Planned construction of carbon capture and storage CCS facilities will only be able to capture and sequester 5% of anthropogenic CO₂ produced within the projected 39 year infrastructure construction timeframe.
Global carbon sequestration now faces a dilemma.

- Are there impending dangers for inaction with regards to reducing current levels of atmospheric carbon dioxide (CO$_2$), and are we fully persuaded that rising atmospheric CO$_2$ may induce unpleasant changes to global climate or has it already begun in the midst of this discussion?

- Has the portion of green house gases pumped into the atmosphere by human activities brought us to a tipping point, and if so, will a reduction of CO$_2$ in the atmosphere return us to normalcy?

- If we were to try to reverse this trend, do we have a technology that is ready to implement, able to effectively capture large volumes of CO$_2$, and can we afford the cost of this mitigation?
The ideal technical solution must be efficient, safe, economically sustainable and ready to implement.
As we tackle these issues, the ideal technological solutions need to be practical, efficient, safe and ecologically and economically sustainable. They should also be ready to implement and have a positive effect on other environmental sectors without causing negative downstream effects.

Researchers from the Institute for Sustainable Agricultural Research (ISAR) at New Mexico State University (NMSU) are now demonstrating a viable agricultural-based approach to carbon sequestration fulfilling all of the parameters for the ideal technological solution. This approach develops multiple benefits from the capture of atmospheric CO$_2$ while producing no environmental waste. It also provides benefits for multiple sectors of our environment, promotes long term sustainability of agriculture and tackles both near and long term impacts for reducing the depletion of natural resources. The complete process is implementable now, with no development of infrastructure; it is safe, clean, provides the lowest cost for the energy consumer and can be adopted worldwide.

What are the other current proposed carbon capture approaches and are they effective?

A majority of currently proposed solutions for capturing and storing carbon do not meet expectations. Carbon Capture and Storage (CCS) from power plants is promoted as a process for reducing emissions but the costs of CCS methods to capture CO$_2$ are proving to be very expensive. A 2010 report by the International Energy Agency\(^1\) (IEA) projects a $100-$128/ton CO$_2$ price tag for carbon capture and estimates transport and storage costs to be $6 and $14 /ton CO$_2$ respectively. Estimates from the IEA for CCS have quadrupled\(^2\) since 2007 and they only offer an accuracy range of -30% to +50%. Recovery of funds devoted to building CCS plants, operational costs, transportation and storage could more than double the energy cost for consumers. Besides rising prices, proof of concept for CCS is limited and liability issues remain about transportation and long term storage of sequestered CO$_2$.

Higher costs aside, to maintain similar energy production capacity, the proposed methods for CCS come with serious reservations. For every four power plants adopting

\(^1\) http://www.iea.org/papers/2010/ccs_g8.pdf

this system, a fifth power plant must be built to furnish the process energy, all from
an already stressed energy production grid and in a world with declining fuel reserves.
Transportation and storage of captured CO₂ from a CCS system carry the potential for
leaks. Long term liability issues related to storage, will be shouldered by the taxpayer
with mechanisms similar to the liability structures in the nuclear energy industry¹. Even
with capital outlays of over $3.4 trillion for the construction of 1700 CCS facilities by
the year 2050, the potential capture of CO₂ from the atmosphere will only be 5% of the
anthropogenic CO₂ emitted over the same 39 year period. Within that time frame, some
of the plants will have to be rebuilt due to the projected 25-30 year structure lifespan.

Other alternative CO₂ capture and storage approaches promote forest growth
on land previously cleared for agriculture. This approach captures small
amounts of CO₂ as biomass and in a study by Turner² (2004), the first 13 years
of regeneration averaged 200-400 grams biomass/m²/yr. These carbon sinks are
susceptible to rapid release of captured CO₂ if subjected to forest fires, as witnessed
across the western U.S. this year. This approach has a long-term effect of reducing
agricultural productivity in a world that is gaining population as it loses productive
land and also promotes deforestation as an unintended consequence. Cropland
has decreased to 0.23 hectares per capita for a world of 6.75 billion people⁵. Per
capita cropland in 1960 was 0.5 hectares when world population was only 3 billion⁵. Coupled with these reductions, degradation of a large percentage of remaining soils
has also emerged as a critical agricultural problem. Each year 10 million hectares are
abandoned due to soil erosion and diminished production, and another 10 million due
to salinization⁶. It is projected that we have lost almost one-third of our agricultural land
since 1960. To compensate this lost cropland is being replaced by clearing substantial
portions of the world’s forests comprising more than 60% of the deforestation now
occurring worldwide⁷.

While we search for a viable solution, what is happening?

As the search for effective solutions continue, concerned governments around the globe
are increasing their efforts to reduce CO₂ emissions. Countries are making an effort to
conform to global treaties designed to reduce global atmospheric CO₂ concentrations.
The European Union initiated a carbon exchange in 2005 and experienced 5 billion tons

¹Turner, D.P., Guzy M., Lefsky M.A., Ritts, W.D.,
Carbon Sequestration with Remote Sensing
and Carbon Cycle Modeling Environmental
Management, 33:457-466.

²Turner, D.P., Guzy M., Lefsky M.A., Ritts, W.D.,
Carbon Sequestration with Remote Sensing
and Carbon Cycle Modeling Environmental
Management, 33:457-466.

³Pimentel, D., (2000), Soil as an Endangered
Ecosystem Bioscience, 50: 947

⁴Pimentel, D., Pimentel, M. (1996), A Food,
Energy and Society, Boulder, CO, Colorado
University Press.

⁵Doeoes, B.R. (1994) Environmental
degradation, global food production, and risk for
larger scale migrations, Ambio 23:124-130.

⁶Myers, N.A. (1990) The non-timber values
of tropical forests forestry for sustainable
development program, University of Minnesota

Carbon capture using agriculture can be accomplished for less than one-seventh the current estimate of conventional CCS technologies.

Sesbania Leaflets- Sesbania is a nitrogen-fixing summer cover crop used in agriculture to capture CO₂ and nitrogen through production of large amounts of biomass.
CO₂ trading volume in 2009 and another 5 billion tons volume by the first half of 2010⁸.

As of July 4, 2011, the EU enacted legislation for an emissions trading system to deliver low-carbon air travel on all international flights embarking from or landing in Europe⁹.

Australia has implemented a $23/ton CO₂ (Australian $) carbon tax on large CO₂-emitting industries¹⁰ commencing July 12, 2012 with plans to remove 160 million tons of CO₂ out of the atmosphere every year. On December 7, 2009, the U.S. Environmental Protection Agency administrator, Lisa Jackson, formally declared CO₂ a dangerous pollutant, opening mechanisms to begin developing legislation in the U.S. to find “the most efficient, most economy-wide, least costly and least disruptive way to deal with CO₂ pollution”¹¹.

In the midst of these efforts and at a time when both government entities and industry are searching for a viable carbon sequestration platform to build upon, CCS demonstration systems are not living up to system cost and efficiency expectations¹².

Two CCS demonstration projects recently announced they were stopping plans to commercialize CCS. American Electric Power, in partnership with the Department of Energy, cited project cessation on a conventional pulverized coal electric plant in West Virginia due to uncertainty surrounding U.S. climate policy and a weak economy. Duke Energy’s project to outfit an Integrated Gasification Combined Cycle plant with CCS also was shut down by the Indiana Utility Regulatory Commission due to cost overruns and gross mismanagement. With no current best-available-practice that is both proven and reliable and that can be implemented immediately, governments and industry are unable to effectually address their efforts to reduce atmospheric CO₂.

Is there a viable solution that will allow carbon capture now?

As an answer to this dilemma, ISAR has developed an agricultural-based solution for capture and long-term storage of atmospheric CO₂. Most news has covered the excess of CO₂ in our atmosphere but we hear little about the plight of agricultural soils and the lack of soil carbon in modern agricultural systems. The health of a soil is crucial for all plant growth occurring on this planet and low carbon stocks within these environments is detrimental to soil fertility and plant survival. The soil carbon pool in agriculture, in the form of organic matter, offers a nutrient resource for all biological organisms that grow in or inhabit soils. With this in mind, a truly sustainable agricultural system must promote the health and vitality of these soil biomes. To accomplish this, we

---


⁹ Gelineau, G. (2011) Australia to tax nation’s worst polluters. Associated Press.


must promote the buildup of soil organic matter to supply the nutrient and energy resources for proper operation of soil biomes to provide fertile soils. Both the carbon excess in our atmosphere and the carbon deficit appearing in agricultural soils can be properly managed with one simple solution. This solution is to capture and incorporate atmospheric \( \text{CO}_2 \) into plant biomass grown on agricultural land and place this biomass into soils to promote buildup of soil carbon pools. With this approach we are effectively and economically reducing excess atmospheric \( \text{CO}_2 \) to the benefit and promotion of sustainable agriculture. One simple solution can solve two problems. This approach implements Intensive Production (IP) techniques into agriculture and, based on previous and ongoing research by ISAR members, demonstrates tremendous potential for promoting IP agriculture as a practical vehicle for carbon capture and storage. IP agricultural methods capitalize on the growth of massive amounts of plant material (biomass), with continuous or “intensively” grown crops and the growth of cover crops between commodity crops. This biomass is then incorporated into soils as a nutrient resource for soil microbiomes and as carbon resources for soil carbon pools.

Incorporating plant biomass into soil enables agriculture to mimic the soil biological dynamics present in natural ecosystems. Natural ecosystems require no nutrient amendments but they remain some of the most productive with regards to biomass production. Old growth forests, riparian zones and estuaries produce large quantities of biomass (2,500-2,800 grams/m\(^2\)/year) and are able to transfer large amounts of organic material into soils.

The IP approach promotes growth of large amounts of plant biomass and its incorporation into soils. IP has demonstrated biomass growth greater than 7,200 grams/m\(^2\)/year or approximately three times the production of natural systems with no nutrient amendments. Once grown, the carbon produced in the form of plant biomass is distributed into the soil to function as soil organic matter and as an energy resource for biological components of the soil. The chemical bond structure in these plant materials are an energy vehicle similar to what electricity is to our society. Energy in a society enables settlement of inhospitable areas on our planet and abundant energy resources allow; increases in population, development of social diversity, increases in specialization and enhancement of structural complexity. These same benefits are realized in a soil when there are large amounts of biomass. The energy derived from biomass and the structural carbon components it contains promotes the development of a healthy soil foodweb, builds soil fertility, soil tilth, and biological diversity. Promoting
soil energy dynamics similar to those present in natural ecosystems in an agricultural system is beneficial to agricultural production systems and the societies that depend on them.

How long will the CO$_2$ we capture as plant material remain in the soil?

Turnover of these carbon components in the soil are a critical issue for the success of this approach. Carbon from biomass can have a mean residence time from days to millennia in the soil carbon pool and their stability in this environment is co-determined by interactions between the structural complexity of carbon-substrates, microbial actors and other environmental driving variables$^{13}$. In many instances, microbial processing of biomass in soils has demonstrated additional mechanisms delaying decomposition and increasing mean retention time of organic material$^{11}$. For comparison, the average mean residence times for organic carbon in boreal, temperate and tropical ecosystems range from 200-1200 years$^{14}$. Biomass structure, microbial actions and environmental conditions are the key mechanisms promoting efficient long-term capture of carbon utilizing atmospheric CO$_2$ while benefiting soil foodweb structures and increasing soil fertility. By its nature, the IP system is designed to employ the growth of large amounts of biomass, allow respiration of a certain portion and begin this cycle again with a view towards increasing biomass volume and complexity with each cycle.

Carbon Capture, at what cost?

With the IP system, carbon capture can be accomplished for less than one-seventh the current estimate of conventional CCS technologies (approx $17$/Ton CO$_2$). In comparison, European carbon exchange rate of $17$/ton CO$_2$ (U.S./ short ton) a electrical utility company could purchase these offsets from an agricultural trading exchange and offer them to their customers for approximately $0.01$/kWh, resulting in an average $5.70 increase in monthly consumer costs ($U.S.). Fuel costs for gasoline and diesel would realize a ~$0.15 - $0.18 increase per gallon. Airlines could become “Carbon Neutral” where each passenger would contribute less than the cost of a beverage (~$1.84/
IP procedures reclaim degraded agricultural soils, increase productivity, reduce irrigation water requirements and enhance soil biodiversity.

Sesbania cover crop - field of Sesbania at approximately the four week stage of growth. Sesbania can grow up to 12 feet high in 60 days and produce up to 13 tons biomass/acre. This amount of biomass sequesters over 25 tons of atmospheric CO2/acre and fixes or captures approximately 1200 pounds nitrogen/acre.
passenger for medium distance flights). Each of these examples represents an average 6% increase in energy costs for consumers.

ISAR’s research indicates that farmers growing these crops under carbon trading protocols could grow biomass representing up to 50 tons of net sequestered CO₂ per acre (A) of cropland. These crops would produce revenues of approximately $50-$150/acres, thereby insuring grower’s adoption and enabling a smooth transition from conventional to IP agricultural practices. IP has the capability to absorb current total anthropogenic CO₂ emissions (30,398 million tons CO₂/year) through adoption of year-round IP production on 17% of the world’s arable cropland or through the growth and incorporation of ~4 tons/acre dry biomass on cropland worldwide.

The IP approach does not require high-tech equipment or have high costs for implementation. IP can be practiced in any country by farmers of any ability creating economic opportunities and benefits worldwide, including third world countries. With the implementation of IP, valuable resources of energy, capital and captured CO₂ would not be pumped into a “hole-in-the-ground” or to extreme ocean depths, but will be captured and incorporated into soils to improve the quantity, quality and health of farmland worldwide, while increasing crop yield and food quality.

Cover crops are grown year round in 60-120 day cycles and then “green chopped” and incorporated into the top 6” of the soil with a disc to place carbon containing biomass into the soil structure for utilization by the soil biome.
What are the other benefits?

IP agriculture is not limited to carbon sequestration. IP’s greatest benefits promote environmental stewardship through improvement of soil fertility and reduction in use of the natural resources that traditional agriculture has previously grown dependent on. IP procedures reclaim degraded agricultural soils, increase productivity, decrease nutrient amendment and irrigation water requirements, enhance soil biodiversity and reduce the downstream environmental impacts conventional approaches to agriculture have had on ground and surface water pollution.

Due to its low cost, adoption of IP will enable and encourage society to proactively address the impact of increased atmospheric CO\textsubscript{2} concentrations while simultaneously easing pressure on natural resources and our environment. The IP approach will offer a CO\textsubscript{2} sequestration technology that is reliable, safe and economically and environmentally sustainable. As a solution to a global problem IP demonstrates multiple benefits to society and the environment without a detrimental cost to the economy.

Who is practicing this approach?

ISAR is currently demonstrating this approach at NMSU’s Leyendecker Plant Science Research Center. This approach focuses on biomass growth and incorporation for the development of soil fertility and soil carbon storage dynamics. These efforts have demonstrated improvement in the long-term sustainability of agricultural soils, reduction in chemical inputs and pollution while promoting energy and water conservation, for minimal cost and maximum benefit.

ISAR is composed of a group of scientists who, for the previous ten years, have integrated interdisciplinary approaches to further the advancement of sustainable agriculture. ISAR has the scientific, technical and agricultural expertise necessary to address complex issues confronting the capture and sequestration of atmospheric CO\textsubscript{2}.
Flowering Cover Crops also offer added benefits of providing habitat for raising beneficial insects to promote healthy predator/prey ratios in adjacent production fields. The blossoms also provide nectar and pollen for bees and other pollinating insects, and refuge and nutrition for birds and higher trophic level predators.
How can you help?

- ISAR desires to continue this research to further validate this technology for development and scientific support. These results will be presented to state, federal and world policy makers to promote acceptance of IP agriculture as a viable world-wide platform from which to address the reduction of atmospheric CO$_2$.

- Currently we are seeking funds from state and federal government as well as private industry to continue this research and initiate a pilot project with area agricultural professionals to enable efficient and prompt technology transfer. ISAR is requesting your assistance with this innovative approach towards promoting logical and productive solutions to environmental problems and look forward to your support for this endeavor.