Assessment of GHG and N agricultural emissions, mitigation, and projections for the Packard Foundation

Presentation to C-AGG
March 1, 2012
Provide the Packard Foundation with a concise synthesis of the following:

1) What was the range of plausible scenarios for US agriculture emissions and sequestration between 2008 and 2020 and what trajectory are we following?
2) What are the sources of GHG from agriculture in the US?
3) What are the most promising opportunities for US agriculture to mitigate climate change?
4) What was the range of plausible scenarios for nitrogen pollution associated with US agriculture between 2008 and 2020 and what trajectory are we following?
5) What are the sources of nitrogen pollution from agriculture in the US?
6) What are the most promising opportunities for US agriculture to mitigate nitrogen pollution?
GHG Emissions

Introduction > **GHG emissions** > GHG mitigation > Nitrogen pollution > Nitrogen mitigation

- **Scenarios**
  - Global and national context
  - US agricultural emissions overview
  - Livestock
  - Croplands
Additional projections have been run in recent years. While there is notable variance, the trend lines are comparable excluding outlier projections.

- **Blue lines** are historic projections and 2008 inventory & regression – emissions seem to be lower than was expected.
- **Red lines** show the most recent inventory and the expected trajectory from this data. From 1990-2010, agricultural emissions grew by about 0.5% per year.
- **Green lines** show the most recent set of models and projections. The steep green line is the EPA’s draft 2011 Global Anthropogenic projections are out of line with other models and the trajectory implied by the most recent inventory and we have reason to believe it has some flaws.

**CO₂e emissions (Mt)**

Available scenarios currently include:
- EPA’s 2006 Global Anthropogenic Non-CO₂ GHG projections
- EPA’s 2011 Global Non-CO₂ GHG projections (draft)
- EPA’s 2005 GHG Mitigation Potential in U.S. Forestry and Agriculture (Murray et al., uses FASOMGHG model)
- Nicholas Institute’s 2011 GHG Emissions and Nitrogen Use in U.S. Agriculture (uses FASOMGHG model)
- Iowa State University’s 2011 GHG and Nitrogen Fertilizer Scenarios (uses FAPRI model)
While the projections seem to have a wide range, they are all well within the certainty range provided by the most recent inventory.
ISU scenarios show the emissions from agriculture are very difficult to reduce without taking land out of production - which is a losing proposition.

The afforestation scenario, however, leads to significantly increased GHG emissions globally because of land use change in other countries.

- Domestic GHG emissions change surprisingly little between all of the scenarios except for afforestation (the only scenario that takes a significant amount of land out of production).
- The afforestation scenario, however, leads to a net increase in global GHG emissions (6.6%) because of land use change in other countries. This land is generally less productive from a yields perspective (and thus more is required) and is also typically converted from native vegetation.

GHG Emissions

Introduction > **GHG emissions** > GHG mitigation > Nitrogen pollution > Nitrogen mitigation

- Scenarios
- **Global and national context**
- US agricultural emissions overview
- Livestock
- Croplands
US agricultural emissions are 1% of global GHG emissions

Global GHG emissions in 2005: 45.8 Gt CO$_2$e
- Global agricultural emissions in 2005: 6.2 Gt CO$_2$e
- US agricultural emissions in 2005: 415 Mt CO$_2$e

US agricultural emissions have fairly consistently been 6-7% of all US emissions.

Emissions growth rates for the agricultural sector and all of the US are shown below. From 1990 – 2008 agricultural emissions grew by 17% and all US emissions grew by 14%.

GHG Emissions

Introduction > GHG emissions > GHG mitigation > Nitrogen pollution > Nitrogen mitigation

- Scenarios
- Global and national context
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- Croplands
Both cropland and grassland (grazed land) emissions have high levels of uncertainty. Grassland emissions are the least certain, but emissions are greater for cropland; thus cropland and grassland contributes about equally to overall uncertainty.


<table>
<thead>
<tr>
<th>Source</th>
<th>Estimate</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>Range $Tg \text{CO}_2e$</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>Range percent $Tg \text{CO}_2e$</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livestock</td>
<td>203</td>
<td>185</td>
<td>230</td>
<td>45</td>
<td>-9</td>
<td>+14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crops$^1$</td>
<td>154</td>
<td>84</td>
<td>215</td>
<td>131</td>
<td>-34</td>
<td>+71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassland$^1$</td>
<td>33</td>
<td>5</td>
<td>132</td>
<td>127</td>
<td>-84</td>
<td>+298</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Emissions</td>
<td>390</td>
<td>274</td>
<td>577</td>
<td>303</td>
<td>-30</td>
<td>+48</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 - Includes sequestration in agricultural soils.

Source: USDA Agriculture and Forestry Greenhouse Gas Inventory: 1990-2008
Gross agricultural GHG emissions are split 58/42 between livestock and cropland. The biggest contributors are agricultural soils (~33%) and enteric fermentation (~30%).

Gross agriculture emissions in 2008: **463 Mt CO$_2$e**
- Net emissions totaled 390 Mt, due to C sinks in Grazed Lands and Mineral Soils
- Gross emissions for livestock and crops combined have risen 9% since 1990.

**Gross GHG Emissions from Livestock and Crops (Mt CO$_2$e)**

**Gross GHG emissions in 2008 (Mt CO$_2$e)**

- Rice Cultivation, 7, 2%
- Residue Burning, 1, 0%
- Soil Management, 153, 33%
- Grazed Lands, 65, 14%
- Organic and Liming Soils, 34, 14%
- Manure Management, 62, 14%
- Enteric Fermentation, 141, 30%

Texas, Iowa, and California lead the country in per state agricultural GHG emissions, together accounting for nearly 25% of US agricultural emissions.

Maps created by GreenInfo Network

Mt CO$_2$e
Texas – 40
Iowa – 30
California - 27
GHG Emissions

Introduction > **GHG emissions** > GHG mitigation > Nitrogen pollution > Nitrogen mitigation

- Scenarios
- Global and national context
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  - **Livestock**
  - Croplands
There are three primary sources of livestock emissions which are highly correlated with animal type.

Leading sources of emissions by animal type (2008):

- **Enteric fermentation**: Livestock, primarily rumens, emit methane directly as a byproduct of digestion.
- **Manure management**: Livestock manure and urine cause CH\(_4\) emissions through increased decomposition, and N\(_2\)O emissions through nitrification/denitrification.
- **Grazed lands**: N\(_2\)O emissions from forage nitrogen fixation and manure from grazing livestock. Grazed lands can also act as a source or sink for atmospheric carbon dioxide, depending on whether carbon inputs to the soil from plant residues and manure exceed carbon losses from decomposition of soil organic matter.

Livestock emissions are driven primarily by cattle, both beef and dairy.

Total emissions from Livestock (2008): 208 Mt CO$_2$e
- Emissions from dairy cattle have grown by 26% from 1990 to 2008
- Emissions from swine have grown by 46% from 1990 to 2008
- Emissions from beef have grown by 8% from 1990 to 2008

Livestock GHG Emissions - Excluding Grazed Land (Mt CO$_2$e)

Dairy cattle are by far the largest emitters on a per head basis

- Dairy cattle carbon intensity is due to their 1) size x production rate: CH4 and 2) manure management intensity (a high percent are in feedlots)
- Variability in beef cattle (and horse) per head emissions, are from grazed lands
- There has been significant growth in per head emissions from dairy cattle (due to manure, see next slides)

Dairy cattle lead emissions per head for manure by a staggering amount

- When we just consider emissions from manure management on a per head basis, dairy cattle are off the charts: over 6x the emissions per head of the next most significant animal type (swine)
- Dairy cattle emissions per head has increased over time as dairy operations consolidate and move from pasture to feedlot
- Beef cattle manure emissions are negligible because the vast majority of them are raised on pasture

Even when looking at just enteric fermentation emissions, dairy cattle’s emissions factor – per head – is over 2x that of beef cattle

- Dairy cattle enteric fermentation rates are high because they are mature animals operating at high levels of production (~100 lbs of milk per day) → they EAT A LOT!

Texas, California, and Iowa lead the country in per state livestock GHG emissions – together accounting for 30% of US livestock emissions.
Texas leads the country in enteric fermentation emissions (13% of country total) because it has by far the biggest population of beef cattle.
Dairy cattle in California and swine in Iowa and North Carolina lead GHG emissions from manure. These three states account for 35% of US manure emissions.

Mt CO$_{2e}$
California – 9
Iowa – 8
No Carolina - 5

Maps created by GreenInfo Network
Texas alone accounts for 20% of US grazed land emissions – due to its beef cattle population.
GHG efficiency on a per head basis for beef cattle is within a 35% range for the states with the largest aggregate emissions.

Note: California is the 10th largest state in terms of aggregate Beef Cattle Emissions and has emissions per head at 1.2 Mt CO$_2$e.

For dairy cattle, California is by far the largest aggregate emitter, driven by the number of head and by relative inefficiency of production on a GHG basis.

Iowa, the largest GHG emitter for swine, is a relatively efficient place to locate production on a GHG basis.

Methane emissions potential varies greatly by type of manure system. Liquid systems tend to have higher methane emissions.

- Methane emissions vary with residence time and temperature. Warmer climates lead to higher emissions.
- Dry systems have higher nitrous oxide emissions, but overall, nitrous oxide emissions are a smaller contributor to manure emissions.

### Methane emissions potential (percent of initial content) for manure management systems in the Midwest and Great Plains

<table>
<thead>
<tr>
<th>System Type</th>
<th>Methane Emissions Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagoons</td>
<td>70%</td>
</tr>
<tr>
<td>Liquid</td>
<td>40%</td>
</tr>
<tr>
<td>Deep litter cattle</td>
<td>30%</td>
</tr>
<tr>
<td>Daily spread cattle</td>
<td>20%</td>
</tr>
<tr>
<td>Dry lot</td>
<td>10%</td>
</tr>
<tr>
<td>Solid storage</td>
<td>5%</td>
</tr>
<tr>
<td>Poultry bedding</td>
<td>2%</td>
</tr>
<tr>
<td>Compost</td>
<td>1%</td>
</tr>
<tr>
<td>Pasture</td>
<td>0%</td>
</tr>
</tbody>
</table>

Source: Center for Rural Affairs, “Soil Carbon and Agriculture”.
GHG Emissions

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Cropland emissions are almost exclusively driven by soil management, with corn accounting for the greatest emissions on a per crop basis.

Total gross emissions from Cropland (2008): **196 Mt CO$_2$e**

- Net emissions = 154 Mt CO$_2$e
- 153 Mt from soil management (78% of gross emissions)
- Negligible emissions from residue burning (1.5 Mt) and rice cultivation (7.2 Mt)

**Source:** EPA 2011 U.S. Greenhouse Gas Inventory Report
Corn is both the largest GHG emitter and the least efficient on a per unit area basis.

Corn emissions are larger than other crops on a per hectare basis because of they require much more fertilizer on a per hectare basis.

Note inefficiency of rice compared to other crops. On an aggregate basis, however, rice emissions are very low.

Five Midwestern states and California account for 40% of cropland emissions

Maps created by GreenInfo Network

Mt CO$_2$e
Iowa – 16
Illinois – 12
Minnesota – 10
Indiana – 8
Ohio – 7
California - 7
There are several different approaches to mitigation of agricultural emissions. Those that shift production to less efficient locations should be avoided.

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-category</th>
<th>Risks &amp; limitations</th>
<th>Intervention options</th>
</tr>
</thead>
</table>
| Reduce demand for carbon intensive agricultural commodities | • Reduce per capita meat consumption  
• Reduce % of food waste | • Very distributed problem  
• Difficult to develop mandates or incentives | • Vegetarianism campaign  
• Food service campaign  
• Change in expiration date protocols |
| Reduce agricultural commodity production | • Afforestation  
• Restoration of wetlands, organic soils  
• Convert land to set-asides or buffers | Leakage – without a simultaneous shift in demand, production will likely just shift elsewhere, possibly to a less carbon efficient location. | • Production tax  
• Expand CRP  
• No grazing on fed lands  
• Stricter CWA regulations  
• Decrease commodity subsidies  
• End biofuels subsidies  
• Pay farmers not to farm |
| Shift production to less GHG intensive commodities | • Use more perennials  
• Increase production of woody crops, agroforestry  
• Convert cropland to pastureland  
• Diversify crop rotation | May also be a risk of leakage with these interventions. The dynamics of specific changes in production patterns would need to be modeled. | • Subsidize the lowest GHG crops  
• Revenue neutral tax on top GHG ag products (e.g. dairy and corn) |
| Change practices to reduce GHG intensity of production | • Improve productivity and management of grazed lands  
• Improve productivity and management of croplands (e.g. tillage, cover crops, nutrient use efficiency)  
• Improve livestock efficiency  
• Improved manure management | • Some of the practices in this category may have positive leakage effects and/or positive environmental co-benefits.  
• Some may have negative impacts on other environmental resources (e.g. water, pesticides). | • USDA programs  
• Supply chain pressure  
• Carbon markets  
• Other PES markets |
We scanned the literature for assessments of mitigation potential. We based our analysis on data provided by the Nicholas Institute’s (T-AGG) US Agricultural GHG Assessment Literature Review because it provided the best data on a per practice basis.

<table>
<thead>
<tr>
<th>Study</th>
<th>region - practice</th>
<th>gas considered</th>
<th>price of CO2</th>
<th>mitigation potential estimate (Mt CO2e / yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>McKinsey Cost Curves (2030 abatement)</td>
<td>US - cropland</td>
<td>CO2, N2O, CH4</td>
<td>at various prices</td>
<td>128.97</td>
</tr>
<tr>
<td>Lal et al. (2003)</td>
<td>US - cropland</td>
<td>CO2</td>
<td>biophysical potential</td>
<td>165-360</td>
</tr>
<tr>
<td>McKinsey Cost Curves (2030 abatement)</td>
<td>US - grassland</td>
<td>CO2, N2O, CH4</td>
<td>biophysical potential</td>
<td>63.73</td>
</tr>
<tr>
<td>McKinsey Cost Curves (2030 abatement)</td>
<td>US - livestock</td>
<td>CO2, N2O, CH4</td>
<td>biophysical potential</td>
<td>18.29</td>
</tr>
</tbody>
</table>
Current literature is reasonably consistent in its assessment of GHG mitigation potential in US agriculture. Soil carbon sequestration presents the greatest opportunity.
A review of the biophysical potential of cropland and grassland mitigation practices

The Nicholas Institute published a series of reports in the fall of 2011 / winter 2012 presenting a thorough review and synthesis of the literature on the greenhouse gas mitigation potential from US agriculture.

• We used the Nicholas Institute’s January 2012 “Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature” to conduct the following analysis.

• This report provided mean estimates as well as high and low ranges for the soil carbon sequestration potential, methane and nitrous oxide emissions reductions potential, and process and upstream emissions reductions potential for 42 mitigation practices.

• The report also provided an assessment of the maximum area available for each mitigation practice.

• Although there are many data gaps and high levels of uncertainty for many of the practices, and there is a wide range in the level of scientific certainty between the different practices, this report provides by far the best data set of the biophysical potential for cropland and grassland mitigation in the U.S.

• The authors chose not to aggregate the data to show overall biophysical mitigation potential per practice because they felt that the resulting data could be misleading for several reasons including:
  • It over emphasizes the opportunity to sequester soil carbon because many practices are occurring on the same land base and would not be additive.
  • It does not take into account the economic potential of these practices.
Comparison of mitigation opportunities (t CO₂e) on a per hectare basis

Double asterisk (**) indicates practices that are based on data with significant research gaps.

Set aside histosol cropland has been removed to provide a more granular scale. On a per ha basis, set aside histosol cropland provides on average 37 t CO₂e of mitigation potential.
The most promising practices are those that have a high biophysical potential on a per ha basis, and a low implementation cost.

- The economic viability of these practices needs to be considered. Unfortunately, we lack an economic analysis at a comparable level of detail.
- We do know that practices that require taking land out of production have a high opportunity cost and thus are only viable if there is there is a comparably high payment for doing so.
- Transaction costs are kept low for those practices that are easily monitored and widely applicable (e.g. tillage, cover crops, fallow mgmt.)

<table>
<thead>
<tr>
<th>Practice</th>
<th>Requires land use change or significant change in crop production patterns</th>
<th>biophysical potential (CO₂e per ha)</th>
<th>applicable area (Mha)</th>
<th>enviro co-benefits</th>
<th>scientific certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use winter cover crops</td>
<td>N</td>
<td>1.9</td>
<td>66</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Switch to no-till</td>
<td>N</td>
<td>1.5</td>
<td>94</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Adjust rice water management</td>
<td>N</td>
<td>1.1</td>
<td>1.3</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Switch to other conservation tillage</td>
<td>N</td>
<td>0.7</td>
<td>72</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Eliminate summer fallow</td>
<td>N</td>
<td>0.4</td>
<td>20</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Reduce fertilizer N application rate by 15%</td>
<td>N</td>
<td>0.3</td>
<td>68</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Plant rice cultivars that produce less CH4</td>
<td>N</td>
<td>1.0</td>
<td>1.3</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Switch fertilizer N source from ammonium-based to urea</td>
<td>N</td>
<td>0.6</td>
<td>37</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Manage species composition on grazing land</td>
<td>N</td>
<td>0.6</td>
<td>80</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Use nitrification inhibitors</td>
<td>N</td>
<td>0.4</td>
<td>92</td>
<td>+</td>
<td>M</td>
</tr>
<tr>
<td>Change fertilizer N placement</td>
<td>N</td>
<td>0.3</td>
<td>63</td>
<td>+</td>
<td>M</td>
</tr>
<tr>
<td>Switch to slow-release fertilizer N source</td>
<td>N</td>
<td>0.2</td>
<td>93</td>
<td>+</td>
<td>M</td>
</tr>
<tr>
<td>Change fertilizer N timing</td>
<td>N</td>
<td>0.2</td>
<td>53</td>
<td>+</td>
<td>M</td>
</tr>
</tbody>
</table>
Practices that take land out of production or significantly change crop production patterns have a high opportunity cost and may not be beneficial on a net global GHG basis.

- Several studies indicate that taking land out of production in the US can result in a net increase in GHG emissions on a global basis.
- Those practices that do not require a change in land use but may reduce yields (e.g. perennials, fertilizer N management), may need further study.

<table>
<thead>
<tr>
<th>Practice</th>
<th>Requires land use change or significant change in crop production patterns</th>
<th>biophysical potential (CO₂e per ha)</th>
<th>applicable area (Mha)</th>
<th>enviro co-benefits</th>
<th>scientific certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establish agroforestry (windbreaks, buffers, etc.)</td>
<td>partial</td>
<td>3.9</td>
<td>21</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Switch to short-rotation woody crops</td>
<td>Y</td>
<td>3.9</td>
<td>40</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Set aside cropland or plant herbaceous buffers</td>
<td>Y</td>
<td>3.6</td>
<td>17</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Convert cropland to pasture</td>
<td>Y</td>
<td>3.1</td>
<td>unknown</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Include perennials in crop rotations</td>
<td>Y</td>
<td>0.7</td>
<td>56</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Diversify annual crop rotations</td>
<td>Y</td>
<td>0.2</td>
<td>46</td>
<td>+</td>
<td>H</td>
</tr>
<tr>
<td>Set aside histosol cropland</td>
<td>Y</td>
<td>37.8</td>
<td>0.8</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Reduce rice area</td>
<td>Y</td>
<td>6.3</td>
<td>1.3</td>
<td></td>
<td>L</td>
</tr>
<tr>
<td>Set aside grazing land</td>
<td>Y</td>
<td>-1.0</td>
<td>unknown</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Restore wetlands</td>
<td>Y</td>
<td>3.9</td>
<td>3.8</td>
<td>+</td>
<td>M</td>
</tr>
<tr>
<td>Replace annuals with perennial crops</td>
<td>Y</td>
<td>1.4</td>
<td>13</td>
<td>+</td>
<td>M</td>
</tr>
</tbody>
</table>
Several mitigation practices do not have sufficient data to be pursued aggressively at this time. The practices listed below are worth pursuing because they are likely to have positive mitigation potential.

- Given the available data, the technical potential of **biochar** seems to dwarf other mitigation opportunities, but we do not know enough about the economic potential or the life cycle impacts. Further research is necessary.
- **Grazing land management** is an area that deserves further inquiry. Mitigation opportunities on pasture land seems to have more certain potential than rangelands, but the sheer acreage of rangelands in the US mean that the potential could be very significant and further research would be a worthwhile investment.

<table>
<thead>
<tr>
<th>Practice</th>
<th>Requires land use change or significant change in crop production patterns</th>
<th>biophysical potential (CO₂e per ha)</th>
<th>applicable area (Mha)</th>
<th>enviro co-benefits</th>
<th>scientific certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apply biochar to cropland</td>
<td>N</td>
<td>10.1</td>
<td>124</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Manage farmed histosols</td>
<td>N</td>
<td>7.5</td>
<td>0.8</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Apply organic material (e.g., manure)</td>
<td>N</td>
<td>2.6</td>
<td>8.5</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Establish agroforestry on grazing land</td>
<td>N</td>
<td>2.1</td>
<td>70</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Introduce rotational grazing on pasture</td>
<td>N</td>
<td>1.4</td>
<td>42</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Improve manure management to reduce N2O</td>
<td>N</td>
<td>0.8</td>
<td>12</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Improve irrigation management (e.g., drip)</td>
<td>N</td>
<td>0.5</td>
<td>20</td>
<td>+</td>
<td>L</td>
</tr>
<tr>
<td>Increase cropping intensity</td>
<td>N</td>
<td>unknown</td>
<td>unknown</td>
<td>+</td>
<td>L</td>
</tr>
</tbody>
</table>
High level take-aways from Nicholas Institute’s assessment

Soil carbon sequestration provides a bigger opportunity than reduction of N$_2$O or CH$_4$.

- Understanding the aggregate mitigation opportunity for soil carbon is challenging because the ability of any single ha of cropland to sequester soil is limited and only 1-2 practices can be applied at one time. Adding the potential of all of these practices together is counting the same carbon multiple times.
- The additionality, reversibility, and additive (i.e. time limited) characteristics of soil carbon sequestration need to be considered.
- Because soil carbon sequestration opportunities are largely diffuse, they may be costly to implement.
- The soil sequestration potential of both biochar and grazing lands may be very large and should be studied further.

The impact of mitigation practices on commodity markets needs to be carefully considered.

- Baker et al. 2011 finds that “climate mitigation opportunities increase the demand for land for nonfood benefits, reduce commodity supply, and result in significant commodity market impacts.”
- Recent studies from both Iowa State University (Elobeid et al. 2011) and Nicholas Institute (Mosnier et al. 2012) find that taking land out of food production in the US, either for biofuel production or afforestation, can lead to a net rise in global GHG emissions.

Nutrient use efficiency that is managed so as not to reduce yields is worth pursuing despite implementation barriers. It has potential to be a low cost, scientifically valid, widely applicable opportunity with significant environmental co-benefits.

Mitigation opportunities that are only applicable to very limited areas (e.g. rice, organic soils restoration, wetlands restoration) may be low hanging fruit and worth pursuing, but will not have a significant impact in the aggregate.
Livestock mitigation opportunities are less well studied, but seem to have lower potential overall than soils management.

- Based on an initial literature review, it seems that livestock mitigation potential is less than 50 Mt CO$_2$e per year.
- The McKinsey study indicates that livestock mitigation potential may be lower hanging fruit from an economic perspective.
- Enteric fermentation emissions reductions (methane)
  - The production efficiency gains inherent in reducing enteric fermentation emissions support the hypothesis that these mitigation practices are cost effective.
  - Opportunities are focused on improving diet quality (higher quality forage, feed additives).
  - There seems to be an important opportunity to further research forage crops and forage crop breeding to improve their digestibility. Few public sector breeders work on forage crops.
- Manure management emissions reductions (methane and nitrous oxide)
  - Opportunities include: changing diet to reduce manure production, improved management of manure application to fields, and changing manure storage systems.
  - Methane digesters and other improved manure management systems are relatively well proven technologies that should be supported.
  - Improved management of manure application on fields is a ripe opportunity at the intersection of livestock and croplands emissions. Improving management of this resource will help close the loop on the nitrogen cycle, improve water quality, and reduce nitrous oxide emissions.
The mitigation potential for carbon sequestration is concentrated in the Midwest, particularly in the Corn Belt.

The Nicholas literature review provided total hectares available per mitigation practice, but did not provide regional distribution for this potential within the US. Murray et al. 2005, while outdated, provides some indication of where in the U.S. mitigation potential is greatest.

- This data was generated from an earlier version of the FASOMGHG model – thus up-to-date versions of this analysis are possible from the modelers.
- While these results are dated, we believe that the concentration of mitigation potential in the Midwest, especially in the Corn Belt, is still valid.

Regional distributions of soil carbon sequestration under payment for soil carbon only: $15/t CO2e

A 2009 study of mitigation opportunities in the Midwest supports the finding that approximately half of the agricultural mitigation opportunities in the US can be found in the Midwest.

This study, sponsored by the Chicago Council on Global Affairs estimates total agricultural mitigation potential in the US to be 330 Mt, and mitigation potential in the Midwest to be approximately 170 Mt.

Most economic studies apply sectoral economic models to determine the potential of different broad categories of practices at different prices of carbon.

- The McKinsey study offers a relatively granular economic analysis and indicates that agricultural mitigation opportunities are relatively cost effective.
- However, the McKinsey findings were not generated with a sectoral economic model and are most useful for comparing the relative scale of practice types and should not be relied upon for supporting the development of individual practices.
Nitrogen pollution

Introduction > GHG emissions > GHG mitigation > **Nitrogen pollution** > Nitrogen mitigation
1) What was the range of plausible scenarios for US agriculture emissions and sequestration between 2008 and 2020 and what trajectory are we following?

2) What are the sources of GHG from agriculture in the US?

3) What are the most promising opportunities for US agriculture to mitigate climate change?

4) What was the range of plausible scenarios for nitrogen pollution associated with US agriculture between 2008 and 2020 and what trajectory are we following?

5) What are the sources of nitrogen pollution from agriculture in the US?

6) What are the most promising opportunities for US agriculture to mitigate nitrogen pollution?
About 35 Tg of reactive nitrogen is added generated each year in the US. Agriculture is responsible for more than half, and for almost 2/3 of anthropogenic sources.

- Agricultural nitrogen is growing at about 1.5% per year.
- Crop biological fixation is growing more quickly than synthetic fertilizer (2.4% vs. 0.9%).
- Future growth rates will depend a lot on ethanol production patterns.

After substantial growth through the 1960s, 70s, nitrogen fertilizer use has leveled off in recent decades.

Source: NASS
All cereal crops together use 66% of nitrogen fertilizer, with corn being the single biggest user.

Nutrient use by crop 1960 – 2009 (1,000 tons)

Corn receives 43% of all nitrogen fertilizer application in the United States.

Source: NASS – ask Mark for full source, and EPA Science Advisory Board 2011, Reactive Nitrogen in the United States
On a per hectare basis, corn consumes the most nitrogen of the row crops. Many specialty crops demand more nitrogen per ha, but have much smaller acreage.

- In 2010, there were 88 million hectares of corn planted in the US
- California had 8.9 million total hectares of cropland in production in 2007

The good news is that nutrient use efficiency for corn has been rising since the mid-70s.

- Despite this steady increase in NUE, the average N fertilizer uptake efficiency for corn in the north-central U.S. was 37% of applied N in 2000 (Cassman et al. 2002).
- These results indicate that greater than 50% of applied N fertilizer is vulnerable to loss pathways such as volatilization, denitrification, runoff, and leaching.

Trend in corn grain produced per unit of applied fertilizer in the US