NON-MANURE AGRICULTURAL METHANE EMISSION SOURCES AND MITIGATION OPTIONS

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1. EXECUTIVE SUMMARY

The Methane to Markets Agriculture Subcommittee works to reduce methane emissions from agricultural sources. The Subcommittee currently focuses on promoting methane capture and use from manure management, which has the most viable, near-term opportunities for methane recovery and utilization. The Methane to Markets Partnership is considering the possibility of incorporating other sources of agricultural methane into the scope of its work.

The main sources of agricultural methane emissions are enteric fermentation and rice cultivation. The purpose of this paper is to provide a brief overview of the methane emission mitigation options for enteric fermentation and rice cultivation and to provide information regarding the groups that are doing work to promote methane emissions reduction work from these two sectors. This information will assist the Steering Committee in determining whether the Methane to Markets Partnership should consider incorporating any of the mitigation options into the scope of work of the Methane to Markets Partnership.

Many methane mitigation are currently in practice in large-scale operations in developed countries, but barriers still exist for implementation in developing countries. Barriers to some of these options include requiring capital investment such as purchasing new equipment or supplement ingredients, while others require extensive training and outreach. More research is needed for some mitigation options to prove their effectiveness. In addition, the lack of a simple and low-cost methodology for measurement of enteric methane is a barrier. Estimations can be made based on established methodologies, but the calculations to estimate baseline levels and reductions require skills that do not translate well into small, rural livestock operations. Because of these barriers, the potential for promoting enteric methane emission mitigation projects through Methane to Markets is low.

Methane mitigation options for rice cultivation are in various levels of development; substantial research and continued development will be required to make these technologies commercially viable and socioeconomically feasible. Steps must also be taken to ensure that adequate training on various techniques and equipment is provided. Most important, the opportunity to reduce greenhouse gas (GHG) emissions should not outweigh the need to feed a growing population.

Evaluating mitigation options to decrease methane emissions should consider total reductions in all GHGs including nitrous oxide which may be affected by some of the mitigation options reviewed in this paper.

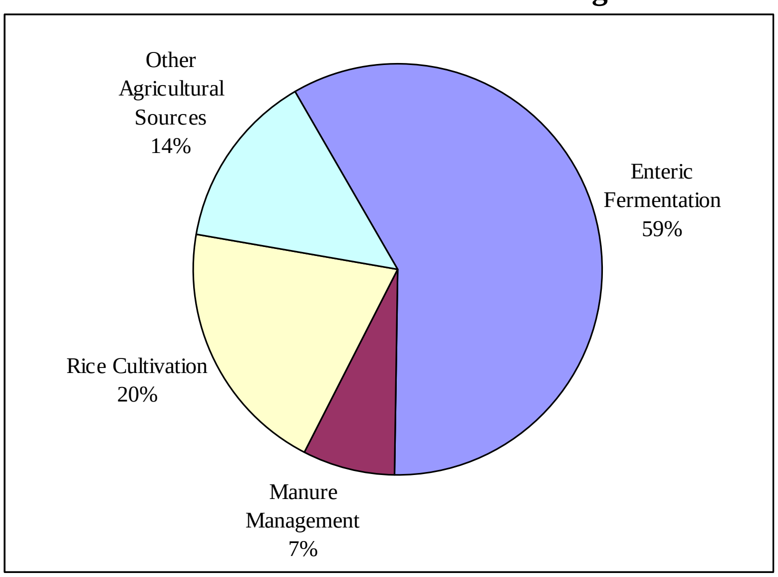
2. PURPOSE OF THIS PAPER

At the Methane to Markets Steering Committee meeting in Beijing in October 2007, the Agriculture Subcommittee agreed to investigate the possibility of including a broader set of methane emission sources into the Methane to Markets Agriculture portfolio. The purpose of this paper is to educate the Steering committee on this topic so the group can consider whether expanding the Methane to Markets work into new areas would be worthwhile.

2.1 Overview of Agricultural Methane Emissions and Identification of Top Sources

Agricultural sources produce 3,290 million metric tons of carbon dioxide (CO_2) equivalents, or 51 percent of worldwide anthropogenic methane emissions (EPA 2006a). The Intergovernmental Panel on Climate Change (IPCC) includes the following agricultural categories in greenhouse gas (GHG) inventories: enteric fermentation, manure management, rice cultivation, agricultural soils, prescribed burning of savannas, and field burning of agricultural residues. Emissions from all agricultural sources are shown in Figure 1. The majority (59 percent) of methane emissions from agriculture are generated from enteric fermentation. Rice cultivation is the second largest source of agricultural methane, producing 20 percent of agricultural methane emissions. Manure management produces 7 percent of worldwide agricultural methane emissions, and other agricultural sources produce 14 percent.

Figure 1. Worldwide Methane Emissions from Agricultural Sources (2005)



Source: EPA 2006a

Sources and amounts of methane emissions vary by region throughout the world. World regions are presented in Table 1 along with the percent of total methane emissions from each region and the percent of the region's methane emissions from agricultural sources.

Table 1. Percent of Total and Agricultural Methane Emissions From World Regions

Region	Percent of Total Worldwide Methane Emissions From Region	Percent of Region's Methane Emissions From Agriculture
Central and Eastern Europe	2%	27%
Eastern Asia	15%	57%
Latin America and the Caribbean	16%	66%
Middle East and North Africa	5%	16%
Newly Independent States of the Former Soviet Union	10%	20%
North America	10%	31%
Oceania	2%	71%
South Asia	11%	64%
South-Eastern Asia	9%	59%
Sub-Saharan Africa	12%	65%
Western Europe	7%	52%

Source: U.S. EPA 2006a

The sources of agricultural methane in each region are presented in Table 2. Rice cultivation is the main source of agricultural methane emissions in South-Eastern Asia; enteric fermentation is the main source in all other regions of the world.

Table 2. Percent of Methane Emissions From Agricultural Sources, by Region

Agricultural Source	World Regions										
	Central and Eastern Europe	Eastern Asia	Latin America and the Caribbean	Middle East and North Africa	Newly Independent States of the former Soviet Union	North America	Oceania	South Asia	South-Eastern Asia	Sub-Saharan Africa	Western Europe
Enteric Fermentation	78%	51%	69%	75%	77%	71%	80%	65%	22%	52%	68%
Manure Management	18%	4%	3%	5%	10%	22%	2%	7%	4%	3%	30%
Rice Cultivation	0%	44%	3%	19%	2%	4%	1%	28%	59%	10%	1%
Other Agricultural Sources	4%	0%	25%	2%	11%	3%	17%	1%	15%	36%	1%

Source: U.S. EPA 2006a

The major sources of agricultural methane not currently covered under the Methane to Markets Partnership are enteric fermentation and rice cultivation. These sources and possible mitigation technologies are described in the next two sections. Other sources, including forest and grassland fires, account for less than a quarter of total worldwide methane emissions and are not included in this paper.

3. OVERVIEW OF ENTERIC FERMENTATION

Ruminant livestock such as cattle (dairy and beef), sheep, and buffalo have a unique digestive system that allows them to eat coarse plant material that humans and other animals cannot digest. The unique digestive system of a ruminant animal consists of a four-part stomach, which includes the rumen, reticulum, omasum, and abmasum.

The rumen is the first and largest compartment, making up about 80% of the total stomach volume, and is unique to ruminant animals. In the rumen, microbial organisms such as bacteria, protozoa, and fungi break down and ferment the plant material into products that the animal can use for energy. This process, called enteric fermentation digests plant matter into organic acids which are then absorbed into the animals' bloodstream to provide energy to support maintenance and product. Maintenance functions are those bodily processes that allow the animal to survive including respiration, blood circulation, skeletal support etc… Production functions include growth of body tissue (meat), lactation (milk, work (draft power) and reproduction. A by-product of a ruminant animal's digestive process is methane, produced by microorganisms in the rumen called methanogens. The animal releases methane into the atmosphere by exhaling or belching the gas through its mouth and nostrils. Methane produces by cattle and other ruminants is actually a loss of feed energy from the diet and represents inefficient utilization of the feed. (Reference: Global climate Change and Environmental Stewardship by Ruminant Livestock Producers)

3.1 Potential Opportunities for Economically Feasible Mitigation of Enteric Fermentation Methane Emissions

The most promising approach for reducing methane emissions from livestock is by improving the productivity and efficiency of livestock production, through better nutrition and genetics, Greater efficiency means that a larger portion of the energy in the animals' feed is directed towards the creation of useful products such as milk or meat so that methane emissions per unit produces are reduced. Ruminant nutrition researchers produced a great deal of information regarding the factors that influence methane production in ruminants including:

- The physical and chemical characteristics of the feed;
- The feeding level and schedule;
- Other dietary components such as feed additives that promote growth and production efficiency; and
- The activity and health of the animal.

There are a variety of mitigation options to reduce methane emissions from enteric fermentation. The majority of these mitigation options increases the animals productivity by improving nutrition and animal health resulting in more milk or meat per animal. This increased efficiency can result in reduced methane emissions per unit of product (e.g., milk, meat, wool) because emissions associated with animal maintenance are spread over a larger amount of product. However, it is important to note that emissions per animal are typically higher because higher productivity is associated with increased food intake. By improving animal production efficiency, emissions per unit product can be reduced by 25 to 75 percent depending on animal management practices (Bowman 2000). In addition, improved productivity can allow managers to reduce the size of the herd necessary to produce a certain quantity of product (O'Mara 2004).

Options that decrease methane emissions from enteric fermentation include:

- Improving quality and type of forage and feed
- Mechanical and chemical processing of feed
- Supplementing feed with nutrients
- Supplementing feed with fats and oils
- Supplementing feed with propionate precursors
- Supplementing Feed with secondary metabolites
- Administering hormones
- Administering antibiotics
- Administering anti-methanogen vaccines
- Balancing herd supply versus demand
- Decreasing animal-based protein consumption
- Improving reproductive productivity and efficiency
- Improving genetic characteristics
- Increasing animal longevity
- Improving pasture through intensive grazing

The options are described in the following sections and summarized in Table 3.

Improving Quality and Type of Forage and Feed

Improving the quality of forage and feed resources improves nutritional value and results in more productive animals. Improved nutrition reduces methane emissions per unit product by optimizing animal performance factors and converting more food energy to beneficial activities, which include weight gain, milk production, work production, and reproductive performance. Increased digestibility of feed also reduces methane emissions because more food energy is used by the animal and less is used to produce methane (O'Mara 2004).

Some forage types, including legumes (e.g., clover), have higher intake and digestibility rates than typical grass pastures and can result in increased productivity and lowered methane emissions. Several promising strategies can reduce methane emissions through forage selection, but these require further investigation, particularly at a whole farm level (O'Mara 2004).

Mechanical and Chemical Processing of Feed

Mechanical and chemical feed processing can provide other options for improving feed to reduce methane emissions from enteric fermentation. Food processing techniques include wrapping and preserving rice straw to enhance digestibility, chopping straw to enhance intake, and treating low-digestible straws with alkali to enhance digestibility. These options are applicable to ruminant animals with limited or poor quality feed. Assuming feed digestibility is increased by 5 percent, this method can decrease methane emissions per unit product on the order of 10 to 25 percent. (Bowman 2000).

Supplementing Feed With Nutrients

Supplementing the amount of critical nutrients in feed is another method of increasing animal productivity to reduce methane emissions. One nutrient that can be supplemented is nitrogen, through the addition of urea. An example of this method is the use of molasses and urea multi-nutrient blocks (MNBs). Molasses is mixed with urea and other supplemental nutrients to make the MNB palatable to ruminants and provide the energy needed to realize the improved microbial growth that can result from enhanced ammonia levels. Demonstration projects have added the molasses and urea mixture directly into the feed or have supplied the supplement as a pre-mixed lick block (Makkar 2007).

The use of MNBs is a cost effective and proven diet supplementation strategy (Bowman 2000). The application of MNBs has been extremely successful in improving productivity, such as milk yields, growth rates, and reproduction (EPA 1991a). MNBs have been used as a supplement in many countries including India, Pakistan, Indonesia, Bangladesh, Thailand, Vietnam, Venezuela, Sudan, and China (Makkar 2007). Typical results include milk yield increases of 20 to 30 percent; growth rate increases of 80 to 200 percent; and increased reproductive efficiency (Bowman 2000). Based on these results, methane emissions per unit product are expected to decrease by up to 50 percent (Jianxin 2002), while methane emissions per animal are estimated to increase by 10 percent per year (Bowman 2000).

Supplementing Feed With Fats and Oils

Feed can also be supplemented with certain fats and oils, such as coconut oil or fish oils. This practice has been shown to remove the ruminal protozoa that work in concert with methanogenic bacteria (Tamminga 2007). Recent studies have shown that coconut oil effectively reduced enteric methane emissions by up to 25 percent in beef cattle (O'Mara 2004). These supplements have not been researched on dairy cows; the impact on milk production has not yet been determined (Tamminga 2007).

Much of the research on supplementing feed with fats and oils has been short term, and the positive effects observed in studies have not yet been conclusively established over the long term. Positive effects have not been persistent, perhaps because of fermentation adaptation, which occurs when the methanogenic bacteria in the rumen adapt to changing feed. The supplements have short-term positive effects that decrease over time as bacteria in the rumen adapt. Alternating feeding strategies might alleviate fermentation adaptation.

Supplementing Feed With Propionate Precursors

Propionate precursors (e.g., malate, fumarate, citrate, succinate) are other types of feed additives that can decrease methane emissions from enteric fermentation. Hydrogen in the rumen can be used to produce either methane or propionate. Supplementing feed with propionate precursors encourages the production of propionate and decreases the production of methane (O'Mara 2004).

Propionate precursors are currently very expensive. Research is being conducted to identify affordable natural sources and engineered feedstocks with high concentrations of propionate precursors. Propionate precursors occur in naturally high concentrations in some feed stocks such as alfalfa but must be extracted and concentrated further to be refined in an additive that provides the desired result (O'Mara 2004).

Supplementing Feed With Secondary Metabolites

Adding plant secondary metabolites (saponins and tannins) to feed is also a current focus of research to determine potential effects on methane production. Plants produce a variety of secondary metabolites to protect themselves against microbial and insect attack. The antimicrobial properties of the metabolites have shown some potential as methane production inhibitors in ruminants during in vitro experiments (Pen 2006). Saponin-containing plants and their extracts have demonstrated the ability to suppress methane production in small-scale experiments. Feedstocks with high concentrations of saponins might have potential to reduce enteric methane; however, most of the research has been short term, and more research is needed before these practices can be used for mitigation purposes. The reduction of methane has not been consistent, possibly due to adaptation of fermentation (Tamminga 2007).

Administering Hormones

The use of hormones in cattle can directly increase milk or meat production and decrease methane emissions per unit of production. Enhancing agents such as hormones are generally most applicable to large-scale commercial systems with well-developed markets. Emission reductions of 5 to 15 percent per unit product have been demonstrated (Bowman 2000).

One hormone used to increase milk production and reduce methane in dairy cattle is bovine somatotrophin (bST) (Etherton 2008). Methane emissions per animal increase, but the number of animals needed to produce the same quantity of milk decrease (EPA 1996). Therefore, methane emissions per unit of milk produced will decrease. The use of hormones on animals is not supported in many countries, however, so this solution might not be broadly applicable.

Administering Antibiotics

Administering antibiotics to ruminants is another option that can potentially reduce methane emissions. In particular, a class of antibiotics called ionophores has been shown to increase animal production and decrease methane emissions. This type of antibiotic alters fermentation acids in the rumen from acetate and butyrate, which are precursors to methane, to propionate, which the alternative chemical pathway and does not contribute to methane production. Ionophores most commonly used in research to reduce methane production are monensin and lasalocid. Monensin is a naturally occurring ionophore and is currently used extensively in U.S. beef and dairy cattle farming to improve growth rates (Swainson 2008). Several ionophores have been licensed for use in beef cattle in many countries and in dairy cows in countries such as Australia, Mexico, and Brazil (O'Mara 2004).

Ionophore supplementation seems to lead to a short-term decrease in methane production; however, that reduction does not seem to persist, and long-term trials indicate that microbial adaptation occurs and translates into antibiotic resistance and a resurgence of methane emissions after an initial drop (Guan 2006). In addition, many countries, including all European Union (EU) nations, have policies that ban the broad use of antibiotics on animals (Tamminga 2007).

Administering Anti-Methanogen Vaccines

An anti-methanogen vaccine is under development, and research is being conducted to measure the effectiveness of its use on ruminants. The vaccine works by triggering an animal's immune system to produce antibodies that recognize and destroy the methanogenic bacteria that live in the rumen of the animal. Methanogenic bacteria appear to be opportunistic microorganisms that colonize in the rumen, and their removal or reduction does not appear to affect the animal (Wright 2008).

The anti-methanogen vaccine is under development by the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. In recent research, a number of experimental vaccine preparations were given to sheep. The studies have shown that up to a 20-percent reduction in methane production is possible, but the observed reductions are dependant on diet, climate, and time of year. To date, sheep have been used as the experimental animal because of the ease of use and availability. CSIRO's next task is to develop a vaccine and test its effectiveness in cattle (Wright 2008).

Balancing Herd Supply Versus Demand

One opportunity to mitigate enteric methane is limiting the size of a herd supply so that it does not exceed product demand. Many operations in developing countries maintain large herds because of cultural beliefs that livestock value and because of the "just-in-case" mentality regarding future demand increases. An imbalance between herd supply and demand increases emissions per unit product sold.

Conversely, there may be situations when there is unmet demand due to inadequate production or inadequate supply. In these situations, improvements in production efficiency can help farms meet the demand without increasing herd size. Increased productivity will likely also reduce methane emissions per unit product (O'Mara 2004).

Decreasing Animal-Based Protein Consumption

A reduction in animal-based protein consumption would decrease the demand for cattle, which would lead to a decrease in the number of animals. Fewer cattle would directly decrease methane emissions.

Improving Reproductive Productivity and Efficiency

Another herd management strategy that can mitigate enteric methane emissions is to improve reproductive productivity and efficiency. Because large percentages of ruminant herds are maintained for the purpose of breeding, methane emissions per unit product can be significantly reduced if reproductive efficiency is increased and fewer animals are required to provide the desired number of offspring. Options such as artificial insemination, twinning, and embryo transplants address reproduction directly; however, these techniques are limited to commercial operations in developed countries. Nutritional improvement in feed, as discussed previously, also can increase reproductive efficiency (Bowman 2000).

Improving Genetic Characteristics

Enteric methane emissions can vary as much as 27 percent from animal to animal in cattle consuming a diet of forage, which suggests potential genetic variation (Whittenberg, n.d.). Further research has yet to determine whether these differences are related to intake behavior, potential anatomical and physiological differences in the gastrointestinal tract of cattle, or the heritability of genetic characteristics. The degree of variability suggests that there is potential to genetically select for low-methane-emitting animals through reproductive genetic selection, however (Whittenberg, n.d.). To reduce overall methane emissions, the low-emitting animals would have to produce as much or more milk or meat as the higher emitting animals, otherwise a larger quantity of animals would be required to produce the same amount of product and emissions could increase.

Improvements in the genetic characteristics of a herd of large ruminants holds potential in mitigating enteric methane because the genetic makeup of herds is a limiting factor in the productivity of large commercial operations. Continued improvements in genetic potential will increase productivity and thereby reduce methane emissions per unit product. Genetic improvements are made by selectively breeding animals with the desired characteristic (e.g., high milk production), which can be done most efficiently by employing artificial insemination or embryo transplants (Bowman 2000).

Increasing Animal Longevity

For dairy cows, an increase in animal longevity will decrease methane emissions from the herd (O'Mara 2004). The longer a cow stays in the herd, the fewer the number of replacement animals required, which results in fewer animals present on the farm and lower total farm methane emissions.

To increase dairy cow longevity, genetic selection can be used to select for characteristics that can prolong an animal's life span, such as favorable hoof and udder traits (USDA 2001). In addition, herd management practices can be employed to improve herd health and prevent unnecessary culling. Proper management includes appropriate housing, nutritional feed, and practices to keep cows healthy and free of disease.

Improved Pasture through Intensive Grazing

Ruminant production efficiency in some production systems is hampered by inadequate management of grazing lands. In particular, overgrazing leads to reductions in livestock productivity and can increase methane emissions per unit of product. The use of a method called "intensive grazing" could mitigate methane emissions from enteric fermentation in situations where the herd is on pasture. Intensive grazing involves rotating animals among pastures to permit grazing of higher quality pasture land. This practice might result in lower animal yields if the animals were previously fed a high energy (grain) diet; however, this practice will decrease methane emissions overall. Intensive grazing is currently applied to beef and dairy cattle in developed regions (EPA 2006b) and could be applied to all ruminants.

Table 3. Summary of Potential Methane Mitigation Opportunities for Enteric Fermentation

Mitigation Technique	Overview	Feasibility/Barriers	Time Frame
Improving Quality and Type of Feed and Forage	This option involves investigating feed or forage types (e.g., grains, grasses, legumes, silage, mixtures) for best nutrient value and digestibility, both of which can affect the amount of methane emissions per unit product.	This option is very feasible for large operations in developed countries and is a current practice because of its benefits. Barriers exist where food types are limited to native plants and grasses and rangeland is confined or limited.	Near term
Mechanical and Chemical Processing of Feed	Techniques include processing food with equipment or adding chemicals to make it more digestible.	This option is feasible but might require additional equipment or a chemical supplier. Barriers include cost and availability of equipment and chemical additives.	Near term
Supplementing Feed With Nutrients (including MNBs)	Supplementing critical nutrients, such as nitrogen, can improve productivity and milk yields. The technique that shows the most promise is using molasses and urea nutrient blocks (MNBs). Studies have shown that MNBs effectively increase productivity and reduce methane emissions.	The use of MNBs is a cost-effective and feasible diet supplementation strategy. There are cost restraints due to equipment requirements.	Near term
Supplementing Feed With Fats and Oils	Fats and oils, such as coconut and fish oils, have been demonstrated to remove the ruminal protozoa that are required for methanogens to produce methane in short-term studies.	Effects have not been persistent, perhaps because of fermentation adaptation. More research is needed in this area.	Long term
Supplementing Feed With Proprionate Precursors	These additives can decrease methane emissions by using some of the hydrogen in the rumen to produce proprionate instead of methane.	This option is not very feasible due to current costs. More research is needed to make this option cost-effective.	Long term
Supplementing Feed With Secondary Metabolites	Metabolites are a plant's natural defense against insects and disease. Metabolites have antimicrobial properties that show potential as methane production inhibitors in ruminants during in vitro experiments.	Most of the research has been short term, and more research is needed before these practices can be used for mitigation purposes. The reduction of methane has not been consistent.	Long term
Administering Hormones	Hormones can directly increase production and decrease methane emissions per unit of production. Hormones have been proven to effectively increase milk production.	Hormones are most applicable to large-scale commercial systems with well-developed markets and are commonly used in U.S. dairy cattle. The use of hormones on animals is not supported in many countries, so this option might not be broadly applicable.	Near term

Mitigation Technique	Overview	Feasibility/Barriers	Time Frame
Administering Antibiotics	A class of antibiotics called ionophores (e.g., monensin) has been demonstrated to reduce methane emissions by altering fermentation acids in the rumen responsible for methane production.	While ionophores are currently used extensively in U.S. beef and dairy cattle farming to improve growth rates, many countries, including all EU nations, have policies that ban the broad use of antibiotics on animals. The effects of ionophores have also been noted as only short term. Long-term studies have shown that that microbial adaptation in the rumen occurs, which translates into antibiotic resistance, and methane emissions revert back to previous levels.	Near term
Administering Anti-Methanogen Vaccine	An anti-methanogen vaccine works by triggering an animal's immune system to produce antibodies that recognize the methane-producing organisms that live in the rumen of the animal and destroy them. Such organisms are not necessary for maintaining the health of the animals, and the animals would not suffer ill effects. Such a vaccine has been tested and has shown promising results.	More research is needed before a vaccine can be demonstrated as a feasible mitigation option.	Long term
Balancing Herd Supply Versus Demand	Limiting supply (or herd size) so that it does not exceed the demand is a simple method to decrease methane emissions. Many operations in developing countries carry a larger herd than the market demand requires.	Balancing supply versus demand is feasible if the current demand is known and future demand can be forecasted. Barriers to balancing the equilibrium between supply and demand include cultural beliefs that livestock hold real and perceived value. Another barrier is the "just-in-case" mentality that influences large herd size in case future demand increases.	Near term
Improving Reproductive Productivity and Efficiency	Improving reproductive rates is an effective mitigation option because large percentages of ruminant herds are maintained for the purposes of breeding. Methane emissions per unit product can be significantly reduced if reproductive efficiency is increased and fewer animals are required to provide the desired number of offspring.	Improving reproductive rates in ruminants is generally feasible for operations in developed and developing countries through the use of artificial insemination. Barriers include availability of techniques and knowledge gaps in smaller operations and less developed countries.	Near to long term. Can be implemented in the near term but emission reductions might take longer to achieve.

Mitigation Technique	Overview	Feasibility/Barriers	Time Frame
Improving Genetic Characteristics	Currently, genetic improvements are made mostly by employing the same techniques as improved reproductive efficiency. By choosing the most productive individuals for breeding, operations can improve the genetic makeup of their herd over time.	While the practice of improving genetic characteristics is widely used in large and sophisticated operations, more research is required to determine whether reductions in methane emissions are related to intake behavior, potential anatomical and physiological differences in the gastrointestinal tract of cattle, or the heritability of genetic characteristics from parent to offspring.	Near to long term. Can be implemented in the near term, but emission reductions might take longer to achieve.
Increasing Animal Longevity	For dairy cows, an increase in animal longevity will decrease methane emissions from the herd. Longevity can be increased though genetic selection and proper herd management.	Genetic selection and proper herd management are widely used in large and sophisticated operations; however, operations in developing countries can have more difficulties implementing these practices due to lack of funding and education.	Near to long term. Can be implemented in the near term, but emission reductions might take longer to achieve.
Intensive Grazing	Rangeland with limited or poor-quality forage can affect livestock productivity. Rotating herds among grasslands can prevent overgrazing, which can lead to reductions in livestock productivity and decrease methane emissions per unit of product.	Currently, this option is widely applied to beef and dairy cattle in developed regions including North America, South America, and Europe. The only barrier is limitations or shortages of adequate grassland.	Near term

3.2 Mitigation Projects for Enteric Fermentation

The United Nations Framework Convention on Climate Change (UNFCCC) passed the Kyoto Protocol in 1997 to reduce GHGs in industrialized countries. The countries might reduce emissions directly or through the use of three market based mechanisms, including: emission reduction trading on the carbon market, the Clean Development Mechanism (CDM), and joint implementation (JI). The CDM permits emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, which can be traded and sold and used by industrialized countries to meet a portion of their Kyoto emission reduction targets. JI allows a country with an emission reduction or limitation commitment under the Kyoto Protocol to earn emission reduction units (ERUs) from an emission reduction project in another country with Kyoto Protocol commitments.

All CDM emission reduction projects must undergo a thorough registration and issuance process and be proven to be real, measurable, and verifiable emission reductions that are additional to what would have occurred without the project. Part of the process involves the development of a UNFCCC-approved methodology for the category of emission reductions. There is no current existing CDM methodology to estimate enteric fermentation emission reductions under CDM and, therefore, there are no current projects to reduce enteric fermentation methane emissions being funded under this mechanism.

The following project to reduce enteric fermentation emissions has been submitted to the UNFCCC for review:

Providing MNBs to Small Farms in Uganda: In July 2006, an application was filed with the UNFCCC for a CDM project and methodology on behalf of the Republic of Uganda. The project proposes to manufacture and sell livestock feed supplements throughout Uganda to improve the nutritional balance of the animals so that they become more productive and profitable for small-scale farmers. The focus of the project is to facilitate and provide the technological capacity to introduce the use of molasses and urea multi-nutrient supplements in the low-quality, low-digestible food stocks typical of Uganda’s small-scale cattle operations (UNFCCC 2006). This project and methodology have not been approved by UNFCCC due to concerns with the applicability conditions, the project boundary, the identification of the baseline scenario and additionality, the baseline emissions, the project emissions, the data and parameters monitored, and the handling of uncertainties (UNFCCC 2008).

3.3 Barriers to Mitigating Enteric Methane Emissions

For enteric fermentation, there are several issues and barriers that must be addressed before any emission reduction project would be approved. Barriers to enteric fermentation project implementation are listed as follows, including issues related to the difficulties of meeting the CDM requirements (which state that emission reductions must be real, measurable and verifiable, and additional to reductions that would have occurred without the project):

- ***Unknown Effects.*** More research is required to understand the full effectiveness of many of the mitigation options previously discussed. Each enteric fermentation methane mitigation option should be evaluated to confirm that methane emissions are reduced without increasing the production of other GHGs such as nitrous oxide or carbon dioxide, while maintaining or enhancing yield. In addition, using productivity enhancing agents, such as antibiotics or experimental supplements, allows for the possibility of adaptation of fermentation and development of antibiotic resistance. Many of the methane reductions achieved by such options might be short lived or inconsistent. Adaptation of fermentation is a phenomenon in which the rumen ecosystem adapts to changing factors from newly introduced supplements. While these supplements can have short-term positive effects, the rumen adapt to their presence and eventually return to baseline conditions.

- ***Limited Measurement Techniques and Lack of Detailed Baseline.*** In general, the cost restraints of actual emission monitoring equipment make estimating emissions through established equations and emission factors the only realistic way to measure enteric methane emissions. In both developing and developed countries, the complexity of the calculations required to estimate emissions are a barrier to establishing baselines and estimating reductions. While lacking baseline emissions does not prohibit an operation from implementing mitigation options, these operations also lack the ability to measure the effectiveness of methane and other GHG reduction efforts.

- ***Capital Costs and Other Restraints.*** Increases in productivity resulting in potential methane reductions are relatively easy to achieve through today's technological advances; however, most animal operations are sensitive to cost, even in developed countries. Methane emission reductions must be valued monetarily for farm operators to realize the benefits of reducing emissions. In addition, small farming operations in developing countries have additional barriers to overcome including lack of capital costs and education.

3.4 Organizations Involved in Promoting Methane Mitigation From Enteric Fermentation

Numerous organizations are currently contributing research and outreach to promote mitigation of methane emissions from enteric fermentation, including scientific institutes, research organizations, universities and governmental organizations.

As described in Section 3.2, ***UNFCCC***, through its CDM, holds the most promise for use as a delivery mechanism of potential mitigation options. The CDM requires that emission reductions are real, additional, permanent, and verifiable. These requirements can be difficult to meet in many sectors. For example, the lack of detailed baseline data for methane emissions from enteric fermentation can lead to controversy over how large the actual emission reductions are for enteric fermentation projects.

While no projects are currently underway to mitigate enteric methane emissions under the CDM, research, implementation, and outreach of mitigation options for developing regions is in

accordance with the goals and objectives of the CDM program.
(http://cdm.unfccc.int/index.html)

As part of its *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* report in 2001, IPCC provided UNFCCC with guidance pertaining to enteric methane (www.ipcc-nggip.iges.or.jp/public/gp/english/). The function of the IPCC guidance is to set procedures for countries submitting emission estimates to UNFCCC. The guidance included methods for accurately estimating methane emissions from livestock for the purpose of setting an enteric emission baseline. The guidance states that if the methane emissions of livestock are poorly characterized, the baseline data will not be effective for measuring resulting reductions of mitigation options. Well-characterized livestock emission data, on the other hand, will be sensitive to the effect of mitigation options. The report contains region-specific emission factors for dairy and beef cattle and other livestock, which may be used to estimate emissions in a "Tier 1" emission estimation methodology. The report also contains more detailed equations, which can be used for calculating emissions in a "Tier 2" or "Tier 3" methodology. These methodologies more accurately reflects conditions such as diet and would be superior for estimating emissions and emission reductions; however, a Tier 2 or Tier 3 methodology requires detailed input, which is not always available. The complexity of accurately estimating enteric methane emissions is one barrier to implementing mitigation options and measuring results on a wide scale.

The ***Commonwealth Scientific and Industrial Research Organization of Australia (CSIRO)*** is Australia's national science agency. CSIRO's focus ranges from astronomy and space exploration, to manufacturing, to health and well being, to food and agriculture. Some of CSIRO's Livestock Industries Division goals are to develop approaches to increase the beneficial environmental impacts of livestock production and to anticipate concerns about livestock products. CSRIO is currently committing extensive resources to researching ways to mitigate enteric methane emissions, with a specific focus on increased understanding of gut microbiology. CSRIO publishes the *Australian Journal of Experimental Agriculture*, in which several recent entries have been published covering relevant topics. (www.csiro.au/)

The ***Food and Agriculture Organization (FAO) of the United Nations*** assists developing nations in improving agriculture, forestry, and fisheries management practices. FAO aims to defeat world hunger through sustainable and sound practices that improve agricultural productivity, and to better the lives of rural populations and contribute to the growth of the world economy through continuous improvement. (www.fao.org/)

In 2006, FAO, with the help of the EU's ***Livestock Environmental and Development (LEAD)*** initiative, published *Livestock's Long Shadow: Environmental Issues and Options*. This document recognized enteric methane emissions not only as an environmental hazard but also as a loss of productivity and stated that an increase in productivity is relatively easy to achieve through technology. The report also concluded that these technologies are not being adopted by small farming operations in developing countries due to the lack of capital and education.
(www.fao.org/ag/againfo/programmes/en/lead/lead.html)

The ***Livestock Emissions and Abatement Research Network (LEARN)*** was established in November 2007 at an international meeting in Christchurch, New Zealand. The intent of this research network is to use a collaborative approach to facilitate the development of cost-effective GHG mitigation solutions. Methane emissions from ruminant livestock is one of the focus areas of LEARN (www.livestockemissions.net/). The member organizations of LEARN are the United States, Canada, Mexico, Brazil, Columbia, Argentina, Chile, Bolivia, Uruguay, Peru, United Kingdom, Ireland, Sweden, Denmark, Germany, France, Spain, Portugal, Belgium, the Netherlands, Italy, Switzerland, Austria, Ukraine, Turkmenistan, India, China, Cambodia, Thailand, Japan, South Korea, Indonesia, Philippines, Indonesia, Australia, New Zealand, Senegal, Nigeria, Ethiopia, Kenya, the United Republic of Tanzania, and South Africa.

3.5 Conclusions for Enteric Fermentation

Many of the mitigation options discussed are currently in practice in large-scale operations because they also lead to improved productivity. Some of these practices could be applied more broadly internationally. However, quantifying the reductions for an offset project utilizing these practices is remains problematic because of lack of cost effective measurement technology, detailed baseline data, and the potential cost of assessing the actual impact of the intervention. Additional economic and technical barriers to implementing many of these practices exist for small farms and for farmers in developing countries.

However, there much positive work is being performed to reduce methane emissions from enteric fermentation and the Methane to Markets Partnership could play a role in a variety of ways. The first could be to promote the development of more detailed baseline information for each country. The second would be to work to promote development of methodologies for ruminant emissions that could be approved by CDM. Finally, another alternative is to promote farming practices that are known to reduce methane and also have the co-benefit of improving productivity for the farmers. These practices may include intensive grazing and certain types of feed supplementation. If the Partnership engages in any of these activities it will be critical for to fully engage the research and extension organizations already working in this area to identify the areas of collaboration and support.

4. OVERVIEW OF RICE CULTIVATION

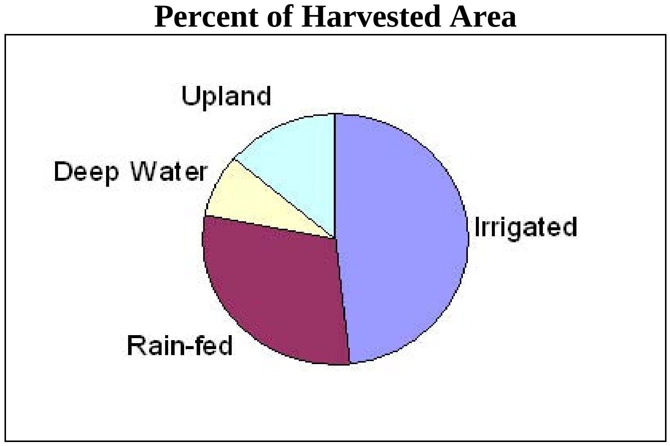
Rice cultivation is the second largest contributor of global agricultural methane after enteric fermentation. Global methane emissions from rice cultivation are expected to rise by 22 percent by 2020 from 2000 levels, according to the U.S. Environmental Protection Agency (EPA) (EPA 2006b). According to the International Rice Research Institute (IRRI), the world will need nearly 700 million tons of rice annually (almost 10 percent above current production) to meet expected consumption rates in 2015.

Rice cultivation generally occurs in flooded paddy fields. The flooding of fields leads to anaerobic conditions where degradation of organic matter by methanogenic bacteria produces methane. It is released from submerged soils to the atmosphere by diffusion and ebullition, and through the roots and stems of rice plants (Neue 1993).

Methane emissions from rice cultivation are primarily affected by the water management system used. The types of rice field water management in the world are presented in Figure 2, and described below:

- **Irrigated—** Floodwater is fully controlled and kept shallow; accounts for nearly half of the current harvested area.
- **Rain-fed—**Precipitation alone controls flooding of soils. During the growing season, rice fields might dry out or flood up to 50 centimeters.
- **Deepwater**—Floodwater rises to more than 50 centimeters during the growing season and might reach several meters.
- **Upland—**This area does not flood, and the topsoil does not become saturated for any significant time period (Neue 1993).

Figure 2. Global Water Management Systems for Rice Cultivation: Percent of Harvested Area



Source: Bouman, 1991

The primary reason for flooding rice fields is weed suppression. Flooding also provides the ideal growth medium and sufficient water supply for the rice plants and makes preparing soils easy when hand tools or simple animal-operated equipment are used. Flooding or irrigation practices help encourage soil conservation or erosion control via terracing on sloping terrain and also utilize wet or annually flooded (i.e., alluvial) lowlands that are not suitable for other crops (Bouman 1991).

If fields remain flooded for the entire growing season, there is more potential for methane emissions than if the fields are drained or permitted to dry at least once during the season. Wetland rice soils with high percolation rates, coupled with occasional drying of the soil during the cultivation period, have been shown to reduce methane release (Bouman 1991). In rain-fed fields, methane emissions are much lower and more variable due to periods of drought during the growing season. Methane production might be higher in deepwater fields, but actual emissions might be lower due to reduced pathways. As expected, methane production is negligible in upland rice systems because the fields are not flooded for any significant period of time (Neue 1993).

Aside from the amount of water present and the length of time that water is present, methane emissions from rice cultivation also depend on the following factors:

- Soil amendments
- Tillage (plowing)
- Rice cultivars
- Nature of the soil (e.g., texture, temperature)
- Climate (IPCC 2001; DeAngelo et al, 2006; Ananda et al, 2004)

Adding soil amendments, including organic matter such as compost or peat, chemical fertilizers, or manure has been found to have varying effects and may increase or reduce methane emissions from rice fields depending on the specific practice. Alternatively, applying manure has been found to increase methane emissions from rice fields. Tillage disturbs and releases stored methane from the soil. Different varieties, or cultivars, of rice produce varying amounts of methane depending on the plant features; in particular, the type of root system. The nature of the soil, overall climate of the region, and the impact of seasonal events such as monsoons and droughts also affect methane production from rice. These variables are not within human control, however, and are therefore not able to be managed.

4.1 Potential Opportunities for Economically Feasible Mitigation of Rice Cultivation Methane Emissions

Methane mitigation opportunities within the rice cultivation sector include:

- Temporary drainage of rice fields
- Direct seeding
- Use of chemical fertilizers
- Use of different rice cultivars
- Improved tillage and crop residue management practices

These options are described in the following sections and summarized in Table 4.

Temporary Drainage of Rice Fields

In the early 1980s, when Chinese rice farmers began draining their fields midway through the rice growing season to save water, they experienced higher yields than they had when practicing the traditional continuous flooding method. Researchers also found that less methane was emitted from rice fields as a result of this practice. Draining stimulates root development and accelerates decomposition of organic materials in the soil, resulting in more mineralized nitrogen available for plant uptake. Midseason drainage aerates the soil, interfering with the anaerobic conditions and thereby interrupting methane production (NASA 2002). In the Beijing region of China, the local practice of drying fields midseason has been found to reduce methane emission rates by 23 percent, as compared with continuous flooding (Wang et al, 2000). Additional research has shown the methane emission reduction associated with midseason drainage could be as high as 44 percent (Lu et al, 2000).

Field experiments conducted in the Philippines showed field drying at the mid-tillering stage reduced methane emissions by 15 to 80 percent, as compared with continuous flooding, without having a significant effect on rice yield (Wassmann et al, 2000). Studies in India have also shown that controlled irrigation can effectively reduce methane without affecting yield (Parashar et al, 2002).

Water management practices (intermittent drainage) aimed at reducing methane emissions are feasible; however, specific conditions must be met for these practices to work—the drainage must take place only during specific periods of the rice growing season in flat, lowland irrigated rice fields with a high guarantee of water availability and water supply control and must be coordinated with nitrogen fertilizer applications (Bouman 1991; EPA 1991b).

Intermittent drying or drainage of soils must not be feasible on terraced rice fields, because the drying could cause cracking of the soil, leading to water losses, or in extreme cases, complete collapse of the terrace construction (Bouman 1991; EPA 1991b). There is also the potential that field drainage might induce weeds and/or reduce rice yield (Smakgahn et al, n.d.). Drainage has also been shown to have the unintended effect of increasing nitrous oxide emissions (Yu et al, 2004; Xu et al, 2003).

Direct Seeding (Versus Transplanting)

Direct seeding of pregerminated rice instead of transplanting rice seedlings has been shown to reduce methane emissions due to shorter flooding periods and decreased soil disturbances. Research was conducted in Pakistan that sought to assess water-saving potential through alternative wheat and rice establishment and crop management practices (e.g., direct seeding versus transplanting). The research revealed that methane emission reductions were an unintended benefit of direct seeding (IWMI, 2007). Other research has shown that transplanting 30-day seedlings, direct seeding on wet soil, and direct seeding on dry soil reduced methane emissions by 5, 13, and 37 percent, respectively, when compared with transplanting eight-day old seedlings (Ko and Kang 2000). Another study on direct seeding (versus transplanting) resulted in a 16- to 54-percent reduction in methane emissions (Metra-Corton et al, 2000).

Direct seeding is faster and easier than transplanting and requires less labor. Barriers to direct seeding include lack of adequate land preparation technology and pest control strategies, as well as the need for rice varieties with higher resistance to lodging (falling over due to early flooding) (Balasubramanian and Hill 2000). Despite the emission reductions and labor savings associated with direct seeding, transplanting rice seedlings has a number of benefits that are important to consider for the farmer. These include higher yields and an assurance that transplanting planting is done at the optimal time for the plants (Bouman 1991). Direct seeding could be one way to reduce methane emissions in this sector, but additional research is required to determine how to overcome the potential for reduced rice yields and lodging.

Use of Chemical Fertilizers

Most of the increases in Asian rice production resulting from the "Green Revolution" have been attributed to increased nitrogen use (EPA 1991b). Nitrogen use may also have the benefit of resulting in lower methane emissions. Incorporating urea into the soil has been shown to reduce methane emissions; however, surface-applied urea resulted in nearly 20-percent greater emissions compared to unfertilized fields (EPA 1991b).

The use of sulfate-based fertilizers has also been linked to methane emission reductions. A study in the Philippines found that the use of ammonium sulfate reduced methane emissions by 25 to 36 percent (Metra-Corton et al, 2000). Applying phosphogypsum (calcium sulfate dihydride) in combination with urea has been determined to reduce methane emissions by more than 70 percent (Metra-Corton et al, 2000).

Further research is required to better understand the interactions between soil chemicals and physical properties (e.g., temperatures, range of pH), as well as soil, water, and crop management, on methanogenesis (Bouman 1991). In addition, the impact to total GHG emissions should be considered.

Use of Different Rice Cultivars

The type or variety (cultivar) of rice has been shown to have an effect on methane emissions. Given plant structure, some varieties transmit more methane than others. In the Beijing region of China, for example, studies have shown that the use of cultivar Zhongzhou (modern japonica) reduced methane emissions by approximately 50 percent when compared with Jingyou (japonica hybrid) and Zhonghua (tall japonica) (Wang, Z.Y. et al, 2000). Another study in China found that rice cultivars with small root systems, high root oxidative activity, high harvest indices (the ratio of harvested yield to total yield), and productive tillers (shoots) are likely to produce less methane than other cultivars (Wang and Adachi 2000).

Studies conducted in Korea measured methane emissions from eight different rice cultivars. The studies determined that some rice cultivars can emit more than twice as much as others (Shin and Yun 2000). The Annada rice variety (commonly used in Andhra Pradesh, a major rice growing region in India) has high yield and comparatively low methane emissions, which might mitigate emissions from paddy fields in that region (Parashar et al, 2002).

In addition to identifying variations in existing rice cultivars, research is also being conducted to develop new rice varieties that produce and/or transmit less methane (Ananda et al, 2004). Additional research is needed to identify important plant features, screen existing varieties, and then develop new varieties that meet all the requirements for pest resistance and high productivity as well as methane reduction (EPA 1991b).

Although low-methane-emitting rice cultivars have been identified, methane emission reductions due to cultivar selection have been shown to be less significant than those identified due to modifying water management regimes or adding organic amendments (Lu et al, 2000). In addition, the rice yield of the low-emitting cultivars would need to be evaluated; if the low-emitting rice cultivar produced less rice, then more rice would need to be cultivated to meet the demand for rice, and therefore overall methane emissions may increase.

Improved Tillage and Crop Residue Management Practices

Methane emissions are very intense during the tilling stage of rice field preparation, which can account for more than 80 percent of total annual emissions. Wetland tillage, compared with dryland or zero tillage, results in an earlier onset of methanogenesis and, therefore, contributes to greater methane production during the growing season (EPA 1991b). Zero tillage results in the lowest methane emissions and is a practice that involves leaving crop residue in place to compost or mulch the soil.

Increased land and water productivity, as well as improved net income, has attracted some farmers to adopt zero tillage techniques when preparing rice fields for wheat planting. Lack of familiarity with the zero tillage technique is a major constraint for small farmers to adopt new practices (IWMI, 2007). There is also potential for certain harmful pests such as the stem borer to survive on the unincorporated residue or stubble. Some crop residue management techniques can be implemented in the near term; however, deploying new machinery and training is a longer-term endeavor.

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Table 4. Summary of Potential Methane Mitigation Opportunities for Rice Cultivation

Mitigation Technique	Overview	Feasibility/Barriers	Time Frame
Temporary Drainage of Rice Fields	Draining rice fields midway through the rice growing season has been found to reduce methane emissions.	This option is feasible only for specific growing periods (midseason), for flat, lowland irrigated rice fields with guaranteed water availability and supply control. It can require the application of nitrogen fertilizer. This option is not applicable for all types of rice fields (may cause cracking, water losses, and/or collapse in terraced rice fields). Can increase weeds during nonflooded period, and can also increase nitrous emissions and potential for reduced rice yields.	Near term
Direct Seeding	Direct seeding of pregerminated rice instead of transplanting rice seedlings has been shown to reduce methane emissions.	This option reduces labor requirements but requires land preparation, and lacks pest control.	Near term
Use of Chemical Fertilizers	Increased chemical fertilizer use (e.g., ammonium sulfate, urea, phosphogypsum) in Asian rice production has been attributed to increased yields but has also been found to reduce methane emissions.	Further research is required to determine the true feasibility of this option. It is dependent on cost and commercial availability of fertilizer products.	Near term
Use of Different Rice Cultivars	Studies have shown that different rice cultivars (i.e., varieties) produce varying amounts of methane under similar growing conditions.	This mitigation option is easily adopted with existing cultivars (uses same practices with different rice variety) but results in less significant emission reductions than other techniques (such as water management, organic amendments). Additional research and development is required for new varieties of cultivars.	Near term for existing cultivars, longer term (5+ years) for development of new strains
Improved Tillage and Crop Residue Management Practices	Methane from previous crop residues that have been tilled under is released during rice field preparation. Zero tillage has the potential to reduce methane emissions.	This option is easily implemented but requires increased education and outreach. It can also attract pests to crop residue.	Near term for zero tillage, longer term (5+ years) for new equipment

NOTE: Many studies have been conducted at the field level (involving field-scale testing in specific areas) and yielded successful results, but more research and development might be required at the system-wide level (such as irrigation system, river basin) in order to convince farmers to switch practices.

4.2 Mitigation Projects for Rice Cultivation

As described in Section 3.2, CDM emission reduction projects must undergo a thorough registration and issuance process and be proven to be real, measurable, and verifiable emission reductions that are additional to what would have occurred without the project. There is no current existing methodology to estimate rice cultivation emission reductions under CDM and therefore there are no current projects to reduce rice methane emissions being funded under this mechanism.

The following projects demonstrate the implementation of water management techniques that reduce methane emissions:

Encouraging Innovative Water Management in Vietnam

A demonstration project funded by the Global Environment Facility/Small Grants Programme (GEF/SGP) developed a model aimed at reducing methane emissions from paddy rice cultivation through innovative water management regimes with intermittent irrigation practices. This project can be replicated throughout Vietnam.

Vietnam is an agricultural country, with 80 percent of its population living in rural areas. The agricultural sector contributes nearly one-third of the national gross domestic product. The project focused on transferring technology on water management regimes with intermittent irrigation technical practices and building technical capacity for the local community. Twelve training courses were provided for 20 irrigation workers and 100 households. The courses taught irrigation operations and water management in paddy rice cultivation. The project met the GEF/SGP goal by reducing GHG emissions. The associated benefits included reduction of water and electricity use for paddy rice production, as well as increased yields. The project has great replication potential due to the environmental and economic benefit of the models, and it fit well within the local program on agricultural extension and concretization of irrigation systems. (http://sgp.undp.org/web/projects/5750/)

Promoting New Rice Cultivation Methods in Nepal

The System of Rice Intensification (SRI) has been used to cultivate in Nepal. Using the SRI method, fields are not flooded, and soil is kept well drained and aerated, thus avoiding the production and emission of methane. SRI also has the benefit of increasing rice yields by 50 to 100 percent, while utilizing 25 to 50 percent less water for irrigation purposes. SRI is labor intensive and requires approximately 25 percent more labor than traditional techniques, primarily due to increased weeding. Despite increased labor costs, the overall decrease in costs of production can be as much as 20 percent compared with standard methods. (www.adb.org/Clean-Energy/documents/NEP-PDD-System-Rice-Intensification.pdf)

4.3 Barriers to Mitigating Rice Cultivation Methane Emissions

For rice cultivation, there are several issues and barriers that must be addressed before any emission reduction project would be applicable for consideration in the work of the Methane to

Markets Partnership. Barriers for rice cultivation project implementation are listed as follows, including issues related to the difficulties of meeting the CDM requirements (which state that emission reductions must be real, measurable, and verifiable, and in addition to reductions that would have occurred without the project):

- ***Limited Applicability to Different Types of Rice Fields (e.g., Irrigated, Deepwater).*** Many of the mitigation strategies associated with water management are limited to only certain types of rice fields (e.g., midseason drainage in flat, lowland irrigated fields).

- ***Technical Capacity.*** The technical capacity of workers who operate the water management or irrigation systems is often limited and has been a major obstacle in applying advanced techniques and technologies in irrigation system management (SGP). Additional outreach and training is necessary to overcome this barrier.

- ***Limited Measurement Techniques and Lack of Detailed Baseline.*** In general, the cost restraints of actual emission monitoring equipment make estimating emissions through established equations and emission factors the only realistic way to measure rice cultivation methane emissions. In both developing and developed countries, the complexity of the calculations required to estimate emissions are a barrier to establishing baselines and reductions. While lacking baseline emissions does not prohibit an operation from implementing mitigation options, these operations also lack the ability to measure the effectiveness of methane reduction efforts.

- ***Increased Costs.*** Application of soil amendments (e.g., chemical fertilizers) and crop residue management techniques require additional purchases, labor, and/or machinery (e.g., tilling equipment), which small local farmers lack.

- ***Reduced Yield and Field Fertility.*** Some of the mitigation techniques described previously reduce rice yields as well as methane, which negatively impacts the farmer (e.g., income), as well as those consumers who rely on that rice for food. Use—or more importantly, overuse or misuse—of chemical fertilizers has also been shown to have the negative effect of diminishing field fertility after prolonged or repeated applications.

- ***Cultural Diversity.*** Many local rice farmers' families or villages have been using the same practices for centuries, and it is difficult to encourage them to change. Agricultural practices also vary from region to region so a one-size-fits-all approach is not appropriate. Technologies and techniques must be customized for each scenario.

- ***Large Number of Farmers Involved.*** Because many rice growing areas consist of several small fields, it might be difficult to unify all of the farmers with the same mitigation technique (Garg et al, 2004).

Special attention and sensitivity should be placed on understanding cultural practices and meeting the needs of the farmers. In one study sponsored by the Consultative Group on International Agricultural Research (CGIAR), farmers were more concerned with ensuring farm incomes and food security than focusing on innovative water management techniques to conserve resources. Switching to alternative practices and methods require significant funding and/or institutional support for things such as training. There is also the challenge to reduce methane emissions without increasing the production of other GHGs such as nitrous oxide or carbon dioxide—all while maintaining or enhancing yields (Yu et al, 2004).

4.4 Organizations Involved in Promoting Methane Mitigation From Rice Cultivation

The following organizations are involved in research and project development to reduce methane emissions from rice cultivation activities:

The ***Consultative Group on International Agricultural Research (CGIAR)***, established in 1971, is a strategic partnership whose 64 members support 15 international research centers, working in collaboration with many hundreds of government and civil society organizations as well as private businesses around the world. The new crop varieties, knowledge, and other products resulting from the CGIAR's collaborative research are made widely available to individuals and organizations working for sustainable agricultural development throughout the world. (www.cgiar.org/)

The ***International Rice Research Institute (IRRI)*** (www.irri.org) is the oldest and largest international agricultural research institute in Asia and is also a CGIAR member. It is an autonomous, nonprofit rice research and education organization with staff based in 14 countries in Asia and Africa. IRRI's mission is to reduce poverty and hunger, improve the health of rice farmers and consumers, and ensure that rice production is environmentally sustainable. Examples of IRRI efforts include:

- A collaborative project on new water-saving rice technologies, specifically aerobic rice. The project is being developed for Bangladesh, India, Nepal, and Pakistan and is funded by the Asian Development Bank (ADB). IRRI is the executing agency responsible for the project's successful implementation.
- An IRRI-led project with the China National Rice Research Institute (CNRRI) and Chinese Academy of Agricultural Sciences (CAAS) to compile a database of methane emission levels in irrigated rice fields.
- A five-year study of methane emissions in wetland rice lands in collaboration with Germany's Fraunhofer Institute of Atmospheric Environmental Research (FhG), Garmisch-Partenkirchen. FhG also collaborated with IRRI and five rice-growing Asian countries in an interregional research program that focused on quantifying methane emissions from major rice ecosystems. In 1996, the Federal Ministry of Economic Cooperation funded a new three-year project on reducing methane emissions from rice fields by screening rice varieties for low-methane transport capacity.
- A collaboration with Japanese scientists on a project to study methane oxidation from rice plants.
- A project from 1993 to 1997 with the Thailand Ministry of Agriculture and Cooperatives aimed at identifying technologies (e.g., crop management and breeding

strategies, options for high-yielding rice cultivars) that mitigated methane emissions from rice fields.

The ***International Water Management Institute (IWMI)*** is another of the 15 international research centers supported by CGIAR. IWMI is a nonprofit organization with a staff of 350 and offices in more than 10 countries across Asia and Africa. IWMI's mission is to improve the management of land and water resources for food, livelihood, and nature. With funding from the Australian Centre for International Agricultural Research (ACIAR), IWMI led a five-year project in Australia and China to promote water management techniques in rice-based irrigation systems that sustain the environment. With ADB funding, IWMI also worked with the Pakistan Agricultural Research Council (PARC) to assess water savings potential at field, farm, and watercourse levels through alternative wheat and rice establishment and crop management practices. Much of IWMI's water-related research supports methane mitigation efforts from midseason drainage and/or other water conservation techniques, and simulations using an IWMI-developed model entitled Options Analysis in Irrigation Systems (OASIS) are used to evaluate the role of alternating (field) wetting and draining. (www.iwmi.cgiar.org/)

The ***Food and Agriculture Organization (FAO) of the United Nations*** leads international efforts to defeat hunger. Serving both developed and developing countries, FAO acts as a neutral forum where all nations meet as equals to negotiate agreements and debate policy. FAO is also a source of knowledge and information: it helps developing countries and countries in transition modernize and improve agriculture, forestry, and fisheries practices, and ensure good nutrition for all. Since its founding in 1945, FAO has focused special attention on developing rural areas, home to 70 percent of the world's poor and hungry people.

The United Nations declared 2004 the International Year of Rice (IYR) to address increasing world hunger, malnutrition, poverty, and conflict. As part of the IYR, FAO convened a two-day Rice Conference that brought together leading world experts to present perspectives on latest trends and industry developments. The aim of this conference was to mobilize the international community to confront the most pressing issues facing the global rice sector, from local farming practices to international trade. Additional workshops and symposia were held throughout the year to address issues related to rice production (e.g., water management). Following the IYR, the International Rice Commission of FAO has been responsible for strengthening its capacity aimed at assisting member countries in the formulation and implementation of programs and projects to help transfer specific technological innovations. (www.fao.org/)

The ***Indian Agricultural Research Institute (IARI)*** is India's premier national institute for agricultural research, education, and extension. Besides basic research, applied and commodity research gained great importance resulting in the development of several popular high yielding varieties of almost all major crops and their associated management technologies, which brought about an unprecedented increase in the national food and agricultural production. IARI is credited with devising collection devices for measuring methane flux from rice fields. Recent projects include evaluating methane and nitrous oxide emissions from rice growing regions of India and assessments of mitigation options, funded by the National Agricultural Technology Project of the Indian Council of Agricultural Research (ICAR). (www.iari.res.in/)

The ***Small Grants Programme (SGP)*** was launched in 1992 and funded by the GEF as a corporate program. It is implemented by the United Nations Development Programme (UNDP), and executed by the United Nations Office for Project Services (UNOPS). SGP supports activities of nongovernmental and community-based organizations in developing countries. Activities of interest to SGP include those that address climate change abatement, conservation of biodiversity, protection of international waters, reduction of the impact of persistent organic pollutants, and prevention of land degradation while also generating sustainable livelihoods. The overall SGP project portfolio includes 60 percent biodiversity, 20 percent climate change, 6 percent international waters, and 14 percent multi-focal issues. SGP has assisted with methane mitigation projects from rice cultivation in Vietnam (see previous description) and India, where a soon-to-be-established, environmentally friendly rice production system (i.e., SRI) will nearly double the rice productivity in that area. Rice production under these moist aerobic soil conditions will also alleviate methane emissions. (http://sgp.undp.org/index.cfm)

4.5 Conclusions for Rice Cultivation

Some mitigation technologies and techniques associated with rice cultivation are available, although many others are still at the research stage. Barriers to offset projects exist because emission reduction practices cannot be precisely quantified on a project basis because of lack of measurement technology, detailed baseline data, and information on the actual impact of the intervention. Continued research and development will be required to make these technologies commercially viable and socioeconomically feasible (Garg et al, 2004; EPA 1991b). Most importantly, the opportunity to reduce GHG emissions should not outweigh the need to feed a growing population.

The Methane to Markets Partnership could play a role in promoting the development of more detailed baseline information, and/or promote development of methodologies that could be approved by CDM. Alternatively, the Partnership could also work with key organization promote farm practices that have multiple benefits including reduced methane emissions. Utilizing this method would not necessarily lead to a CDM type projects with verifiable emissions reductions but nonetheless could lead to overall emissions reductions. The Partnership could also support research and demonstration projects in this area coordinating with the key organizations listed that are working on in this sector. In any case, it will be critical for the Partnership to fully engage the research and extension organizations already working in this area to identify areas of collaboration and support.

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