manual labor

Color Key	**-2**	**-1**	**0**	**1**	**2**