6. Enteric Fermentation

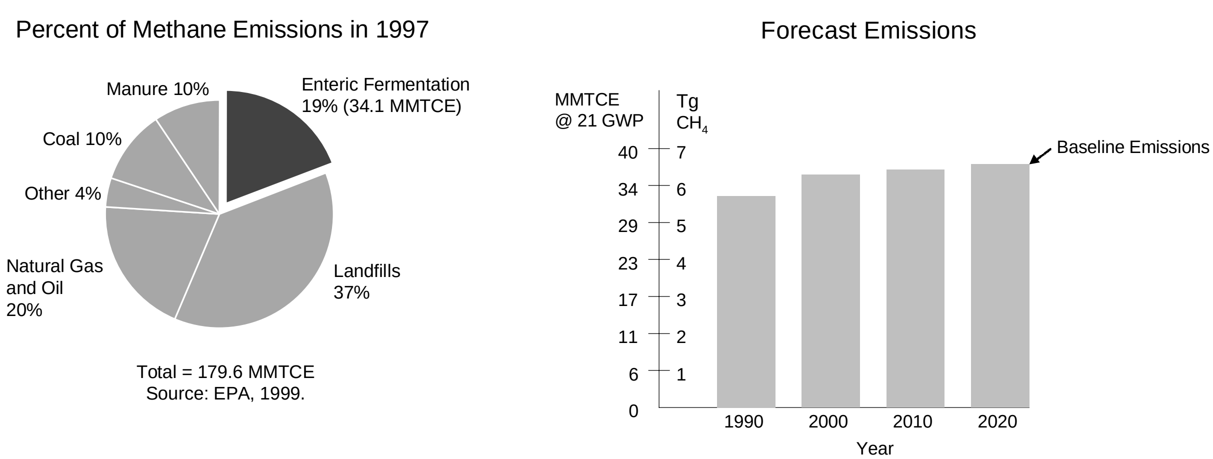
Summary

EPA estimates 1997 U.S. methane emissions from livestock enteric fermentation at 34.1 MMTCE (6.0 Tg), which accounts for 19 percent of total U.S. methane emissions in 1997. EPA expects methane emissions from livestock enteric fermentation to increase through 2020 as livestock populations grow to meet domestic and international demand for U.S. livestock products. In 2010, methane emissions are forecasted to reach 36.6 MMTCE (6.4 Tg) as shown below in Exhibit 6-1.

When estimating methane emissions from livestock enteric fermentation, EPA categorizes livestock populations, collects population data, and develops emission factors that account for the diversity of feed and animal characteristics throughout the U.S. Among livestock, cattle are examined more closely than other livestock species because they are responsible for the majority of U.S. livestock emissions, and significant variation exists in feed and animal characteristics for cattle. The greatest opportunity for reducing methane emissions from cattle is to increase production efficiency through improved management techniques.

This chapter describes methane emissions from livestock enteric fermentation, the methodology used to estimate methane emissions, and the approaches underway to reduce emissions from cattle. Cost-effective management practices and techniques can be used to improve animal health and nutrition, increase production efficiency, and reduce methane emissions per unit of product. Based on assumptions about the use of these practices to improve productivity, EPA has developed three scenarios (low, middle, and high) of future emissions from livestock enteric fermentation. Unlike other chapters in this report, no cost estimates have yet been developed for methane reductions from enteric fermentation.

Exhibit 6-1: U.S. Methane Emissions from Enteric Fermentation (MMTCE)



1.0 Methane Emissions from Enteric Fermentation

Livestock emit methane as part of their normal digestive processes. The U.S. livestock population consists of ruminant livestock (cattle, sheep, and goats), monogastric livestock (pigs), and pseudo-ruminants (horses and mules). Cattle emit more than 90 percent of the methane from livestock. The amount of methane produced is influenced significantly by animal and feed characteristics.

This section describes the source of methane emissions from livestock enteric fermentation and the method EPA uses to estimate emissions. The emission estimates and sources of uncertainty also are presented.

1.1 Emission Characteristics

Methane emissions from enteric fermentation depend on animal type and diet. This chapter primarily focuses on emissions from ruminant livestock.

Ruminant Livestock. Cattle, sheep, and goats are the primary ruminant livestock in the U.S. These animals produce more methane per unit of feed consumed than monogastric and pseudo-ruminant animals. Plant material consumed by ruminant livestock is fermented by approximately 200 species of microbes in the rumen, the first of a four-part stomach. The microbes convert the plant material into nutrients that livestock can use, such as volatile fatty acids. Methane, a by-product of this fermentation process, is released to the atmosphere mainly via the mouth and nostrils.

Methane from ruminant livestock is derived from a portion of the carbon energy in an animal's diet. Consequently, methane emissions generally decrease when production efficiency increases because a greater portion of feed energy consumed goes to production (milk or meat) rather than for methane.

Monogastric Animals and Pseudo-Ruminants. These animals contribute a comparatively small proportion of the total methane emitted by livestock in the U.S. Monogastric animals (pigs) do not have a rumen, but produce small amounts of methane during digestion.

Pseudo-ruminants (horses and mules) produce less methane than ruminant livestock and more methane than monogastric animals. Pseudo-ruminants do not have a rumen, but feed is fermented during digestion, which allows them to obtain important nutrients from coarse plant material.

1.2 Emission Estimation Method

Animal and feed characteristics have a significant impact on methane emissions. Consequently, methods used to estimate methane emissions from livestock incorporate information on animal and feed characteristics. The factors affecting methane emissions, and the methods used to estimate past, current, and future emissions are described below.

1.2.1 Factors Affecting Methane Emissions from Enteric Fermentation

Methane emissions are a function of the size of the animal population, the quantity of feed consumed, and the efficiency by which an animal converts feed to product. The lower the efficiency, the greater the amount of methane emitted.

Improving animal productivity decreases methane emissions per unit of product. At the basic level, feed goes to maintenance and product. Maintenance is the proportion of feed needed to satisfy the basic metabolic requirements that keep the animal alive. A significant fraction of the methane emitted by cattle (40 to 60 percent) comes from the proportion of the feed used for maintenance (EPA, 1993b). The remaining feed energy is used for production. Maintenance requirements generally remain constant. Consequently, as maintenance remains constant and animal productivity increases, methane emissions go up slightly, but methane emissions per unit of product decrease.

Increasing animal productivity also reduces the number of animals needed to satisfy demand. By increasing productivity, i.e., producing more meat or milk per animal, meeting national demand for products is possible with fewer animals. As a result, overall methane emissions decrease. In the U.S., the dairy industry has demonstrated the impact of improved productivity on methane emissions. Between 1960 and 1990, the dairy industry increased annual milk production by ten million tons with 7.4 million fewer cows, reducing estimated methane emissions by almost one million metric tons of carbon (MMTCE) (USDA, 1990; EPA, 1993a).

Dairy and beef producers can increase production efficiency by improving feed conversion efficiency, which is defined as the efficiency by which feed is converted to product. Feed conversion efficiency is influenced by feed type. For example, grain feeds are converted to product more efficiently than forages, such as hay, because they are more digestible and are higher in protein.

1.2.2 Method for Estimating Current Methane Emissions

Emissions are estimated for cattle, sheep, goats, pigs, and horses. The methods used to estimate emissions are presented below. Information on the emission factors are presented in Appendix VI, Section VI.2. Methane emissions from livestock in the U.S. are estimated by: (1) dividing animals into homogenous groups; (2) developing emission factors for each group; (3) collecting population data; (4) multiplying the population by the emission factor for the respective group; and (5) summing emissions across animal groups and geographic regions (EPA, 1993a). The relationship between the emission factor estimate and the activity data is presented in the following equation:

$$CH_4 = \sum_{i}^{animal} \sum_{k}^{region} \left(EF_{ik}\right)\left(N_{ik}\right)$$

Where:

CH_4 = Total methane emissions (kg);

EF_{ik} = Emission factor for animal type *i* in region *k* (kg/animal); and

N_{ik} = Animal population for animal type *i* in region *k*.

Emission factors for different animal types are presented in Appendix VI in Exhibits VI-3 through VI-5.

EPA uses a variety of data sources to develop emission factors and estimate population sizes. Exhibit 6-2 presents the data sources for the emission factors and population data used to estimate methane emissions, in addition to criteria used to categorize the populations. Because management practices affect methane emissions, cattle are broken down into dairy and beef sectors. However, sheep, goats, pigs and horses are not broken down beyond the national level because they make up a small proportion of emissions from livestock.

1.2.3 Method for Estimating Future Methane Emissions

EPA develops future emission estimates based on assumptions regarding animal and feed characteristics.

Exhibit 6-2: Sources of Emission Factors and Population Data

Animal Type	Emission Factor	Population Data	Categorization
Dairy Cattle	Based on milk production data and on the model by Baldwin, et al. (1987a-b) [a]	USDA, 1998a,d [b]	Categorized by age, diet, and region [c]
Beef Cattle	Based on the model by Baldwin, et al. (1987a-b)	USDA, 1998a-c	Categorized by age, diet, and region
Sheep	Based on Crutzen, et al. (1986) [d]	USDA, 1998e	Not broken down beyond the national level
Goats	Based on Crutzen, et al. (1986)	USDA, 1998e	Not broken down beyond the national level
Pigs	Based on Crutzen, et al. (1986)	USDA, 1997	Not broken down beyond the national level
Horses	Based on Crutzen, et al. (1986)	FAO, 1998	Not broken down beyond the national level

[a] The model by Baldwin, et al. (1987) simulates digestion in growing and lactating cattle using information on animal and feed characteristics.

[b] The USDA National Agricultural Statistics Service collects data on the U.S. livestock population.

[c] Regions are West, North Central, South Central, North Atlantic, and South Atlantic.

[d] Crutzen, et al. (1986) developed emission factor estimates using information on typical animal size, feed intakes, and feed characteristics. Emission factors for developed countries are used for the U.S. inventory, as well as emission estimates in this analysis (EPA, 1999).

Source: EPA, 1999.

These assumptions differ by animal type and sector, and are summarized below.

Beef Cattle. Current emission factors (EPA, 1993a) are used to estimate future emissions from beef cattle. The beef cattle population is projected using future production estimates.

Dairy Cattle. For dairy cows, emission factors used to estimate future emissions are adjusted using projected milk production estimates. Consequently, future emission factors are estimated under the assumption that milk production per cow increases by 300 pounds per year (lbs/yr) through 2020. For dairy calves and replacement heifers, current emission factors (EPA, 1993a) are used to estimate future emissions.

The dairy cow population is estimated by taking net demand (including exports) and dividing it by the projected milk production per cow. Populations of calves and replacement heifers are estimated using the 1995 ratio of calves and replacement heifers to cows.

Sheep, Goats, Pigs, and Horses. Future population estimates are multiplied by current emission factors (EPA, 1993a) to estimate future emissions.

EPA estimates future animal populations using USDA projections through 2005 (USDA, 1996). Populations are projected beyond 2005 through 2020 for each species using the following assumptions.

- **Sheep.** Consumption of lamb/mutton is expected to decrease, causing a decrease in the sheep population.
- **Goats.** The goat population is expected to remain constant.
- **Pigs.** The pig population is expected to increase in response to increased consumption per capita.
- **Horses.** The horse population is calculated by estimating the future number of horses per capita, and multiplying it by the extrapolated human population.

1.3 Emission Estimates

The methods described in the previous section are used to estimate methane emissions from livestock enteric fermentation. This section presents emission estimates from 1990 to 1997, and projected estimates through 2020. Uncertainties in current and projected estimates are also discussed.

1.3.1 Current Emissions and Trends

U.S. livestock emitted 34.1 MMTCE (6.0 Tg) of methane in 1997. Cattle accounted for 96 percent of these emissions (32.6 MMTCE or 5.7 Tg) and sheep, goats, pigs, and horses for the remainder (1.5 MMTCE or 0.3 Tg). Exhibit 6-3 presents emissions for 1990 to 1997. Emissions from cattle increased by five percent from 1990 to 1997.

During 1990 to 1997, emissions from dairy cattle fell slightly. The main factor slowing the growth in emissions was the decrease in the cow and replacement heifer populations because of increased production efficiency in the dairy industry. As production efficiency increases, fewer animals are required to satisfy demand, and total methane emissions decrease.

As presented in Exhibit 6-3, beef cattle accounted for approximately 75 percent of cattle emissions in 1997. The growth in total emissions over the 1990 to 1997 period is largely due to an increase in emissions from beef cattle. This increase is driven primarily by an increase in the demand for beef, which is driven by human population growth and food preferences. Higher demand for meat increases the beef cattle population and emissions. Non-cattle and dairy cattle emissions over the period remain about the same.

1.3.2 Future Emissions and Trends

As presented in Exhibit 6-4, methane emissions from livestock are projected to increase between 2000 and 2020, excluding possible Climate Change Action Plan (CCAP) reductions. In 2020, emissions from livestock are expected to reach 37.7 MMTCE (6.6 Tg), 36.2 MMTCE (6.3 Tg) from cattle and 1.5 MMTCE (0.3 Tg) from sheep, goats, pigs, and horses. The increase in emissions will be driven by beef cattle, due to the same factors that underlie the trends discussed above – increased human population and food preferences leading to higher beef consumption and more beef cattle. Exports of beef also are expected to increase.

Exhibit 6-3: Methane Emissions from Livestock (MMTCE)								
Animal Type	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
Non-Cattle								
Sheep	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.3
Goats	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pigs	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Horses	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Total Non-Cattle	**1.6**	**1.7**	**1.7**	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**
Dairy Cattle								
Cows	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Replacement Heifers 0-12 Months	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4
Replacement Heifers 12-24 Months	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3
Total Dairy	**8.4**	**8.4**	**8.4**	**8.4**	**8.4**	**8.4**	**8.3**	**8.3**
Beef Cattle								
Cows	12.5	12.6	12.8	13.0	13.5	13.6	13.5	13.2
Replacements 0-12	0.7	0.7	0.7	0.8	0.8	0.8	0.7	0.7
Replacements 12-24	1.9	2.0	2.1	2.2	2.3	2.3	2.2	2.1
Slaughter-Weanlings	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8
Slaughter-Yearlings	5.6	5.6	5.6	5.6	5.9	6.1	6.0	6.2
Bulls	1.2	1.3	1.3	1.3	1.3	1.4	1.3	1.3
Total Beef	**22.6**	**22.8**	**23.1**	**23.6**	**24.5**	**24.9**	**24.6**	**24.3**
Total Cattle	**31.1**	**31.2**	**31.6**	**32.0**	**32.9**	**33.3**	**32.9**	**32.6**
Total Livestock	**32.7**	**32.8**	**33.2**	**33.6**	**34.5**	**34.9**	**34.5**	**34.1**
Totals may not sum due to independent rounding.								

Exhibit 6-4: Projected Baseline Methane Emissions from Livestock (MMTCE)					
Animal Type	**2000**	**2005**	**2010**	**2015**	**2020**
Sheep	0.3	0.3	0.3	0.3	0.3
Goats	0.1	0.1	0.1	0.1	0.3
Hogs	0.5	0.6	0.6	0.6	0.1
Horses	0.6	0.7	0.7	0.7	0.8
Total Non-Cattle	**1.5**	**1.7**	**1.7**	**1.8**	**1.5**
Dairy Cattle	8.5	8.8	8.8	8.9	8.9
Beef Cattle	25.1	25.4	26.1	26.7	27.3
Total Cattle	**33.7**	**34.1**	**34.9**	**35.6**	**36.2**
Total Livestock	**35.2**	**35.9**	**36.6**	**37.3**	**37.7**
Totals may not sum due to independent rounding.					

Future emissions will also be influenced by changes in animal management and feed practices. In the next section, some of these alternative management and feeding practices are described. Depending on how widespread these practices become, they will affect future levels of methane emissions.

1.4 Emission Estimate Uncertainty

The methane emission estimates used in this analysis are based on estimated animal and feed characteristics. Although the animal and feed characteristics used in the analysis represent the range of U.S. characteristics, they may not represent the full diversity in the U.S.

For sheep, goats, pigs, and horses, emission factor estimates are based on data from developed countries (U.S., Germany, and England), and not specifically from the U.S. Consequently, there is moderate uncertainty in how closely the emission factors represent typical animal sizes, feed intake, and feed characteristics in the U.S.

2.0 Emission Reductions

Unlike other methane emission sources for which there are technologies or practices aimed specifically at reducing emissions, no such control options are currently available for enteric fermentation. For this reason, EPA did not develop marginal abatement curves for emission reductions from enteric fermentation. Nevertheless, some aspects of livestock management can result in lower emissions, principally by improving dairy and beef production efficiency. This section describes techniques available or in-use that improve production efficiency. Additionally, this section provides forecasts of emissions under various assumptions, and describes how improved techniques will be implemented industry-wide.

2.1 Technologies for Reducing Methane Emissions

Implementing proper management techniques to improve animal nutrition and reproductive health is the primary means of improving production efficiency. Other reduction options, such as production enhancing agents, trade, and pricing systems are also used to increase production efficiency. Specific management techniques that improve animal production efficiency are discussed below.

Animal Nutrition and Health. The principal areas for improving animal productivity involve applying sound nutrition and veterinary practices. Feed that is better tailored to the metabolic requirements of the animal and that can be digested efficiently results in a greater proportion of the energy consumed going towards production, and less to waste and methane emissions. Some feeds, such as distiller grains, are high in protein and are highly digestible.

Combining proper nutritional management with proper veterinary care promotes growth and leads to higher levels of production than in the absence of such care. This care includes applying proper management techniques to maintain the comfort and health of the animals.

Grazing Management. Grazing cattle emit a significant portion of the methane from enteric fermentation. Consequently, implementing proper grazing management practices to improve the quality of pastures increases animal productivity and has a significant impact on reducing methane emissions from livestock enteric fermentation. By examining soil and plant composition and implementing steps to improve the health of the soil and ensuring the right mixture of plants, producers can enhance the nutrition and health of the cattle, and increase production.

Management intensive grazing is an effective form of grazing management. Unlike continuous grazing, in which cattle graze on large pastures for long periods of time and deplete the pasture of healthy plants, management intensive grazing is a form of grazing in which animals are rotated regularly among grazing units (paddocks) to maximize forage quality and quantity. This form of grazing management leads to vigorous plant growth, healthy soil, and a constant, nutritious source of food for the cattle. Overall, the health of the pasture is increased significantly. Production efficiency increases as a result, thereby reducing methane emissions per unit product and total methane emissions.

Artificial Insemination. An animal's genes have a significant influence on its productivity. Artificial insemination enables farmers to improve the genes of their herd by impregnating the animals with semen from healthy and productive bulls. In the U.S., artificial insemination is widely used by dairy operations. Artificial insemination is less popular in the beef industry with approximately seven percent of operations using the procedure in 1997 (USDA, 1998f). Given that genes affect animal productivity, artificial insemination is an excellent technique to improve the genes of an animal herd. An increase in the use of artificial insemination by beef operations could increase animal productivity and reduce methane emissions per unit product.

Production Enhancing Agents. With advances in science and biotechnology, a number of production enhancing agents are available that increase production efficiency in cattle. Production enhancing agents are meant to enhance the effect of proper animal health, nutrition, and grazing management practices. Three production enhancing agents are commonly available and are discussed below.

- **Bovine Somatotropin (Dairy Industry).** Bovine Somatotropin (bST), also known as bovine growth hormone (BGH), is a naturally occurring growth hormone in bovines produced by the pituitary gland. Recombinant bST (rbST), an essentially identical form of bST, is produced using modern biotechnology. The use of rbST with dairy cows can increase milk production per cow per year by 12 percent or by 1,800 lbs (EPA, 1996). After the U.S. Food and Drug Administration (FDA) approved the use of rbST, it was released on the market in 1994. Approximately 15 percent of the dairy cow population is treated with rbST (Monsanto, 1998). While there is still considerable public debate regarding the health risks of rbST, the FDA approved the use of rbST after performing a rigorous analysis of the potential health effects. Given that rbST is cost-effective and considered safe by the FDA, increased use of rbST is expected to take place in the future. If adopted widely by the dairy industry, the use of rbST could increase production efficiency and reduce methane emissions from dairy cattle by one to three percent, holding other factors constant (EPA, 1996).

- **Anabolic Agents (Beef Industry).** Anabolic steroids increase the rate of weight gain and feed intake in growing heifers and steers. The increased rate of weight gain reduces the time it takes for calves to reach slaughter weight. Steroid implants are considered cost-effective (USDA, 1987) and have been approved by the FDA. Steroids can reduce emissions by enhancing growth rates, feed efficiency, and lean tissue accretion (EPA, 1993b).

- **Ionophores (Beef Industry).** Ionophores are polyether antibiotics produced by soil microorganisms that gained attention in the 1970s for their ability to improve feed digestibility in cattle. They are administered to cattle by mixing them with feed or by providing them as a component of a multi-nutrient block, which is often a solid block of molasses supplemented with nutrients. Two types of ionophores, monensin and lasalocid, have been approved for use in the U.S. (EPA, 1993b).

Market Based Strategies. Practices that are focused on improving the health and nutrition of the animals are key to improving production efficiency. However, other strategies, such as trade and pricing systems, also have a substantial influence on production and management techniques.

- **Trade.** Changes in beef and dairy trade policy could result in higher U.S. emissions, but possibly lower emissions worldwide. Because U.S. dairy and beef operations are among the most efficient operations in the world, increasing U.S. exports could displace less efficient operations in other countries, and lower emissions. Although U.S. beef and dairy exports are currently low, they are expected to increase in the future as the U.S. beef industry seeks to gain greater access to foreign markets.

- **Dairy Prices.** Changes in the pricing systems for dairy products can reduce methane emissions. In the U.S., milk is uniformly graded and priced according to its butterfat content. This pricing system was useful when the demand for high-fat milk was stronger than it is today. With the demand for low-fat milk increasing, the dairy industry has begun changing from a single-component pricing system to a multiple-component pricing (MCP) system in which other components of milk, primarily protein, are reflected in the price.

  If this trend continues, producers will modify the feeding regimes of their dairy cows to include or increase the amount of high-protein feedstuffs, such as grain, which is also highly digestible. Increasing the proportion of high-protein feedstuffs will increase production. In addition, producers will breed cows that are genetically favored to produce low-fat, high-protein milk. These modifications would reduce methane emissions by increasing production efficiency.

- **Beef Prices**. Industry efforts are also underway to improve the quality of beef through Value-Based Marketing, an industry trend leading to more accurate pricing of beef based on value. One effect would be a reduction in incentives to produce excess fat in beef. Reducing fat in the animals would be achieved through genetic improvements and more efficient feeding practices. The result would also lead to lower methane emissions.

  This Value-Based Marketing trend may also provide incentives for a more efficient calf-slaughter system. Generally, calves go through one of two paths after they are weaned. Approximately 80 percent of calves pass through a stocker or backgrounding phase for several months, before entering the feedlot. The remaining 20 percent of calves go straight to the feedlot. Calves that are backgrounded are slaughtered at an older age and consequently emit more methane during their life cycle than calves that go straight to the feedlot. The Value-Based Marketing trend may cause an increase in the number of calves going directly to feedlots, with a consequent reduction in methane emissions (EPA, 1993a).

2.2 Achievable Emission Reductions

This section provides potential emission reductions under varying assumptions about how some of the practices and strategies described above are implemented. Potentially achievable emissions for dairy and beef cattle are presented in Exhibit 6-5 and Exhibit 6-7, respectively.

Dairy Cattle. Exhibit 6-5 provides future emission estimates from dairy cattle using scenarios in which rbST and MCP are adopted. USDA (1996) estimated milk production per cow and demand for dairy products through 2005. Demand after 2005 is expected to remain constant. In Exhibit 6-5, a constant baseline increase of 300 pounds of milk per cow per year is used to estimate future milk production. This increase is a current trend that is expected to continue as the dairy industry improves production efficiency. Future cow populations are estimated by using projected estimates of demand and milk production.

The emission factor estimates are multiplied by projected population estimates to estimate future emissions. The emission factor estimates for dairy cows change through time to account for changes in milk production levels.

Exhibit 6-5 shows the reduction in methane emissions when rbST and MCP are adopted. Improvements in animal and feed characteristics could potentially increase production efficiency and reduce emissions further.

Beef Cattle. EPA estimated methane emissions from beef cattle for three sets of emissions scenarios: (1) low; (2) medium; and (3) high emissions. The scenarios are presented in Exhibit 6-6, and the emissions estimates for each scenario are presented in Exhibit 6-7. For each of these sets, a baseline is defined by the level of domestic consumption and exports. Within

Exhibit 6-5: Projected Dairy Methane Emissions (MMTCE)

Scenario	2000	2005	2010	2015	2020
(1) Current emission factors	8.59	9.05	9.39	9.62	9.91
(2) Baseline increase of 300 lbs of milk/yr	8.53	8.82	8.82	8.88	8.93
(3) Low rbST Adoption – no MCP	8.48	8.71	8.76	8.82	8.88
(4) High rbST Adoption– no MCP	8.42	8.65	8.71	8.76	8.82
(5) No rbST Adoption- with MCP	8.25	8.48	8.48	8.53	8.59
(6) Low rbST Adoption - with MCP	8.19	8.42	8.42	8.48	8.53
(7) High rbST Adoption - with MCP	8.13	8.36	8.36	8.42	8.48

rbST = Recombinant Bovine Somatotropin; MCP = Multiple Component Pricing each set, EPA evaluated alternative scenarios that are defined in terms of improvements in the cow-calf phase and the growth-to-slaughter phase. These characteristics are described below.

- **Domestic Consumption**. As presented in Exhibit 6-6, future emissions are calculated under low, middle and high beef consumption scenarios, which combine different levels of domestic and export consumption. Consumption projections are the product of future per-capita consumption and population estimates. USDA (1996) published projected estimates of beef consumption through 2005.
- **Exports**. The U.S. cattle industry is highly efficient compared to the cattle industries of other countries. Consequently, increasing U.S. cattle exports would displace less efficient operations, and reduce methane emissions per unit product worldwide. Exhibit 6-6 summarizes the low, medium, and high export scenarios.
- **Cow-Calf Phase**. Improvements in management and nutrition are underway in the cow-calf sector, which accounts for a large portion of methane emitted by cattle in the U.S. Researchers and extension agents are working with producers to improve pasture management and implement better management techniques that improve animal health and nutrition. Because cow-calf operations in the southeastern U.S. are less efficient than cow-calf operations in other regions of the U.S., improving management practices in the southeast could have significant impacts on reducing methane emissions. Consequently, the cow-calf phase scenario in this analysis is for cow-calf operations in the southeastern U.S.

Implementing these measures improves production efficiency, which can be expressed in terms of calving rates and two-year-old heifer calving rates. The calving rate is the proportion of calves born from the total number of mature cows. The two-year-old heifer calving rate is the proportion of heifers in the population that successfully produce a calf by two years of age. Currently, the calving rate and two-year-old heifer calving rate for cow-calf operations in the southeast are approximately 70 and 50 percent, respectively. Improving these efficiencies would reduce the number of mother cows needed and, therefore, would reduce methane emissions. Exhibit 6-6 presents three cow-calf scenarios for low, medium, and high emissions.

Exhibit 6-6: Scenarios for Estimating Future Emissions from Beef Cattle

Scenario	Domestic Consumption Scenario	Export Scenario	Cow-Calf Phase Scenario [a-c]	Growth-to-Slaughter Phase Scenario [d]
Low Emissions	Continues to decline at the rate projected for 2000 to 2005	Increase by 25 million pounds per year by 2020	By 2010, the calving rate and two year old heifer calving rate increase to 85 and 75 percent, respectively	By 2010, 20/80 percent weanling/yearling changes to 80/20 percent
Medium Emissions	Average of low and high demand scenarios	Average of low and high scenarios	By 2015, the calving rate and two year old heifer calving rate increase to 85 and 75 percent, respectively	By 2010, 20/80 percent weanling/yearling changes to 50/50 percent
High Emissions	Remains at the 2005 consumption level	By 2015, equal to ten percent of total consumption	By 2020, the calving rate and two year old heifer calving rate increase to 85 and 75 percent, respectively	By 2010, 20/80 percent weanling/yearling changes to 30/70 percent

[a] For the baselines, the calving rate and two year old heifer calving rate are 70 and 50 percent, respectively.

[b] The calving rate is the proportion of calves born to the total number of cows in the population (expressed as a percentage).

[c] The two year old heifer calving rate is the proportion of heifers calving at two years of age to the total number of heifers that are two years of age or older in the population (expressed as a percentage).

[d] For the baselines, the growth-to-slaughter phase is 20 percent weanling/80 percent yearling.

- **Growth-to-Slaughter Phase**. Efforts are also underway to improve productivity in the growth-to-slaughter phase by increasing the proportion of calves that go directly from weaning to feedlots. Currently, approximately 20 percent of the calves go straight to feedlots, while 80 percent are held in a stocker phase for backgrounding. For this analysis, calves that go straight to feedlots are called weanlings, while calves that go through extended backgrounding are called yearlings. Increasing the percentage of weanlings would reduce the age at slaughter and would reduce methane emissions. In addition to increasing the proportion of calves that are weanlings, improved health and nutrition also increases production efficiency in the growth-to-slaughter phase. EPA created three scenarios to estimate projected emissions in growth-to-slaughter (see Exhibit 6-6).

Exhibit 6-7 presents the methane emissions for each scenario.

2.3 Reduction Estimate Uncertainties and Limitations

Considerable uncertatinty is associated with the scenarios shown in Exhibit 6-7. The major source of uncertainty are the forecasts of emission factors which depend on the extent to which the various strategies to improve production efficiency are implemented. In addition, there are major uncertanities in forecasts of demand for dairy and beef products that will influence the future animal population.

Exhibit 6-7: Methane Emissions from Beef Cattle (MMTCE)

Scenario	2000	2005	2010	2015	2020
Low Emissions Scenario					
Baseline - Low	25.1	25.4	25.4	25.4	25.2
Large Weanling/Yearling shift to 80%	24.4	23.9	23.0	23.0	22.9
Improved cow-calf by 2010	24.9	24.8	24.5	24.4	24.2
Both – Low	24.1	23.3	22.1	22.1	21.9
Middle Emissions Scenario					
Baseline – Medium[a]	25.1	25.4	26.1	26.7	27.3
Medium Weanling/Yearling shift to 50%	24.8	24.6	24.9	25.4	25.9
Improved cow-calf by 2015	24.9	25	25.3	25.7	26.2
Both – Medium	24.5	24.2	24.1	24.5	25.0
High Emissions Scenario					
Baseline – High	25.1	25.4	27.7	30.2	31.4
Small Weanling/Yearling shift to 30%	25.0	25.2	27.3	29.8	31.0
Improved cow-calf by 2020	25.0	25.1	27.1	29.4	30.3
Both – High	24.9	24.8	26.7	28.9	29.8

[a] EPA used this scenario to estimate future methane emissions from beef cattle as indicated in Exhibit 6-4.

3.0 References

Baldwin, R.L., J.H.M. Thornley, and D.E. Beever. 1987a. "Metabolism of the Lactating Cow. II. Digestive Elements of a Mechanistic Model," *Journal of Dairy Research*, 54: 107-131.

Baldwin, R.L., J. France, D.E. Beever, M. Gill, and J.H.M. Thornley. 1987b. "Metabolism of the Lactating cow. III. Properties of Mechanistic Models Suitable for Evaluation of Energetic Relationships and Factors Involved in the Partition of Nutrients," *Journal of Dairy Research*, 54: 133-145.

Crutzen, P.J., I. Aselmann, and W. Seiler. 1986. "Methane Production by Domestic Animals, Wild Ruminants, Other Herbivorous Fauna, and Humans," *Tellus*, 38B:271-284.

EPA. 1993a. *Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress.* Atmospheric Pollution Prevention Division, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, EPA 430-R-93-003. (Available on the Internet at http://www.epa.gov/ghginfo/reports.htm.)

EPA. 1993b. *Opportunities to Reduce Anthropogenic Methane Emissions in the United States, Report to Congress.* Atmospheric Pollution Prevention Division, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, EPA 430-R-93-012.

EPA. 1996. *An Environmental Study of Bovine Somatotropin Use in the U.S.: Impacts on Methane Emissions.* Prepared by: ICF Incorporated. Atmospheric Pollution Prevention Division, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, EPA 430-R-93-012.

EPA. 1999. *Inventory of Greenhouse Gas Emissions and Sinks 1990-1997.* Office of Policy, Planning, and Evaluation, U.S. Environmental Protection Agency, Washington, DC; EPA 236-R-99-003. (Available on the Internet at http://www.epa.gov/globalwarming/inventory/index.html.)

Food and Agriculture Organization (FAO). 1998. *Statistical Database*. June 12, 1998. (Accessed July 1998.) (Available on the Internet at http://www.fao.org.)

Monsanto. 1998. *Monsanto Release: Status Update: Posilac® Bovine Somatotropin.* December 15, 1998, St. Louis, MO.

USDA. 1987. *Economic Impact of the European Economic Community's Ban on Anabolic Implants.* Food Safety and Inspection Service, U.S. Department of Agriculture, Washington, DC.

USDA. 1990. *Agricultural Statistics*. U.S. Government Printing Office, U.S. Department of Agriculture, Washington, DC.

USDA. 1996. *Long-term Agricultural Baseline Projections, 1995-2005.* National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC.

USDA. 1997. *Hogs and Pigs.* National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998a. *Cattle*. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998b. *Cattle on Feed*. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998c. *Livestock Slaughter Annual Summary*. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998d. *Milk Production*. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998e. *Sheep and Goats*. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998f. *Part IV: Changes in the U.S. Beef Cow-Calf Industry, 1993-1997*. National Animal Health Monitoring System, Fort Collins, CO. (Available on the Internet at http://www.aphis.usda.gov/vs/ceah/cham.)

Appendix VI: Supporting Material for the Analysis of Enteric Fermentation

This appendix provides additional information regarding the methods used to estimate emissions from livestock enteric fermentation. Methane emissions associated with enteric fermentation from the U.S. population of cattle, sheep, goats, pigs and horses are estimated. The estimates primarily depend on the livestock population and associated emission factors.

The first section describes the livestock population and presents population data used to estimate 1997 emissions from livestock enteric fermentation. The second section presents and describes the emission factors used for the 1997 emission estimates.

VI.1 Population Data

This section provides the population data used to estimate 1997 methane emissions from livestock enteric fermentation. In addition, this section elaborates on the three main beef industry sectors. The U.S. Department of Agriculture (USDA) collects population data at the state level annually. Population data from 1997 for cattle, sheep, goats and pigs are presented in Exhibit VI-1. Cattle population data are broken down beyond the national level to account for variation in management practices and type of feed throughout the country. Because these factors affect methane emissions and are highly variable, breaking the population down into groups improves the accuracy of the analysis. The animal groups are presented and described in Exhibit VI-2.

EPA divides the beef population into three main categories to account for different animal and feed characteristics. The three main beef sectors are the cow-calf, stocker (backgrounding), and feedlot sectors.

- ➢ **Cow-Calf Sector**. In the cow-calf sector, calves feed on their mother's milk for two to three months, after which they start a diet of milk and forage. Calves are simulated to start producing methane at 165 days, and are weaned at 205 days.
- ➢ **Stocker Sector.** Following the cow-calf sector, most calves enter the stocker sector, during which they consume primarily forages. Animals are placed in the stocker phase to increase their weight be-

Exhibit VI-1: Animal Population Sizes for 1997

Animal Type	Population (000)	Animal Type	Population (000)
Mature Dairy Cows	9,304	Yearlings	22,767
Dairy Replacement Heifers (0-12 Months)	3,828	Bulls	2,320
Dairy Replacement Heifers (12-24 Months)	3,828	Sheep	7,607
Mature Beef Cows	34,486	Goats	2,295
Beef Replacement Heifers (0-12 Months)	5,678	Horses	6,150
Beef Replacement Heifers (12-24 Months)	5,678	Pigs	58,671
Weanlings	5,692		

Source: FAO, 1998; USDA, 1997 and 1998a-d.

fore being placed in the feedlot. Animals going through stockering are called Yearlings (see Exhibit VI-2).

➢ **Feedlot Sector.** Approximately 20 percent of the calves from the cow-calf sector enter the feedlot sector directly after they are weaned at about 205 days. These animals are called Weanlings (see Exhibit VI-2). The remaining calves (Yearlings) go through the stocker sector before entering the feedlot. Once in the feedlot, animals consume a high energy, high protein diet until they reach slaughter weight.

Exhibit VI-2: Animal Groups and Animal Characteristics

Animal Type	Initial Weight (kg)	Final Weight (kg)	Initial Age (days)	Final Age (days)	Other Characteristics
Dairy Replacement Heifers 0-12 Months	170	285	165	365	Calves feed on milk for first several months, a mixture of milk and forage from 60-90 days, and are weaned at 205 days, after which they consume all forage.
Dairy Replacement Heifers 12-24 Months	285	460	365	730	Dairy replacements are simulated to give birth at about 24 months, and to increase in body weight to the size of a Holstein cow, i.e., 550 kg.
Beef Replacement Heifers 0-12 Months	165	270	165	365	Calves feed on milk for first several months, a mixture of milk and forage from 60-90 days, and are weaned at 205 days, after which they consume all forage.
Beef Replacement Heifers 12-24 Months	270	390	365	730	Beef replacements are simulated to give birth at about 24 months.
Yearling System	170	480	165	565	Yearling system steers and heifers enter and leave the backgrounding phase at 165 and 425 days of age, respectively. Subsequently, they spend 140 days in the feedlot.
Weanling System	170	480	165	422	Weanling system steers and heifers enter the feedlot at 165 days, and are simulated to stay in the feedlot for 422 days.
Dairy Cows	550	550	365	730	Mature dairy cows produce milk for 305 days, followed by a 60 day dry period. They are simulated to give birth at end of 60 day dry period.
Beef Cows	450	450	365	730	Mature beef cows produce milk for 205 days, and produce less milk than mature dairy cows.
Beef Bulls	650	650	365	730	Beef bulls are simulated to lose weight during the 90 day breeding period, and to gain weight during the rest of the year.

Note: Dairy bulls are not included in the inventory because the dairy bull population is small.

Source: EPA, 1993a.

VI.2 Emission Factors

EPA uses emission factors specific to each animal type. These factors are based on research data and expert opinion. This section presents the factors for cattle and sheep, goats, pigs, and horses.

Cattle. The emission factors for beef and dairy cattle are presented in Exhibit VI-3 and Exhibit VI-4, respectively. Emission factors are developed using the model by Baldwin, et al. (1987a-b).

EPA uses diets in the model developed by Baldwin, et al. (1987 a-b) to estimate emissions from cattle. To account for differences in diets throughout the U.S., thirty-two different diets are defined by EPA (1993a). Fourteen diets are defined for dairy cattle, including six for dairy cows and four each for replacement heifers 0-12 months and 12-24 months. The eighteen beef cattle diets include three each for beef cows, replacement heifers 0-12 months, Weanling System heifers and steers, and Yearling System heifers and steers. Four diets are defined for beef replacement heifers 12-24 months, and two diets are defined for beef bulls. EPA (1993a) provides a breakdown of the diets by region.

Exhibit VI-3: Emission Factors for Beef Cattle (kg/hd/yr)

Animal	North Atlantic	South Atlantic	North Central	South Central	West
Replacement Heifers (0-12) Months	19.2	22.7	20.4	23.6	22.7
Replacement Heifers (0-24) Months	63.8	67.5	60.8	67.7	64.8
Mature Cows	61.5	70.0	59.5	70.9	69.1
Weanlings	--	--	22.6	24.0	23.5
Yearlings	--	--	47.0	47.6	47.6
Bulls	--	--	--	--	100.0

kg/hd/yr = kilograms per head per year

Source: EPA, 1993a.

Exhibit VI-4: Emission Factors for Dairy Cattle (kg/hd/yr)

Animal	North Atlantic	South Atlantic	North Central	South Central	West
Replacement Heifers (0-12) Months	19.5	20.5	18.9	20.3	20.7
Replacement Heifers (0-24) Months	58.4	58.7	57.4	61.7	61.2
Mature Cows	125.8	136.5	111.8	120.5	139.4

Note: Emission factors for mature dairy cows change annually according to milk production. Mature dairy cow emission factors are for 1997.

Source: EPA, 1993a.

With the exception of mature dairy cows, the emission factors for cattle have remained unchanged since those reported by EPA in 1993 (EPA, 1993a). Methane emission estimates from dairy cattle are adjusted annually to reflect increases in milk production per cow. Emission estimates are altered according to milk production levels because milk production is related to feed intake, which influences methane production.

Sheep, Goats, Pigs, and Horses. Average emission factor estimates are from Crutzen, et al. (1986), who developed emission factors for developed and developing countries. These emission factors are shown in Exhibit VI-5. For this analysis, emission factors for developing countries are used. Typical animal size, feed intakes, and feed characteristics are considered in the estimates. Emission factors have not been developed for the U.S., specifically, because emissions from non-cattle are small relative to emissions from cattle.

Exhibit VI-5: Emission Factors for Sheep, Goats, Pigs, and Horses (kg/hd/yr)	
Animal	**Emission Factor**
Sheep	8.0
Goats	5.0
Pigs	1.5
Horses	18.0

Source: Crutzen, et al., 1986; EPA, 1993a.

VI.3 References

Baldwin, R.L., J.H.M. Thornley, and D.E. Beever. 1987a. "Metabolism of the Lactating Cow. II. Digestive Elements of a Mechanistic Model," *Journal of Dairy Research*, 54: 107-131.

Baldwin, R.L., J. France, D.E. Beever, M. Gill, and J.H.M. Thornley. 1987b. "Metabolism of the Lactating cow. III. Properties of Mechanistic Models Suitable for Evaluation of Energetic Relationships and Factors Involved in the Partition of Nutrients," *Journal of Dairy Research*, 54: 133-145.

Crutzen, P.J., I. Aselmann, and W. Seiler. 1986. "Methane Production by Domestic Animals, Wild Ruminants, Other Herbivorous Fauna, and Humans," *Tellus*, 38B:271-284.

EPA. 1993a. *Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress.* Atmospheric Pollution Prevention Division, Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC, EPA 430-R-93-003. (Available on the Internet at http.//www.epa.gov/ghginfo/reports.htm.)

Food and Agriculture Organization (FAO). 1998. *Statistical Database*. June 12, 1998 (Accessed July 1998.) (Available on the Internet at http://www.fao.org.)

USDA. 1997. *Hogs and Pigs.* National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998a. *Cattle*. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998b. *Cattle on Feed*. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998c. *Livestock Slaughter Annual Summary*. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)

USDA. 1998d. *Sheep and Goats*. National Agricultural Statistics Service, Agricultural Statistics Board, U.S. Department of Agriculture, Washington, DC. (Available on the Internet at http://www.usda.gov/nass.)