Sustainability in Agricultural Systems in Transition—
At What Cost?

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CHALLENGES TO AGRICULTURAL SUSTAINABILITY

Global agriculture is facing many demands. It must provide food, fiber, industrial products and ecosystems services. Producers harvest solar energy, reasonably using resources at affordable cost, with acceptable environmental impacts and desired social consequences. It is safe to say that no other human economic activity interacts so broadly. I will not attempt to unravel the complexities of a globally sustainable agriculture, but will suggest a framework for its conceptualization.

There is cause for optimism about global food supply as we approach the 21st century. Total supply should be adequate, probably at a decreasing real world price through the first two decades (Pinstrup-Andersen et al., 1997). Per capita cereal production will continue its upward trend, assuming United Nations median projection for population growth and expected trends in yields (Table 1).

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<tbody>
<tr>
<td>Developed Countries</td>
<td>678</td>
<td>692</td>
<td>722</td>
</tr>
<tr>
<td>Developing Countries</td>
<td>200</td>
<td>214</td>
<td>229</td>
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Source: Alexandratos, 1995, p.45.

The world will face increasing social, political and economic disruption if a more complete agenda for agriculture is not addressed by combined public, commercial and civil sector initiatives. Conditions and trends requiring attention include:

- **food security**: a distant vision for much of the world’s population
- **poverty**, particularly in rural areas, resulting from underemployment and low agricultural productivity
- **competition** intensifying for finite land and water resources
- agriculture sharing an environment burdened by rapidly increasing human activity
  - centralization brings problems of monopoly control and loss of checks and balances
  - inappropriate farm enterprise scale causes instability at both extremes
  - the advent of industrial-scale enterprises reduces community integration, undermining rural community structure and economies during a transition

While many statistics could be cited, I will present only one. The International Food Policy Research Institute’s (IFPRI) International Model for Policy Analysis of Commodities and Trade projects that, under the most likely scenario, 150 million children under the age of six years will be malnourished in 2020, representing 25 percent of the total. This will be down from 33 percent in 1993 (Pinstrup-Anderson et al., 1997). Regional incidence will be far higher, creating significant gaps in agriculture’s effectiveness in achieving true food security, and hence sustainability.

Agricultural "sustainability" has come to represent a broad development agenda, having different components and priorities at global, regional, local and individual farm levels. One definition of sustainability is: an agriculture which can evolve indefinitely toward greater human utility, increased efficiency of resource use, minimal depletion of non-renewable resources, an environmental interaction favorable to humans and to most other species, structured consistently with human goals (Harwood, 1990). A more concise definition, borrowed from industrial development, describes sustainability as "economic growth that does not deplete irreplaceable resources, does not destroy ecological systems, and helps reduce some of the world's gross social inequalities" (Morse, 1998). Many definitions are summarized by Hoag and Skold (1996).
I have constructed a three-part framework: 1) five key forces currently driving agricultural change, 2) supplemental and corrective forces needed to shape their direction and 3) five major areas crucial to agricultural sustainability but which market forces are unlikely to adequately address (Figure 1).

**THE CHANGING GLOBAL AGRICULTURAL ENVIRONMENT**

Ruttan (1996) gave a very concise summary of the world’s food future:

A 1989 study at the International Institute for Applied Systems Analysis (IIASA) advanced what came to be referred to as ‘the 2-4-6-8 scenario’—a doubling of population, a quadrupling of agricultural production, a sextupling of energy production and an octupling of the size of the global economy by 2050. Note that it is the growth of the global economy—particularly per capita income growth in the presently poor countries—that is the source of approximately half the growth in food demand.

Garret Hardin (1998) described the consequences of such growth as follows. "(Scientific) numeracy demands that we take account of the exponential growth of living systems, while acknowledging that resources, when thoroughly understood, will prove to be definable by numbers that are relatively constant." Agricultural land is finite and reasonably well quantified. Fresh water as a product of hydrological cycles is likewise finite. Those cycles can be augmented through technology by purifying and transporting seawater, but at a cost several times higher than that of natural hydrological processes, which now supply nearly all agriculture.

Increased human activity through economic growth and increased wealth will continue to load the environment and its ecosystems. Agriculture will be under ever-increasing pressure to minimize its share of that loading, while at the same time providing ecosystem services to human-settled areas. These services are components of sustainability and include capturing rainfall and recharging aquifers, maintaining biodiversity, providing wildlife habitat, recycling waste, enhancing landscape esthetics and maintaining the landscape-level ecosystem (Costanza et. al., 1997). The required higher productivity means increased material flow from soil to crop...
Sustainable Agricultural Development Dynamics

Driving Forces
- Technologies for the global staples
  - Biotechnology
  - Intellectual property
- Capital mobility
- Global markets
- Infrastructure

A 21st century “transformed world”
- 2X Population
- 4X Agricultural productivity
- 6X Energy
- 8X Global economy

Supplemental Forces
- Germplasm collections
- Genomic information
- Selective breeding of the global staple crops

Corrective Forces
- Global and national policies
- Oversight for: trade
  - monopoly management
  - environmental management

Sustaining Forces
- Production ecology
- Resource protection
- Technology for “regional” staples
- Appropriate local food systems
- Strong civil sector action
and animal and back to the soil, with high economic harvest. This must be done through maintenance of high concentration gradients of nutrients, crop and animal residues and any applied pesticides between fields, upper soil layers, air and underlying aquifers or neighboring streams and lakes.

It is generally agreed that, particularly in fragile environments, current soil losses to erosion and carbon losses from deforestation and soil degradation are unacceptable and non-sustainable. Horizontally expanding commerce, housing, recreation, and other human activities are reducing the agricultural land base with rapid economic growth. A summary of threats is shown in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Sustainability Concern</th>
<th>Sustainability Threat</th>
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<tbody>
<tr>
<td>Soil erosion</td>
<td>Small (U.S.) to Medium-large (global)</td>
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<tr>
<td>Soil quality degradation</td>
<td>Large (global)</td>
</tr>
<tr>
<td>Nutrient runoff</td>
<td>Medium (regionally large)</td>
</tr>
<tr>
<td>Pesticide pollution</td>
<td>Medium (locally large)</td>
</tr>
<tr>
<td>Wetland loss</td>
<td>Small</td>
</tr>
<tr>
<td>Farmland loss</td>
<td>Potentially very large</td>
</tr>
<tr>
<td>Declining farm numbers</td>
<td>Economically small, socially very large</td>
</tr>
<tr>
<td>Germplasm loss</td>
<td>Large</td>
</tr>
<tr>
<td>Global climate change</td>
<td>Regionally disruptive</td>
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Adapted from Faeth, 1997.

We assume that most output increases will come from either land-based crop and animal production or managed fisheries. Marine-capture fisheries seem to have reached a production plateau. While better fish stock management, less destructive harvest technologies and other efforts may result in modest offtake increases (Alexandratos, 1995), continued development increases that disrupt coastal and riverine spawning grounds are likely to continue contributing to lower marine productivity. The lack of understanding about how coastal ocean processes occur is a major limit to their better management (National Research Council, 1998). There is no consensus and few projections of significant future marine productivity increases.

It is against this rapidly changing and uncertain backdrop that agriculture must evolve toward sustainability.

**FORCES DRIVING AGRICULTURAL CHANGE**

Agriculture is often seen as a “leading edge” of a region or country’s early commercial growth, a force which in turn has a multiplier effect on the overall economy (Miller, 1995). The forces for change and growth, often called “engines”, have origin, energy resources, momentum, guiding forces and enabling environment rate and direction. Sustainability is a function of rate and direction as well as inclusion. Most change forces lead to changes in agriculture’s commercial structure, from the local to the global level. Agricultural sustainability is thus defined not
only by needs and goals, but by process. What are the driving forces? Toward what eventual social, political and economic structure are they directed?

Global agriculture’s growth in the last 50 years has been largely science and technology-driven, resulting in a lower real food cost. Per capita food production today is 18 percent above that of 30 years ago (Alexandratos, 1995). The world’s 5.7 billion people have, on average, 15 percent more food per person than the global population (four billion people) had 20 years ago (FAO, 1996). Developments in crop and animal genetics, engineering and agricultural chemicals and publicly supported infrastructure provided the early stimulus.

The change forces originate, and receive resources and direction, from three separate but interrelated sectors:

- the public sector (formal governance, largely tax-based)
- the private (commercial) sector
- the community-driven (civil) sector (organizations with common interests in issues, influence or service)

In highly developed, pluralistic societies there is a complex pattern of checks and balances between these three sectors, with each having specific and rapidly-evolving roles. There is considerable empirical evidence that pluralism (i.e. democracy) does not function well without that balance. The evidence from nations emerging from centrally managed economies indicates that formal governance alone is inadequate as a check and balance on an emerging commercial sector. Formal governance (public) and commercial sectors alone do not adequately provide services and individual expression leading to high quality of life. The most well-known analysis of this subject, while using terminology different from this paper, is that of Putnam (1993), who provides an in-depth analysis of “civic” tradition in Italy and its relationship to community development. Further discussion of sector balance in sustainable agricultural development will be given below.

Public Institutional and Physical Infrastructure

The three sector’s evolving roles suggest changes in thinking for public sector institution sustainability. Developing, maintaining and operating public sector institutions is critical to their role in a sustainable agriculture. In developing countries, that role has evolved toward providing scientific checks and balances for the private and community-based sectors which rely on perceived values, often without major scientific content. Public sector roles in developed countries increasingly focus on basic science, particularly in genomics, and process-level studies, such as agroecology and environmental interaction. In the developing world, public sector research in varietal development of global staple crops will diminish as alternative (commercial) supply sources increase, but “minor” staple crops (primarily used in regional and local food systems and by poor people) will be a public sector responsibility for the foreseeable future. While the need for technology to fuel change forces is constant, varied sustainability requirements demand varied pathways for that technology evolution (Harwood, 1995) (Figure 2).

Human, scientific and technical resource development will be the ongoing responsibility of all three sectors, but major responsibility will remain with a viable and participating agricultural public sector. Developing and maintaining physical infrastructure will remain a public sector role in sustainable agricultural development. Sustainability and efficiency require systems for collecting and managing water to be of an appropriate scale for public sector management and user input at a local level. With all public systems serving agriculture, efficiency and market force responsiveness suggest identifying appropriate user fees restricted to use in developing, maintaining and operating the infrastructure. Subsidies, especially in areas of poverty and low resource availability, should be only partial.

Technologies for Global Staples

The traditional staples that became the “growth engines” of the Green Revolution (rice, wheat and maize) have given rise to a broader “core group” of commodities that today provide the major stimulus for global agricultural growth. Maize, wheat, rice and sorghum meet most global food and feed grain needs, with soybeans, poultry, hogs and beef as global staples.

Technology development has moved rapidly with most of these commodities from individual farmers and farmer communities to public sector institutions and the corporate private sector. Much of today’s sustainability
debate revolves around that transition. Neither public nor commercial sector institutions maintain levels of active, in-use biodiversity found in traditional farmer systems. Traditional systems, however, have not made the rapid genetic improvements needed to drive production and production technology developments that a concerted public sector effort has made in food and feed grains. Modern soybean, poultry, hog and feedlot beef technologies have been developed largely through global private sector investment. Food and feed grain genetic improvement in developed countries has rapidly moved to the private sector, though in much of the developing world, genetic improvement is mostly concentrated in the public sector, with International Agricultural Research Centers playing a dominant role in germplasm preservation and basic genetic research.

The International Maize and Wheat Improvement Center (CIMMYT) estimates that new wheat plant architecture could increase yield potential 10-15 percent above current lines. With hybrids, increased grain-filling and heterosis, together with the new plant architecture, “could jointly shift the yield frontier by 25-30 percent” (CIMMYT, 1998). The International Potato Center reports that current world potato production growth rates have risen to about four percent per year, increasing in developing countries from 75 million tons annually in 1988, to more than 100 million tons today. Potatoes and sweet potatoes together will increase in value more than 6.5 percent in developing countries, spurred by new varieties with greater insect and disease resistance levels along with newly evolving biocontrol methods (International Potato Center, 1998). The International Rice Research Institute is well on its way to producing new plants “that would have a (maximum) yield potential 20-25 percent more than today’s best high-yielding Indica modern varieties” for irrigated conditions. The new lines will be available to farmers by Year 2005, with a goal of producing 590 million tons of rice by 2025.
Figure 2  The relative roles of public, commercial and civil sectors in technology development and flow for sustainable agriculture

- **PUBLIC SECTOR**
  - Process knowledge
  - Knowledge of process

- **COMMERCIAL SECTOR**
  - Partnership
  - High-technology capital-intensive technologies
  - Generic production packages
  - High-technology bioengineering

- **CIVIL SECTOR, INCLUDING THE NGO COMMUNITY**
  - Indigenous production systems
  - Diversified commercial systems
  - Specialized, large-scale commercial systems
  - Farm sector (indigenous knowledge)
  - Diversified-product commercial sector
This will require a one-and-a-half percent irrigated rice yield increase each year, moving from five tons per hectare in 1995 to 7.9 tons per hectare in 2025 (IRRI, 1998).

While that list of technological advances is impressive, a key factor is the changing source. On a global scale, Consultative Group on International Agricultural Research (CGIAR) Centers and the national agricultural programs (NARS) are dominant players, representing the public sector for most food and feed grain genetic technologies. Chemical, fertilizer and engineering developments have come mostly from the commercial sector, as have almost all genetic, engineering and production systems technologies for poultry and hog production. These, along with feed grain processing and marketing, have become increasingly dominated by multinational commercial sector corporations, driven by economic efficiency and profit, while succeeding in providing low-cost product. In most developed countries public sector controls over food quality, and to a lesser extent over environmental quality, have provided reasonable checks and balances not adequately addressed by the commercial marketplace.

Centralized control, industrial location, structure, scale and resulting environmental loadings have many undesirable (and therefore unsustainable) social, political and environmental consequences. Public sector institutions can only make modest technological contributions with poultry, hogs and in cereal processing, thus offering little to the technology pool. Control in these areas is either regulatory or through financial policy, making guidance toward sustainability with these industries highly political.

The public sector has traditionally held a strong developmental role in food and feed grain genetic improvements, with heavy influxes not only on the type of materials, but who did or did not control them. That public sector role is still very prevalent in developing countries through CGIAR and NARS efforts. The public sector’s genetic development role has decreased in developed industrial economies as the commercial sector has become the primary source of new genetic technologies. Vegetable, fruit and ornamental crops have a long history of commercial dominance in breeding, but in widely diverse, small-to modest-scale businesses. Recent industrial consolidations along with genetic and chemical developments have led to increased economic efficiency, but also major concerns about a narrow genetic base, lost diversity and consolidated control. Consolidation in the U.S. has brought considerable alarm among producers and scientists concerned with agricultural sustainability. Dominance by a few firms in processing, and in some cases production, with thousands of farmers selling, for instance, to just four firms (Table 3), is blamed for market distortion which returns six percent on investment to growers and 20 percent to processors (Heffernan, 1997). While handling control by the top four is about 50 percent in the U.S., the concentration is considerably higher in other countries. The sustainability lessons of these changes are clearly mixed.

The engineering developments of low-tillage systems, low-volume and spray-controlled pesticide applications, position location, data mapping and other site-specific technologies open new avenues toward sustainability, if properly applied.
Table 3

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<tr>
<th>Industry</th>
<th>Firms</th>
<th>Percent of market controlled</th>
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<tr>
<td>Flour milling</td>
<td>ConAgra, Archer Daniels Midland, Cargill, General Mills</td>
<td>35</td>
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<tr>
<td>Soybean crushing</td>
<td>Archer Daniels Midland, Cargill, Bunge, Ag Processors</td>
<td>71</td>
</tr>
<tr>
<td>Dry corn milling</td>
<td>Bunge (Lauhoff Grain), Illinois Cereal Mills, Archer Daniels Midland</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>(Krause Milling), ConAgra (Lincoln Grain)</td>
<td></td>
</tr>
<tr>
<td>Wet corn milling</td>
<td>Archer Daniels Midland, Cargill, Tate and Lyle, CPC</td>
<td>74</td>
</tr>
<tr>
<td>Beef feedlots</td>
<td>Continental Grain, Cactus Feeders, ConAgra (Monfort), Cargill (Caprock)</td>
<td>50</td>
</tr>
<tr>
<td>Beef processing</td>
<td>IBP, ConAgra (Armour, Monfort), Cargill Meat Sector, National Beef</td>
<td>87</td>
</tr>
<tr>
<td>Pork slaughter</td>
<td>IBP, Smithfield, ConAgra (Monfort), Cargill (Excel)</td>
<td>46</td>
</tr>
<tr>
<td>Sheep slaughter</td>
<td>ConAgra (SIDCO, Monfort), Superior Packing, High Country, Denver  Lamb</td>
<td>78</td>
</tr>
<tr>
<td>Broiler processing</td>
<td>Tyson Foods, Gold Kist, Perdue Farms, ConAgra</td>
<td>45</td>
</tr>
<tr>
<td>Turkey processing</td>
<td>ConAgra (Butterball, Longmont) Rocco Turkeys, Hormel (Jennie-O),  Carolina Turkeys</td>
<td>35</td>
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These evolving technologies present significant energy and resources for growth. Their sustainability implications require ongoing input and guidance from a public sector role, which is rather traditional in most developing countries, but rapidly evolving in developed countries toward greater regulation.

**Biotechnology and Intellectual Property Rights**

The growth of biotechnologies (including genomics) coupled with a strengthened global system of intellectual property rights is arguably this century’s most significant change in terms of potentially shifting the balance of both investment and ownership from the public to the private sector. Both sectors’ investments are huge. A new $146 million “center for plant science and sustainable agriculture” is planned for St. Louis. This new not-for-profit center, to open in Year 2000, is funded by both industry and public sector funds, furthering the trend toward partnerships between the public and private sectors (Kaiser, 1998). At the same time, Novartis AG is expected to announce plans for a $250 million plant genomics institute outside of San Diego. Advances in genomics, coupled with stronger global IPR protection, are attracting huge investments and will become a major component of the advancing scientific growth engine. Future technological pervasiveness, huge investments, industries’ multinational stature and a decreasing number of big name players all pose significant strengths, as well as new challenges, to sustainability.

Opposition to these genetic changes offered by many in the community-driven (civil) sector seem increasingly rear-guard in strategy. Short of some unforeseen major event, nearly every crop and animal species will soon have genetically transformed genes or chromosome segments throughout its germplasm base. It will be difficult
for the public to monitor the origins of those materials, whether from outside or from within a genus or species. As with any extremely potent technology, the danger lies in its abuse.

The ability to target very specific genetic improvements and obtain proprietary use for some modest time has opened up investment incentives that far surpass the hybrid-inbred line protection that originally attracted private investment.

**Capital accrual and mobility**

Private (commercial) sector capital accumulation is becoming a major driving force in sustainable agricultural development. The 1960s’ sole reliance on public sector development capital for infrastructure, research, technology development, extension and production subsidies is being supplemented, and has often been replaced, by the rapidly evolving commercial sector. Corporate consolidation and capital mobility can be major destabilizing factors, as transnational corporations roam the world, “sourcing their inputs” as cheaply as possible. With highly mobile capital and technology, operations can move from country to country to obtain lowest-cost production (Heffernan, 1997). This provides the lowest-cost product, at least during this transition stage, to a global economy. It can be extremely disruptive to local economies, local communities, and production agriculture’s fabric and infrastructure. When will the “mobility” stop, and where will sustainable production be located? Who will be the producers? We do not sufficiently understand the impacts of these directions at the global level.

The only part of the agricultural production process that cannot move is land. Real estate parcels are where consumers live, farmers grow food, producers operate factories and workers clock-in their time. The networks of people, art, music, crafts, religion and politics we call community emerge around these stationary islands (Shuman, 1998). Agricultural production is the least mobile community element. With its dependence on land, long-term soil quality, a fixed water source, and a network of suppliers and markets, once production leaves an area it seldom, if ever, returns. The conflict between mobility of capital and agricultural sustainability suggests “buffering” or modifying factors to reduce the irreversible change being caused by short-term, or worse yet, temporary shifts in highly mobile resources.

The adverse impacts are magnified when large-scale, vertically integrated production facilities, such as those for hogs, enter a community. Agriculture’s support to local communities is reduced by the environmental impacts resulting from lack of landscape integration, the competition from large capital investments that replace medium-sized businesses (owner-operated farms) with low-wage labor, and distant, high volume input purchases. Communities sometimes survive and sometimes do not, but the transition is painful. Such movement and scale of operations is bitterly contested in the U.S., often in the name of environmental protection. But much more is at stake. The Kansas Rural Center, typical of broad-thinking in U.S. sustainable agriculture, asks, “Is the alternative to the family farm system of agriculture, which is an industrial system, sustainable (Fund, 1998)?”

What will such mobility mean for developing countries? Will agricultural sustainability mandate that resources must remain in place? How mobile should they be? What requirements must exist for landscape and community integration? Is the “transition period” this conference is addressing one of resource exploitation and then movement to a “cheaper” resource? Where and when must such a “transition” stop? What local price must we continue to pay for global “security”? Are we building our global house on sand?

**The Global Marketplace–All or Nothing?**

The final driving (or enabling) force is reduced barriers to product movement. Public policy for most developed nations is now oriented toward minimal restrictions and, in many cases, subsidies to global product and capital movement. An increasing portion of the world’s population will be based on liberalized trade and a free market system. Those large nations such as India and China that resisted such change for several decades are now moving aggressively toward exporting value-added products. Smaller countries that have resisted such change (North Korea) or have been prevented from entry (Cuba) are paying a high price. Their food security is subject to vagaries of weather and unavailable inputs. Many of the global economy’s advantages seem obvious.

An overarching question centers around what amount of food “security” should be local, community-based, what amount national, and what should be global? Which commodities could be best produced at each level? Questions of freshness, quality and local preference are significant dimensions of quality of life.
The balance will obviously change with development status, geographical location, country size and production resources. The answer will be different for Michigan, Iceland, Saudi Arabia and Kenya. It will be different for East Lansing, MI, a remote village in western Kenya and in the western mountains of Nepal. It is unfortunate that the present fascination with the “global marketplace” almost precludes serious analysis of the problem.

**THE REQUIREMENT FOR SUPPLEMENTAL AND CORRECTIVE FORCES**

(Primarily by Public Sector Intervention)

I accept the major driving forces as inevitable, and overall, desirable. In an era of vastly increasing global population, multiple demands on public sector funds, and increasing private sector capital, these forces represent major global resources that can be used to benefit humanity. To do this, they must be supplemented, guided, and yes, in some cases controlled by public policy at the local, national and global levels. I suggest only a few key interventions. There are many others, particularly at the local level. Those listed here are particularly required for sustainability of the major driving forces. They do not include traditional public sector roles such as infrastructure development and agricultural education, nor do they include the sustaining forces yet to be discussed.

**Preservation of Crop and Animal Germplasm**

Sustainability concerns are now focused on maintaining most of our major species’ germplasm within the public domain, and keeping as much of the scientific base as open as possible. The world’s major species germplasm collection, held in trust by FAO, is critical to sustainability. The public maintenance of that diversity for the good of humankind is especially critical as globalization (particularly of seed sources) with increasing commercial sector involvement, tends to reduce the “active pool” of genetic materials.

**Technology Development for the Global Staple Crops**

Crop technology, more than animal technology, must be adapted to a wide range of soil, temperature, day length, moisture, disease and pest environments, as well as to special use and preference. The private sector can and will increasingly respond to that need. The public sector will play a significant role in meeting the developing world’s need for the foreseeable future in both high- and low-resource areas. Where major private sector resources are invested for long-term development (as in many developed countries), the public sector should shift to more underfunded areas.

**Development of Genomic Information**

Staple crops’ and animals’ genetic maps, and the genomic process information necessary to transform and use the materials, should be developed and maintained in the public sector. This will guarantee access and prevent broad, proprietary control of any given species or block of germplasm. The U.S. National Science Foundation’s effort in funding a plant genome initiative is a step in the right direction. The initiative’s first grant will be $11 million for mapping the maize genome (Science, 1998). In total, this program plans 23 awards totaling $85 million, covering crops such as cotton, tomatoes and soybeans.

**Maintaining Genetic Intellectual Property Rights**

The private sector must have protection for its investment in order to mobilize major commercial resources for genetic improvement. This will take place within guidelines yet to be developed under the Convention on Biological Diversity (FAO, 1996). Those who develop traditional germplasm sources should be appropriately compensated, while recognizing that original genetic materials evolved independently of human intervention and legitimately belong to all.

Process and genetic patents, while protecting commercial investment, should not be so broad as to establish proprietary rights over large blocks of material or species. The patent process guarantees open discovery. If protection is a ten to 20-year duration, one can rationalize the protection as society’s investment in private development and marketing the technology. This duration usually results in an ultimate patent “market life” from five to ten years. One might argue that given the shortage of public sector research funds and given the food adequacy
for the next ten to 15 years, short-term exclusivity and protection are a small price to pay in developing a broad technological base to power development toward a “contemporary solar economy” into the 21st century. Major sustainability questions are not whether or not we should proceed: that is irreversible. Questions of adequate and properly directed public sector research and conservation versus an appropriate public policy and regulation are key to sustainability.

**Environmental Regulation**

Appropriate public policies for protecting air, water, natural areas of biodiversity and general land use are essential to long-term sustainability. Short-term market forces will not offer that protection, particularly where companies have the mobility (and the intention) for short-term gain followed by movement.

**Provide a Watchdog Function Over Commodity Exchanges**

Commodity exchanges such as the Chicago Board of Trade provide an increasingly important market force balance to industry centralization as long as they are well managed, transparent in their operation, and not subject to major monopoly control.

**Regulate Monopolies**

Managing and preventing monopoly control will be an increasing global problem. Many small countries do not have sufficient economic or regulatory power to confront major multinational corporations. Major developed country governments regulate within their borders, but mechanisms are not yet in place to assure global-level competitive markets and operations.

**SUSTAINING FORCES**

Rapidly evolving global agriculture has increased the urgency around developing sustaining forces to avoid further environmental and social disruption. The following five areas are the most critical:

**Enhanced and Accessible Production Ecology Knowledge and Methods for Crop and Animal Systems**

If we expect production systems to allow crops (and animals) to “yield to their full genetic potential, and, at the same time balance pest management and long-term ecosystem stability” (Coalition for Research on Plant Systems, 1998), we need to better understand and manage biological processes and relationships. The emerging agroecosystem concept provides a very useful means of carrying out research attempting to integrate the multiple factors affecting agricultural systems (Gliessman, 1990), especially process-level understanding, which then permits rational system design. Key sustainability factors of high productivity systems depending on that understanding include:

- maintaining or increasing soil productivity and long-term soil health
- ensuring efficient nutrient cycling from soil to crop (at high flow rates) in environments where nutrients must be both mobilized from soil and contained from loss to surface or groundwater
- managing pests and disease with minimal pesticide use and subsequent environmental loading
- using integrative landscape design to provide a range of products, especially in low-resource areas with large poor populations in transition
- providing ecosystem services such as hydrological cycling, wildlife habitat, landscape-level plant and animal diversity and an aesthetically pleasant human living environmental agriculture to enhance the flow of ecological benefits to the community.
- helping maintain an appropriate atmospheric chemical balance.

Agroecosystem thinking has evolved during the past 30 years, appealing first to the 1970s farming systems researchers (Spedding, 1975), later gaining input from "applied" ecologists (Lowrance, 1984; Altieri, 1987; Dover, 1987; Gliessman, 1990). These scientists attracted interest from "alternative" agriculture proponents in the 1980s and early 1990s, but failed to have mainstream impact.
Several areas of "mainstream" global interest have converged during the 1990s to bring greater focus and urgency to production ecology.

- Climate change concerns have brought agriculture into close scrutiny as both a source and sink for carbon and various greenhouse gases (Farquar, 1997).
- The concern with soil quality, and maintaining it under intensively cropped systems by managing carbon and the biota associated with it (Paul et al., 1996, Matson et al., 1997; Cassman and Harwood, 1995).
- The need to reduce pesticide dependence through integrated pest management, and more recently, through ecologically based pest management (NRC, 1995).
- The concern with providing ecosystem services, both at local and global levels (Pimental, 1997).
- Growing knowledge among ecologists about the theoretical, empirical and experimental basis for understanding the relationships between ecosystem processes and the species involved in them (Chapin et al., 1997).

Interests are merging from several of these directions, creating activity and divisions in virtually every professional society dealing with agriculture. The systems' complexity make them difficult to deal with scientifically, as theory is not yet adequate, let alone advanced enough to develop models to deal with such complexity (Roe, 1997).

Much empirical information and case studies of complex systems indicate that many are highly productive and function well in certain environments (NRC, 1993; Harwood, 1996), though they have included few process-level studies. Most soil-related, process-level agroecosystems studies are conducted at experiment stations on long-term managed system plots. The systems studied so far have been mostly in temperate zones under reasonably high management. The pest ecology work has been broader, with a significant amount conducted in tropical areas.

There is a great need to translate evolving process-level agroecological knowledge into a user-friendly applied format. To make the information useful, it has to be reasonably specific to a farming system and environment. The Extension bulletin, Michigan Field Crop Ecology: Managing biological processes for productivity and environmental quality (Cavigelli et al., 1998), is one such attempt. This illustrated guide is based on the assumption that for particular systems and environments key processes serve as focal points for systems adjustment or design. In Michigan, with cold, wet winters, nearby environmentally-sensitive water, and excess winter moisture, field crop productivity and environmental protection depend heavily on a few critical processes. Carbon management is central to soil quality, and subsequently to seasonal nitrogen pulsing, a potential environmental pollutant. Rotation systems provide diversity over time and across the landscape, which appears to greatly determine carbon mineralization seasonality. Cover crops are significant to that diversity, while nematode and other potential pest and disease problems are moderated by it.

In farmer training sessions there is interest in only a very general understanding of process-level factors. It seems that just a modest assurance is adequate--that there is a "scientific" basis for rotation and diversity. Farmers ultimately base their decision on cost, yields and the crop's overall appearance. Some, with a strong philosophical and ethical environmental commitment, will go to great lengths to integrate. Using production ecology information requires that production decisions result from an iterative analysis between process, intervention and outcome.

There is an especially great need for ecologically structuring systems in low soil and water resource areas. Maintaining soil quality, mobilizing and retaining nutrients and managing pests must be done with modest cash inputs on millions of small farms operated by poor farmers. In these areas, especially if rainfall is low or seasonally limiting, adequately maintaining carbon stocks and living biomass (the biological capital) is essential to overall farm productivity (Rhoades and Harwood, 1992).

In summary, the sustainability of production systems ranging from high to low resource areas will increasingly depend on a better availability of "ecosystem technologies" requiring:

- a better understanding of agroecosystem processes
- an understanding of critical processes for farming systems and environmental types
- an ability to move conceptually from ecological process or relationships to production intervention to outcome in a problem-solving, iterative mode during technology development adjustment
- using that information in change-agent (Extension educators, lead farmers, etc.) and farmer understanding
This knowledge and technology must be largely developed by public sector institutions working with both industry and community-based/NGO groups. The C.T. deWit Graduate School of Production Ecology, Wageningen Agricultural University (1997), is an example of one of the leading educational programs. Its mission statement, "How to change present land use systems, including agricultural components to achieve sustainable agricultural production in an environmentally safe, biologically sound and ethically acceptable manner" could well be emulated by more institutions.

Balance Water, Soil and Land Resources Against Competing Uses and Manage for Long-term Productivity While Maintaining Appropriate Ecosystem Quality

Agriculture often shares a fresh water supply that is under increasing demand and degradation from a variety of economic activities. The demand for water is roughly proportional to population growth and economic development. Water use planners refer to a guideline of 1,700 cubic meters of renewable fresh water per person, per year for general adequacy. Below that, water stress occurs, and below 1,000 cubic meters per person there is water scarcity (Falkenmark and Wedstrand, 1992). Population Action International, a Washington-based research and advocacy organization, publishes regular updates on water demand based on population figures. Under United Nations projections of medium population growth to 9.4 billion people by 2050, the number of countries experiencing water scarcity will grow from 18 to 39, and the number of people affected will increase from 160 million to 1.7 billion (Table 4) (Gardner-Outlaw and Engelman, 1997).

There is growing concern for ecosystem water requirements for maintaining wetlands, fresh water fisheries and other ecosystem needs. Fortunately, water use per dollar of GDP and the “water content” of most industrial products is decreasing. Water delivery system costs are increasing, partly due to normal inflation, but also because of increased capital costs of water in more difficult locations. In India and Indonesia, the real costs of new irrigation have more than doubled since the early 1970s, and in Sri Lanka they have tripled (Rosegrant, 1997). In Africa, the average cost for medium-to large-scale projects was estimated at US $8,300 per hectare in 1992 (FAO, 1992). National water balance models are refined by the International Water Management Institute. The institute groups countries into five categories based on their change in projected water use by Year 2025 (IWMI, 1998). Those countries whose projected annual water withdrawals are more than 50 percent of annual water resources are considered water scarce (Seckler et al., 1998). Group One consists of countries that will be extremely water scarce, with eight percent of the population of the 118 countries studied averaging 191 percent of 1990 withdrawals and using 91 percent of their annual water resources by 2025. "It can be expected that cereal grain imports will increase in most of these countries as growing domestic and industrial water needs are met by reducing withdrawals to irrigation."

<table>
<thead>
<tr>
<th>World Population (billion)</th>
<th>Water Conditions</th>
<th>Number of Countries</th>
<th>Population (billions)</th>
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<tbody>
<tr>
<td>5.7 (1995 actual)</td>
<td>stress scarcity</td>
<td>11</td>
<td>0.27</td>
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<td>18</td>
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<td>7.7</td>
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<td>31</td>
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<td>9.4</td>
<td>stress scarcity</td>
<td>15</td>
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<td>stress scarcity</td>
<td>18</td>
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<td></td>
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<td>42</td>
<td>2.2</td>
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stress = between 1000 and 1700m³/person year
Water Availability Under Different Population Assumptions

<table>
<thead>
<tr>
<th>World Population (billion)</th>
<th>Water Conditions</th>
<th>Number of Countries</th>
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<tr>
<td>scarcity = below 1000m³/person year</td>
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For purposes of planning a future sustainable agriculture, the true water cost for all countries will increase, and the quality demands placed on production field effluents will increase. Groundwater overdraft will eventually cease. Water available to agriculture will level off, and in many countries will decrease. Efficiency of use will have to increase in most agriculture. In water scarce areas crop and animal production potential will change, with shifts to higher-value crops and animals. Cereal grain production will shift to areas with greater water resources. Modeling work on national and regional water balance must continue. At the same time many of the agroecosystem approaches discussed above will be critical to maintaining efficiency and reducing effluent stream loading.

While marine ecosystems and production will not be discussed in depth, the leveling off of marine fisheries production has been mentioned (NRC, 1998). A comprehensive review of marine biology and chemistry is found in the July 10, 1998 issue of Science, where ten major scientific articles provide excellent background, including focusing on problems of governance (Upperbrink, 1998). The interaction with onshore activities is striking. The major increase in oxygen-starved coastal "dead zones" during the last 30 years is attributed in large part to agriculture. The "awesome mass of nitrogen that moves down the Mississippi, about 1.82 million metric tons per year", has created an hypoxic zone in the Gulf of Mexico that, like similar zones, blocks access to spawning grounds (Malakoff, 1998). A sustainable agriculture must have acceptable levels of off-site and downstream impact.

Soil quality must be maintained or enhanced for increased productivity. The requirements for maintaining soil quality were discussed under the agroecosystem approach, but will be briefly reviewed here. There is much concern that soil resources continue to degrade at an unacceptable rate (Scherr and Yadav, 1996). A 1995 Annapolis, MD workshop of 35 participants from 14 countries studied a series of review papers on land degradation. The panel concluded that of 8.7 billion hectares of agricultural land, pasture, forest and woodland, nearly two billion hectares (22.5 percent) had been degraded since mid-century, with 3.5 percent degraded so severely that it is reversible only through costly engineering measures (Oldeman et al., 1990). The Annapolis conference concluded that "Land degradation could indeed be a potentially serious threat to food production and rural livelihoods by Year 2020, particularly in more densely populated pockets of rural poverty" (p. 29).

In the U.S., soil degradation is seen more in terms of nutrient and pesticide runoff, with adverse impact on water quality (NRC, 1993; USDA/NRCS, 1997; Faeth, 1997). There is general feeling that while sediment loss is still a problem other water quality factors take precedence.

In developing countries there are concerns, as expressed above, about overall soil degradation. More subtle effects are seen on some of the intensively-cropped tropical soils. Cassman and Harwood (1995) report that of ten long-term experiments on rice systems established before 1975, none exhibited a trend of increasing yields; negative trends were evident in eight experiments in treatments characterized by "optimal" management practices. The average rate of yield decline was 120 kg per hectare, per year. This is probably unique to seasonally submerged soils, as it is hypothesized that chemical changes in organic matter of submerged soils may be ultimately yield-limiting.

There is a general feeling that fertility levels of many tropical soils are being maintained at sub-optimal levels. Suggestions for a significant investment in "recapitalizing" these soils have been made in a major report of the Soil Science Society (Buresh et al, 1997). This problem comes to the fore when considering investment in marginal lands. What should be the development policy toward those lands? Lower-resource lands have about 500 million people on them, comprising more than one-third of the rural poor. By 2020, more than 800 million people will live in less-favored lands (Hazel, 1998). Hazel calls for a strategy of sustainable development that "will be typically different from the Green Revolution approach". A holistic approach to farming systems and land management practices will include plant nutrient generation and recycling and exploitation of favorable niches in a landscape for production of high-value crops and trees. Managing soil organisms by controlling carbon sources and
synchronizing crop demand with soil nutrient release will be an important strategy (Woomer and Swift, 1994). "The successful development of less-favored lands will require strong partnerships for change, including local organizations, national policymakers, and donors (Conway, 1997)." The "less favored lands" thus have both soil and water constraints and will require concerted efforts, using what has been described above as an agroecological approach, to make their productivity sustainable.

Farmland loss is a sustainable agriculture concern which has not yet reached agenda status. There are mixed feelings about farmland loss. Faeth concludes that for the U.S., the loss is "getting worse", is "practically irreversible", but is "probably not a threat". The U.S. has lost an estimated 29.8 million acres of farmland since 1970 (USDA/NRCS, 1997). That represents an area equal to about half our current corn or wheat acreage. With technology and yield increases, such loss does not show in macroeconomic trends. In a time of global food surplus and low prices (partly as a result of depressed economies in Asia and Russia), farmland loss may not seem all that important, but for those thinking more long-term, the loss of an essential and irreplaceable resource seems hardly sustainable!

Since the 1970s, U.S. farmland preservation laws have protected nearly 420,000 acres of farmland at a cost of about $1,750 an acre (USDA/NRCS, 1997).

Improved Technologies are Needed for the "Secondary" Staple Crops, Animals and Trees Which are Unlikely to be Developed Through Commercial Sector Channels

A broad range of staple crops is important to cropping systems diversity, and plays a critical role in the diets and farming system productivity of millions of people in the developing world, particularly poor people. Examples include the grain legumes (chickpea, cowpea, lentils, beans, pigeonpea), the millets (pearl millet, finger millet, setaria) the starchy root crops (cassava, potato, sweet potato, yams) and plantains. Most of these flow through local or regional markets, and are a very small part of international trade. These commodities thus attract very little private development money, being largely outside the area of private capital investment, and since they have lower value than fruit, vegetables and ornamentals, they do not attract small business development attention. These will need major ongoing research support from the public sector to round out the food portfolios of developing countries.

The Development of Local Food Systems is a Critical Engine for the Growth of Rural Economies for Hundreds of Millions of Rural Poor

The 500 million people who live and make their living in less-favored lands are heavily concentrated in Asia and sub-Saharan Africa. Their numbers are projected to increase to more than 800 million by Year 2020 (Hazel, 1998). The solutions to their poverty and low quality of life are considerably different from those of the urban poor. The rural poor depend heavily on the health of local economies and their participation in them.
Global-scale food abundance and low real costs prevent modest resource areas with high populations from profitably competing in production for global markets with the major commodities. Investment capital in these areas will, for the most part, continue to be modest. Public sector funds will remain scarce, and public sector services, whether in research or Extension, will remain at best, modest. Extension services for these areas seem to be devolving from the public sector (Kidd et al., 1998). Communities will increasingly be forced toward self-reliance in many ways. In arguments for self-reliance, both in goods and services, Michael Shuman (1998) states, "A self-reliant community should simply seek to increase control over its own economy as far as is practicable".

I am not arguing, at the moment, for a global model of self-reliant communities, nor for 100 percent self-reliance for any community. I am saying that to most effectively accelerate movement away from poverty toward rural well-being, the initial focus should be on local economy but not isolationism. An economy grows, whether household, local community or nation, as the net value of its total goods and services increases.

For those communities, especially on the periphery of industrial centers, that "export" low-value, raw products and buy back high-value goods and services, the balance of payments is negative. Such communities spiral downward economically as their natural resource base is depleted.

It would seem reasonable, as Shuman and others point out, that the first market for goods and services should be local, meeting as many of the local needs "as is practicable". Export should comprise higher value and value-added agricultural products. An extreme example of a purposeful local-community approach is seen in North American Mennonite and Amish communities. It has been said, "it is far easier to put a dollar into an Amish community than to get one out". Such strategy is not restricted to an ascetic lifestyle, as evidenced by more liberal Mennonite communities who operate with a similar economic strategy, even in the midst of industrial economies.

I am not even arguing for an ultimate self-sufficiency economic state or model. I join those who are skeptical of a completely global economy, but community isolationism at the other extreme would be worse, subjecting the community to the enormous instability of weather and other natural phenomena. A broad and diversified local food system serves as a base for economic growth, where investment can be largely directed toward increasing the production base, rather than toward goods and services. The literature offers many anecdotal studies of individual communities where this has worked, but economic models demonstrating the economic multiplier effects of local economics are not well known. It is argued that such models will work in many, if not most poor rural environments, but perhaps less well in the most harsh environments. For most communities, the evolution and growth of local business will most likely provide transition toward greater national-level economic participation. How far that transition should go is subject to another debate, with most sustainable agriculture advocates making quality of life arguments for a proportion, at least, of local food at the eventually high-development end. There is a valid argument that the quality of life for many Michigan residents is markedly enhanced by access to a diversity of fresh, local food.

How can local economies be stimulated? They need access to appropriate technologies, information on biologically based processes and modest levels of critical inputs. They need access to small amounts of capital at modest rates. They need peace and security. Above all, they need major reliance on civic action and community-based institutions, with modest support from industry and the formal governance sector.

**Developing and Empowering the Community-Based (Civil) Sector**

In this paper community-based refers to community-of-interest. It may be local and geographic, but most communities-of-interest are organized around issues or processes. There are huge numbers of environmental groups, NGOs and other interest groups with agriculture sustainability that form a large part of the community-based sector (Cardenas, 1998). This sector operates to direct and facilitate change from the “bottom-up”. It operates effectively at the local level, organizing people as a key component. The sectors are becoming increasingly adept at leveraging and influencing public policy of governments and institutions such as the World Bank. Its members influence science and science policy primarily through influencing the political process. They provide a “watchdog” function over the commercial sector. Because of their numbers, their broad base and ability to mobilize opinion as a “voice of the grassroots”, they constitute a major force in agricultural sustainability. In particular, they broaden the public sector agenda on sustainability issues.

There is a growing volume of literature dealing with turning development attention to local communities, particularly in dealing with natural resource and biodiversity conservation. "Recent trends toward decentralization or devolution of power and responsibilities to lower levels including local governments and non-government institutions may present promising possibilities as compared to the traditional approach from the 1970s where
impotent national governments in developing countries failed to enforce conservation policies..." (Lutz and Caldecott, 1996).

The same is said for a broad range of social issues, developing of local infrastructure, and providing local initiative for appropriate research and technology development. Conway (1997) devotes a chapter to the "partnerships" needed for agricultural development, referring mostly to public sector relationships or farmers to farmer groups. Most donors will not fund development (or even applied research projects) unless the appropriate "partnerships" are in place and partner roles defined. Everyone, it seems, has to have a "local" partner.

There is lack of clarity as to who are these "partners". It is generally intended that they represent those grassroots people for whom "development" or "assistance" is intended, and that they directly respond to the peoples’ needs.

As deTocqueville (1969) pointed out, "There are not only commercial and industrial associations (in America) in which all take part, but others of a thousand different types--religious, moral, serious, futile, very general and very limited, immensely large and very minute...."

These organizations (associations) form a dense network of secondary associations which both embody and contribute to effective social collaboration. There is a growing feeling that such associations are "a crucial ingredient in successful strategies of rural development" (Esmar and Uphoff, 1984). Many play a crucial role in local resource management (Swallow, 1997) and many are characterized by vertical structure, as are the international NGOs. The more effective seem to be the dense but segregated horizontal networks of local, farmer-led organizations which have ownership and sustain cooperation within each group (smaller community). Putnam (1994) in his book Making Democracy Work, presents an excellent discussion on the topic. He also points out the conflicts which can and do emerge in many developing countries between strong familial structure and association structure.

There is much speculation as to the external factors influencing local organizations. Scherr et al. (1995) list a range of physical, economic, social and governance factors that influence both viability and behavior, while Esmar and Uphoff disagree that physical and economic factors are important.

It seems evident from a broad range of literature that three major sectors are necessary for effective development in a pluralistic society: the formal government sector (the public sector), the commercial sector and the civil sector. In the U.S. there are walls of separation between them. Civil sector organizations have legal status, exemption from taxation (not-for-profit) and are forbidden from public sector electoral activity. They are often highly active in influencing public policy. In agriculture there is a plethora of service organizations representing commodities, environmental issues, philosophical orientations (organic), sustainable agriculture, local food groups, etc. They play an increasing role in information exchange, research, and recognizing and publicizing for a range of causes. They organize farmer training, form on-farm research networks and become the "partners" with both public and commercial sector interests for promoting agricultural change. Along with their counterpart social-service organizations they fill the huge voids left by both commercial and public sector interests. They create tensions by providing a check and balance on the other sectors.

Civil sector organizations are typically absent under autocratic governance. The tradition of civil organization takes years to evolve, and as is the case with modern Russia and its poorly functioning public and commercial sectors, the lack of strong civic associations is particularly detrimental.

It should be noted, however, that not all rural development responsibility can be "downloaded". Horizontal grassroots organizations require considerable time and effort from farmers, who must earn their livelihoods and meet the needs of extended family. The alternative--farming NGO-type groups, with some hired staff for providing service-seems, in the long run, to be most effective. Some form of member assessment, in addition to outside funding sources is nearly always needed. These organizations, supported by networks of centrally funded civil sector not-for-profit institutions, seem to have significant potential.

Public sector institutions need to learn to work more effectively with civil sector groups without placing a heavy burden on them for input and services. We need to identify ways of strengthening without directing and controlling, and provide ready access to the science and technology flowing from the public sector. The three sectors, roles and the alternative pathways for technology flow to and between farmers are illustrated in Figure 2.

SUMMARY
The starting perspective for sustainable agriculture is normally that of the farmer and his/her local community. This analysis began with that perspective, gleaned from personal experience and from a range of cited sources. I moved to a global perspective, relating local needs to dominant international forces, then suggested necessary changes or additions to those forces needed to achieve sustainability. True agricultural sustainability must be reflected at global, national and local levels, or there is no sustainability. The suggested framework for developing a sustainable agriculture (Figure 1) is one in which agriculture’s growing global demands are met by supplementing and guiding the driving forces for change and growth, while investing considerable resources into the addition of five major sustaining forces. This model, designed to operate at the global level, must be adjusted in its particulars to fit the multitude of local needs. Sustainability in a resource-limited world mandates that the momentum of driving forces must be harnessed for public good. Social and environmental needs dictate that no force can operate in an unbalanced and unguided fashion.

WHICH WORLD?

To borrow thoughts from a delightful treatise by Allan Hammond (1998), what kind of world do we want? Agriculture plays a major role in shaping that world, from food security to commerce to individual productivity and well-being.

Will we have a market world, driven by global markets, bringing widespread prosperity, peace and stability?
Will we have a fortress world, driven by the failure of market-led growth to redress social wrongs and prevent environmental disasters, while disrupting communities and their contribution to stability?
Or will we have a transformed world, where enlightened policies and voluntary actions direct and supplement market forces?

The choices we make toward agricultural sustainability are central to that future.

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