REPORT:

A 50-Year Comparison of the Carbon Footprint and Resource Use of the US Swine Herd: 1959 - 2009

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Executive Summary

The purpose for this scientific project was to conduct parallel life cycle assessments to evaluate the impact of increased production efficiency in the U.S. swine industry on the environment and resource use over the past 50 years (1959 to 2009). The project models every aspect of pork production from cradle (upstream emissions and resource use associated with feed production) to finished market hogs at the farm gate (production of the live animal ready to be transported to harvest). The functional unit used for comparison is 1,000 pounds of hot dressed carcass weight (see "red meat" in definitions section).

A process-based deterministic model was used to model the flow of pigs through the U.S. swine industry by animal age-gender subclass for both the U.S. breeding and market hog herds. The model was designed to estimate feed, water, energy, land and crop nutrient resources required to support the population. Furthermore, estimates were made of manure and global warming gases (carbon-equivalents, CO_2e) produced annually. Each population flow was based on the yearlong flow of pigs through each age-gender subclass from December 1 to November 30 of the following year as published by USDA. Then, we estimated the dynamics of the population using known/published biological parameters representative typical of production practices of the era.

Results from the population flow model yielded the number of average animal-days in a year for each age-gender subclass in the population. Knowing the number of animal-days made it possible to estimate resource requirements such as feed and water. From this point, it was a natural progression to determine crop requirements using annual crop yield and input data from inputs such as pesticides, energy and irrigation. Emission factors were obtained for each process, including but not necessarily limited to, swine life functions, cropping, feed processing, feed transportation and manure storage.

The U.S. swine industry produces pigs far more efficiently today (2009) than in 1959. The number of hogs marketed has increased 29% (87.6 million in 1959 to 112.6 million in 2009 after removing market hogs imported directly to harvest) from a breeding herd that is 39% smaller. The efficiency gain is even more impressive when measured against the total dressed carcass weight harvested. Dressed carcass yield leaving the farm has nearly doubled in 50 years from 12.1 billion pounds to 22.8 billion pounds. This increase in productivity has resulted in an increase of 2,231 pounds (2.5x) of carcass harvested annually per sow-year. Today, it takes only five hogs (breeding and market) to produce the same amount of pork that required eight hogs in 1959.

A near doubling of pork output at the farm gate has only required a 25% increase in annual feedstuffs. As a result, feed efficiency as measured over the entire population, including maintenance of the breeding herd, has improved 33% from 6.6 pounds of feed per pound of dressed carcass weight produced at the farm gate to just 4.4 pounds of feed. This improvement is attributable to many factors including increased average daily gain, dietary changes, improved feed conversion, a smaller breeding herd and fewer numbers of idle pigs in the breeding herd.

Increased crop yields have resulted in a 59% decrease in the total amount of land required resulting in a 78% decrease in the amount of land required per 1,000 pounds of dressed carcass produced. This gain in efficiency, while primarily due to improved crop yields, is also a result of by-product feed use (eg. dried distiller's grain solubles (DDGS) and soybean meal (SBM)). Dietary changes based on improved feed milling and ration formulation have most likely played a role as well.

Much like feed utilization, total water demand for animal consumption has increased only 11% from 32.7 million gallons in 1959 to 36.2 million gallons in 2009. This has resulted in water consumption dropping from 2.7 gallons per pound of dressed carcass to 1.6 gallons, a 41% improvement. Most likely this improvement is due to a reduction in the size of the breeding herd and animals going to harvest at a much younger age today than in 1959.

The carbon intensity also known as the carbon footprint (CO_2e) of U.S. swine production to the farm gate has increased 23% in the past 50 years (45.7 million metric tonnes (MMT) to 56.1 MMT). This is to be expected given the increase in the number of pigs going to market and compares very favorably to the 88% increase in dressed carcass weight production during the same period. As a result, the carbon footprint per pound of dressed carcass produced has been reduced 35% from 3.8 kg/CO_2e to 2.5 kg/CO2e. This highlights the positive impact of improved efficiency in the total swine production chain on resource use.

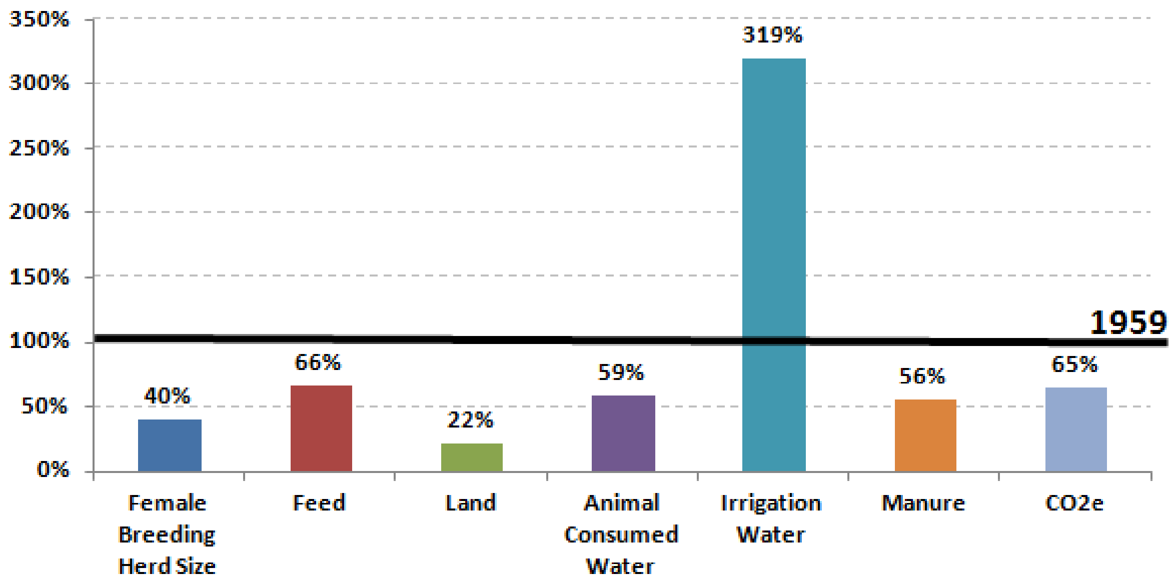
Conclusion

The U.S. swine industry has managed to stabilize its overall resource demand over the past 50 years. This feat is remarkable because pork production, as measured by pounds of dressed carcass leaving the farm gate, has nearly doubled in that same period. What the swine industry has been able to accomplish very successfully over the past 50 years is to significantly reduce its environmental impact and natural resource use nearly 50% across the board per 1,000 pounds of dressed carcass produced.

Summary of Results

Figure 1: Comparison of Key U.S. Swine Industry Environmental and Resource Use Measures (per 1,000 lbs. of hot dressed carcass weight produced)

NOTE: 2009 expressed as a percent of 1959.



1 Background

1.1 Introduction

Today's consumers are increasingly removed from agriculture. They are, however, demanding more information about their food choices and the environmental impact of their choices. Reputable food companies are engaged in Corporate Social Responsibility and Sustainability Initiatives to gain or maintain consumer and shareholder trust. The U.S. dairy and pork industries responded to retailer requests for information on the carbon intensity of dairy and pork products by working with the University of Arkansas Applied Sustainability Center to perform cradle to grave Life Cycle Analysis (LCA) of the greenhouse gas (carbon) intensity of a defined amount of retail product. For dairy, this was a gallon of milk and for pork, a four ounce serving of boneless pork. These studies established an industry baseline to measure future progress in improving the environmental footprint of dairy and pork. The beef industry has recently engaged BASF Corporation to perform a similar LCA for beef.

Because of the biology and physiology associated with animal protein production and the nutrient density of the products, the GHG or carbon intensities of meat and milk products are higher than many other food choices when measured on a simple mass basis (unit of carbon per unit of product). However, this is not always true when based on a nutrient content basis (nutrient density). Furthermore, and maybe more importantly, a common misperception is that extensive, small scale, outdoor pasture or dry lot based pork production systems, often called low-input systems, are more conducive to environmental stewardship than intensive modern pork production systems. While the input per animal per day or per acre is reduced with low-input systems, productivity is typically also reduced. This effect is due to the metabolic hierarchy of living things, which sets a priority on using nutrient intake for survival at the expense of productivity functions (eg. growth, lactation and reproduction) when nutrient intake is limited. As a result, low input systems often require more days for animals to reach market weight or more acres to produce a given amount of crop. Thus, a historical perspective of food production, in this case pork, is important to demonstrate to the food supply chain and consumers how marked improvements in swine productivity have resulted in substantial reductions in the environmental impact of pork production. Key measures often cited in food animal production environmental impact articles include carbon footprint/GHG emissions along with water, land and energy impacts.

Recently, the dairy industry received unprecedented and widespread positive press after publication of the journal article "*The environmental impact of dairy production: 1944 compared with 2007*" (Capper, Cady and Baumann, 2009). These authors modeled every aspect of both the modern and historical dairy production systems and found that modern dairy practices require considerably fewer resources to produce a pound of milk. The carbon footprint of the milk production sector of U.S. dairy industry in 2007 was only 59% of that in 1944. This finding highlighted the importance of improving productive efficiency in reducing the environmental impact of dairy production.

Similarly, a scientific article entitled "*Comparing the environmental impact of the US beef industry in 1977 to 2007*," (Capper 2011) revealed that improvements in nutrition, management, growth rate and harvest weights have significantly reduced the environmental impact of modern beef production and improved its sustainability. The carbon footprint per billion kilograms of beef produced in 2007 was reduced by 16.3% compared with equivalent beef production in 1977.

The purpose of this scientific project was to perform a similar investigation for the U.S. pork industry. Specifically, the project conducts parallel life cycle assessments to evaluate the impact of increased productivity of U.S. pork production systems on greenhouse gas (GHG) emissions, the environment and resource use over the past 50 years (1959 to 2009) as well as land and water demand. Every aspect of pork production from cradle (upstream emissions and resource use associated with feed production) to finished market hogs at the farm gate (production of the live animal ready to be transported to harvest) was evaluated and modeled.

After much research and deliberation, the year 1959 was chosen primarily because of factors such as data availability and 1959 precedes the use of intensive housing systems in the swine industry. The production methods used in 1959 also resemble those advocated by some who are critical of intensive housing and other modern production techniques. Sow productivity (market hogs sold/sow) was low in

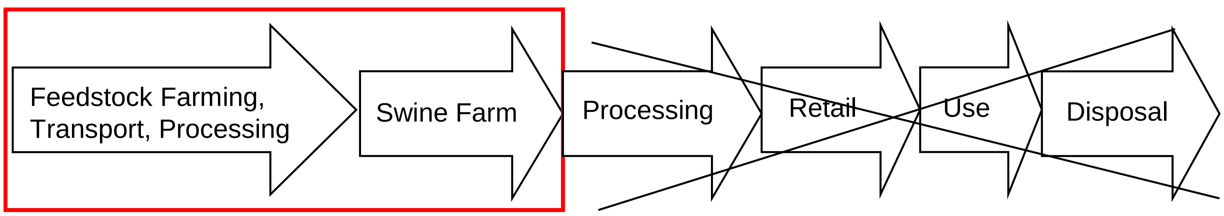
1959 and the year precedes the widespread use of feed antibiotics and industry innovations such as farrowing crates, year-round farrowing and artificial insemination.

2 Materials and Methods

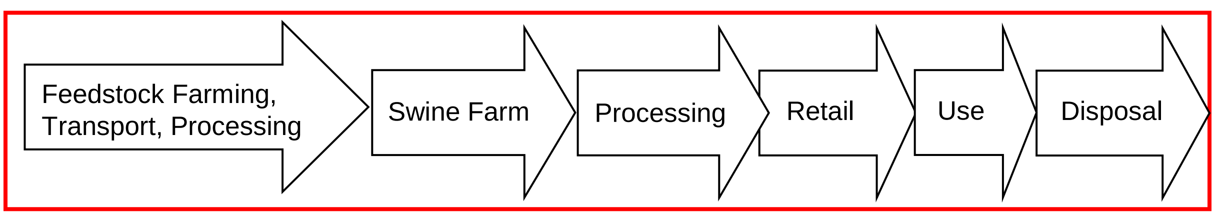
2.1 LCA Boundary

The project followed the general guidelines of a cradle-to-gate GHG LCA model for the GHG emissions associated with production in the years 1959 and 2009 for the U.S. swine herd. The scope of the GHG analysis, therefore, incorporates upstream emissions sources associated with crop production, transportation of feedstuffs from farm to elevator and elevator to feed mills and on-farm emissions sources associated with pork production in order to capture an accurate and adequately comprehensive picture of the cradle-to-gate GHG emissions.

Cradle-to-Gate



Cradle-to-Grave



2.2 Functional Unit

The functional unit is 1,000 pounds of dressed carcass weight ready to be delivered as a live market hog at the farm gate.

2.3 Time Periods Evaluated

The time periods evaluated were December 1958 through November 1959 and December 2008 through November 2009. These time periods were chosen to coincide with the inventory and market reporting cycle of the United States Department of Agriculture – National Agricultural Statistics Service (USDA-NASS) statistical reports.

2.4 Key Indicators Evaluated

- Dressed carcass weight produced
- Number of animals in the breeding herd and market herds
- Feed utilization

- Land use
- Chemical and energy utilization
- Water utilization (animal consumption and crop irrigation, sanitation water use omitted)
- Manure production
- Global warming potential (GWP) as measured by CO_2e emissions. (carbon dioxide - CO_2, GWP = 1; methane - CH_4, GWP = 23; nitrous oxide - N_2O, GWP = 310)

2.5 Definitions

Acre-foot:
Term used to describe the volume of water to irrigate land. One acre-foot is equal to the amount of water covering one acre at a depth of 1 foot. One acre-foot equals 325,852.7 gallons.

Animal-day:
A single animal being present in the population for one day.

Animal-year:
Equals 365 animal days. As examples, a single animal year may be made up of one animal present for 365 days or two similar age-gender animals, one being present for 300 days and the other for 65 days or 365 similar age-gender animals present for one day.

Average Daily Gain (ADG):
The amount of weight an animal of a particular age-gender group gains in one day.

Boar:
An intact male pig.

Breeding Herd:
Sows, gilts and boars used for breeding purposes and serve as parents of the pigs being readied for market.

Carcass Weight or Carcass Wt:
See definition for "Red Meat" below.

Carbon Footprint:
Sum of emissions of carbon dioxide and other greenhouse gases (ie. methane and nitrous oxide) that have a global warming effect.

Carbon Equivalent (CO_2e):
The sum amount of carbon dioxide (CO_2) emitted plus the weighted sum of methane (CH_4) and nitrous oxide (N_2O), weighted by their respective global warming potentials compared to the global warming potential of CO_2. (CO2 =1, CH4 = 23, N2O = 310).

Diminimus:
Term used to describe something of little or no consequence. A factor is diminimus when its impact appears to be less than 5% of the total impact and information to estimate its effect more precisely is unavailable. Therefore, the factor has been left out of the evaluation.

Feed Shrink:
Shrink refers to the amount of feed lost for various reasons between field harvest and the animals' mouth. Losses occur for various reasons. While not consumed by the animal, the loss

must be counted against the industry utilization when the lost feed is intended for consumption by the swine industry.

Farrow:
Give birth to a litter of pigs.

Feed Efficiency:
A measure of the effectiveness of feed utilization for pork production. In this case, it is the pounds of feed used to maintain the breeding and market herds for an entire year divided by the total amount of dressed carcass weight produced from U.S. raised market hogs that same year.

Gilt:
Female pig that has never given birth.

Greenhouse Gas (GHG):
A gas with a known global warming potential. For the sake of this report, that includes carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Also, see “Carbon Equivalent”.

Idle Pig:
A pig or hog in the breeding herd that apparently spent some substantial time not in an active breeding program (male or female), nursing, or gestating.

Litter Size:
The number of piglets born to a pig in a single litter, both alive and stillborn.

Sow:
Female pig that has given birth to at least one litter.

Market Herd:
Those pigs being raised solely for the purpose of being sent to market to produce pork.

Million Metric Tonnes (MMT):
One metric tonne is 1,000 kilograms thus one million metric tonnes is 1 billion kilograms. A kilogram is equal to 2.205 pounds.

Red Meat:
Term used by the USDA-NASS to describe the post-harvest yield of pork. Red meat production is the hot dressed carcass weight after harvest excluding condemnation. Will be called dressed carcass weight, carcass weight, or by the acronym HDWC in this report.

USDA-ERS:
U.S. Department of Agriculture Economic Research Service.

USDA-APHIS-NAHMS:
U.S. Department of Agriculture Animal and Plant Health Inspection Service National Animal Health Monitoring System.

USDA-NASS:
U.S. Department of Agriculture - National Agricultural Statistical Services.

2.6 Livestock Farming Materials and Method

A process-based deterministic model was used to estimate population structure and yearlong animal flow through the U.S. swine population by animal age-gender subclass for both the U.S. breeding and market hog herds and to determine the resource needs and emissions. As is true with virtually all animal production industries, the dynamic and fluid nature of pork production having several natural cycles nearly precludes using the more straightforward inventory method for conducting a full year life cycle assessment (LCA). This modeling technique is the same method used to model published historical and breed comparisons for the U.S. dairy industry ("*The environmental impact of dairy production: 1944 compared with 2007*", Capper, Cady and Bauman, 2009) and *("A comparison of environmental impact of Jersey vs. Holstein milk for cheese production"*, Cady and Capper, 2012) and the U.S. beef industry ("*Comparing the environmental impact of the US beef industry in 1977 to 2007*", Capper 2011) adapted for the U.S. swine industry.

Cycles include but are not necessarily limited to, seasonality, cropping season, innate porcine reproductive cycles, market hog growing periods and parental replacement cycles. Furthermore, the cycles are asynchronous (i.e. out of phase with each other), of separate and distinct duration, with most being shorter than one year. Finally, some cycles, most notably the growing period for market hogs, are not comparable between 1959 and 2009. Thus, a single or even quarterly snapshot of a hog census is insufficient to conduct a full-year LCA. Consequently, it was necessary to model the yearlong flow of pigs through each age-gender subclass of the population, using U.S. Agricultural Census and USDA-NASS data as the starting point and then estimating the flow using known/published biological parameters representative of typical management systems.

Published swine population inventories obtained from USDA-NASS for both years 1959 and 2009 using the USDA-NASS QuikStats online website were used as the model input starting point. More detailed data was available for 2009 than for 1959. Consequently, the 1959 USDA Agricultural Census was used to add supplemental data for 1959. Furthermore, significant numbers of pigs are now imported into the U.S. to augment the pork supply chain. Because the goal of this project was to estimate resource use by pigs that become part of the U.S. production sector, it was necessary to adjust USDA-NASS inventories for 2009 to account for imports. Import data was obtained from the USDA-ERS website. Import data is broken out by purpose and weight class. Those animals imported for breeding purposes or entered some part of the market hog herd and were reared for all or part of their life in the U.S. were accounted for on a pro-rated basis in the population model. Those animals that entered the U.S. directly for harvest were removed from the USDA-NASS statistics. Pigs imported into the market hog herd were removed from all performance estimates of the breeding herd.

Published swine performance data was incorporated to predict the number of pigs sent to market from the established inventories. Predicted values were compared to the USDA-NASS market hog sales records to validate the model was performing appropriately. Breeding and reproductive performance and practices were obtained from *"An update of North American boar stud practices"*, (Knox, et al., 2008). Additional reproductive, mortality data and disposition of dead animals was obtained from *"Reference of swine health and management factors in the United States, 2006, Parts I & III"* (USDA-NAHMS-APHIS).

Results from the population flow model yielded the number of animal-days in a year for each age-gender subclass in the population including an estimate of the number of hogs going to market through the one-year period being researched. The predicted number of marketed pigs was compared to USDA-NASS market statistics (adjusted for imports) as one key validation metric. The model correctly estimated the number of market pigs within ± 0.1% for both years. Once the number of animal-days for each age-gender subclass was established it was possible to estimate resource requirements starting with feed requirements.

A wide variety of feeding practices are employed throughout the U.S. swine industry. It is outside the scope of this project to estimate the impact of all feeding practice variants. Thus, era-typical diets were determined for each of the two years. For consistency across evaluations of the swine industry, diets and age-gender subclasses used in the University of Arkansas LCA project ("*Thoma et al. National Life Cycle Carbon Footprint Study for US Swine. Mar 2011*) were adopted for use in the 2009 evaluation. Dietary intakes for feed and water were obtained from "*Nutrient Requirements of Swine: 10th Revised Edition"* (National Academies Press, 1998). A description of the 2009 diets follows in Table 1: Typical 2009 Diets.

Table 1: Typical 2009 Diets

Diet Description - Typical 2009 Diet[1]	Breeding Herd				Market Pigs							
Age Group:	Sow - Gestating	Sow - Lactating	Sow - Breeding	Boar	Nursery I	Nursery II	Nursery III	Grower I	Grower II	Finsher I	Finisher II	Finisher III
Average Age (d):	N/A	N/A	N/A	N/A	22 to 28	29 to 42	43 to 63	64 to 87	88 to 110	111 to 132	133 to 155	156 to 179
Average Weight (lbs):	440	423	423	440	13	20	38	73	118	163	208	250
Target Avg. Daily Gain: (lb/d):	N/A	N/A	N/A	N/A	0.6	0.7	1.2	2.0	2.0	2.0	2.0	1.7
Feed Intake @ 90% DM (lb/d)[2]:	4.1	11.6	3.7	4.4	0.5	1.2	2.2	3.8	5.2	6.2	6.9	7.4
Water Intake (gal/d)[2]:	5.3	5.5	3.2	3.3	0.2	0.5	0.8	1.1	1.6	1.9	2.1	2.2
Ingredient												
Corn Grain	53%	59%	59%	53%	34%	44%	47%	51%	56%	62%	69%	84%
Dry Distillers Grain (DDG)	30%	10%	10%	30%	5%	10%	15%	15%	15%	15%	15%	
Soybean Meal (SBM)	11%	25%	25%	11%	19%	26%	32%	29%	24%	18%	13%	12%
Oats												
Wheat Midds												
Wheat Bran												
Alfalfa Meal												
Meat & Bone Meal					8%	2%						
Fat	2%	2%	2%	2%	5%	3%	1%	2%	2%	2%	1%	1%
Whey					25%	10%						
Molasses												
Mineral Package & Supplements	4%	4%	3%	4%	3%	4%	4%	3%	3%	2%	2%	2%

Sources: [1] *Thoma et al. National Life Cycle Carbon Footprint Study for US Swine. Mar 2011.*

[2] *1998, Nutrient Requirements of Swine: 10th Revised Edition, National Academis Press*

Information to describe era-typical 1959 diets is only available in historical literature, much of it from Extension publications. The variation in diets in 1959 is greater than present day due to the wide variety of feedstuff availability and differential cropping practices from climate to climate and region to region. Therefore, consensus-based diets were developed using the expertise existing on the research team. Dr. Palmer Holden, Professor Emeritus, Iowa State University developed the diets in Table 2: Typical 1959 Diets.

Table 2: Typical 1959 Diets

Diet Description - Typical 1959 Diet[1]	Breeding Herd				Market Pigs		
Age Group:	Sow - Gestating	Sow - Lactating	Sow - Breeding	Boar	Grower I	Grower II	Finisher
Average Age (d):	N/A	N/A	N/A	N/A	57 to 92	93 to 144	145 to 210
Average Weight (lbs):	427	433	392	440	28	72	170
Target Avg. Daily Gain: (lb/d):	N/A	N/A	N/A	N/A	0.7	1.2	1.5
Feed Intake @ 90% DM (lb/d):	4.4	12.0	4.4	4.4	1.7	3.7	5.7
Water Intake (gal/d)[2]:	5.3	5.5	3.2	3.3	0.7	1.1	1.7
Ingredient							
Corn Grain	27%	51%	27%	27%	65%	61%	68%
Dry Distillers Grain (DDG)							
Soybean Meal (SBM)	7%	12%	7%	7%	3%		
Oats	25%	15%	25%	25%	10%	20%	20%
Wheat Midds	10%		10%	10%	18%	13%	5%
Wheat Bran		5%			3%	3%	3%
Alfalfa Meal	20%	10%	20%	20%	1%	1%	1%
Meat & Bone Meal	5%	5%	5%	5%		3%	3%
Fat							
Whey					1%	0.4%	1%
Molasses	5%		5%	5%	1%	1%	1%
Mineral Package & Supplements	1%	2%	1%	1%	0.3%	0.2%	0.1%

Sources: [1] *Dr. Palmer Holden, PhD, Iowa State University, Personal Communication*

[2] *1998, Nutrient Requirements of Swine: 10th Revised Edition, National Academis Press*

Knowing the dietary requirements, ingredient levels, animal intake rates and the number of animal-days in each age-gender subclass, it is a straight-forward multiplication process to estimate the annual feed ingredient demand to maintain the national pig herd. In addition, not all feedstuffs harvested make it to a pig's mouth; some of it is lost during harvest, transport, mixing, feeding and spoilage. This loss is called shrink and must also be allocated to the industry requirement. There are no known well-documented sources of information estimating the amount of shrink. However, among those experts and companies that work within the swine nutrition industry, it is generally agreed that shrink is significant and should be accounted for in feed inventory requirements. Estimates of shrink range from 5% to as high as 15% for grain feedstuffs. An estimate of 5% shrink was included in this analysis for years, 1959 and 2009. Using required feed ingredient volumes and USDA-NASS QuikStat crop yield statistics, land requirements to grow crops necessary for swine diet feedstuffs were determined. Once the land area is known, crop inputs can be determined for the feedstock farming operations. Feedstock modeling is described in the next section.

Both 1959 and 2009 animal facility energy requirements were modeled based on lighting, ventilation and heating requirements described in the Midwest Plan Service's *Swine Housing and Equipment Handbook* 4th Edition (1983) and normalized on a per animal basis according to livestock category. The temporal relevance of each energy-related activity was considered in calculating total energy consumption. For example, we assume no ventilation was required in 1959 for any livestock category while the 2009 herd required similar ventilation requirements to that which is described in the Handbook. Regarding supplemental heat, we assumed that only lactating sows and their litters were supplemented in 1959, whereas, all livestock categories were supplementary heated in 2009 (using Handbook rates). It was also assumed that cooler average temperatures in two of our three geographic regions (Corn Belt and Upper Midwest) corresponded to a greater number of heating days than the Southeast. Regarding lighting, we assumed a fraction of livestock categories received additional lighting in 1959 versus 2009. Both 1959 and 2009 lighting demands were based on Handbook-proposed requirements of lighting duration per day, flux requirements per square area and space occupied requirements per livestock category for 2009.

Manure volumes and volatile solids excretion rates were obtained from *"ASAE D384.2. Manure Production and Characteristics"* (American Society of Agricultural Engineers. 2005). Regional differences in manure handling practices were recognized for modern U.S. swine production. Furthermore, emissions for various manure handling management practices differ widely. Thus, for the 2009 LCA, the U.S. was divided into three geographic regions based on regions where the most intensive pig populations are located (Corn Belt, Upper Midwest and Southeast). Results from each region were proportionally scaled-up and summed resulting in the overall U.S. emissions estimates from manure. In 1959, manure management practices were much more homogenous. Furthermore, hogs spent more time outside leaving droppings directly on the ground. No documentation could be found as to how many hogs were pastured or for how long. Again, consensus was used to estimate that 35% of animal days were spent outside. As was the case with such consensus estimates, a conservative approach was taken in order to avoid under-estimating emissions and resource use.

Finally, disposal of deceased animals (mortalities) results in emissions. Emissions levels differ by disposal method. Primary methods include burial, incineration, composting and rendering. The *"Reference of swine health and management factors in the United States, 2006, Parts I & III"* (USDA-NAHMS-APHIS) report documented average distribution of disposal among the four methods. Since rendering is a post farm gate method that results in useful products, emissions from rendering were allocated to outside the farm gate. Emissions from burial were estimated based on the accounting approach reported in Yuan et al. *Methane and carbon dioxide production from simulated anaerobic degradation of cattle carcasses*. Waste Management. 2011. Composting and incineration were the two disposal methods for which no emission factors could be found. Given that both methods are aerobic in nature, most of the mortalities carbon is converted to CO_2. Therefore, the method used by Capper and Cady ("*A comparison of environmental impact of Jersey vs. Holstein milk for cheese production"*, 2012) to estimate CO_2 emissions from composting was applied. Again this is a conservative method of estimation.

2.7 Feedstock Production Materials and Method

Feed requirements were estimated for each age-gender subclass using diets typical for the period. Diets for 2009 were obtained from the University of Arkansas *"National Life Cycle Carbon Footprint Study for Production of U.S. Swine* (2011) assuming the use of DDGS. Diets for 1959 were developed using typical ingredients of the time based on published Extension material from Iowa State University and NRC Nutrient Requirements for Swine, 10^{th} revised edition. Using the diets and number of animal-days in each age-gender subclass, the total amount for each feed ingredient was estimated. This is the first LCA study we are aware of that also includes a feed shrink factor in the analysis. From this point, it was a natural progression to determine crop requirements using annual crop yield data obtained from the USDA-NASS database.

2.7.1 Chemical Inputs

The following activities were modeled when estimating the total greenhouse gas impact from this category: production & processing of fertilizer, other feedstock-related inputs such as lime, pesticides and herbicides as well as swine dietary supplements.

Fertilizer, other feedstock inputs, and supplement consumption was estimated based on usage ratios reported from a number of references including: USDA-NASS, personal communication with Dr. Thoma of University of Arkansas and reference materials associated with the University of Arkansas *"National Life Cycle Carbon Footprint Study for Production of U.S. Swine"* and published Extension material from Iowa State University and NRC Nutrient Requirements for Swine, 10^{th} revised edition. Related emission factors were utilized from Intergovernmental Panel on Climate Change (IPCC), Ecoinvent (GHG emissions database) and the University of Arkansas National Swine LCA as well as other individual resources.

2.7.2 Farming and Energy Use

The following activities were modeled when estimating the total greenhouse gas impact from this category: process and fugitive emissions from synthetic and organic fertilizers during field application and fuel consumption associated with cultivating, planting, harvesting and irrigating.

Accounting guidelines for process and fugitive emissions from field application from the *"2006 IPCC Guidelines for National Greenhouse Gas Inventories Vol 4 Agriculture, Forestry, and Other Land Use"* were used to estimate emissions from: direct N_2O via nitrogen application, indirect N_2O from nitrogen-based fertilizer volatilization, indirect N_2O from nitrogen-based fertilizer leaching/run-off and direct CO_2 from lime application (for relevant feedstocks). In 1959 and 2009, it was assumed that aside from synthetic fertilizers, swine manure was also spread on fields. The amount of nitrogen available for direct or indirect emissions on fields was estimated based on IPCC-provided assumptions for nitrogen conversion during manure storage upstream of spreading. Assumptions for manure storage in 1959 and 2009 are discussed above in the *Livestock Farming* section. Fuel and energy requirements for cultivating, planting, harvesting and irrigating corn feedstock were estimated using Shapouri et al. "*The 2001 Net Energy Balance of Corn-Ethanol"*. Requirements for all other feedstocks were estimated on a percentage basis of the energy consumption profile for corn that was reported in the above reference. Emission factors for all activities were sourced from IPCC, Ecoinvent, eGRID2010 and TCR 2011 (all GHG emission databases).

2.7.3 Land Use

Land use was deduced from the estimate of feed ingredient requirements. Knowing the amount of ingredient required (e.g. corn, oats, etc,) it was a simple task of using yield data obtained from USDA-NASS Quikstats to determine the amount of land required to grow the necessary crops to meet the feed demand requirements. Some ingredients such as soybean meal, wheat midds and DDGS are by-products of crops grown with human consumption or ethanol production as the primary justification for the crop. Thus, it is necessary to assign cropland demand fairly by apportioning some of the cropland to human use and only part of the cropland demand to feed for swine consumption. Cropland was thus allocated using a mass substitution method in which cropland use was assigned to swine feed proportional to only that portion of the plant used as a feed ingredient. Land used for farmstead and pasture is an extremely small portion of land required to raise hogs and was thus considered diminimus.

2.7.4 Water Use

Water use for feedstock consists entirely of irrigation of cropland from surface and groundwater sources. USDA provides very detailed irrigation data in the *"Census of Agriculture Farm and Ranch Irrigation*

Survey (2008)", last update July 2010. Irrigation utilization was based solely upon the acres assigned to swine production for both years. It was assumed acres of cropland assigned to feed use for swine production were irrigated at the same percentage of land irrigated as for the remainder of cropland used for all other purposes. In other words, if 1% of total U.S. corn cropland was irrigated, than it was assumed that 1% of corn cropland assigned to swine production was irrigated. Likewise, irrigation rates were assumed the same for corn cropland assigned to swine production as all other corn cropland.

2.7.5 Transport

Feed transport estimates were made using a method similar to transport estimates used by Thoma et al. in the *"National Life Cycle Carbon Footprint Study for Production of U.S. Swine"* (2011). Transport in 1959 was assumed primarily local because hogs were primarily grown either on the same farm or within the same county as cropland for the feedstuffs. Feedstuffs requiring milling were primarily transported in 2.5 ton trucks with the mill being located an average of five miles from the farmstead. By contrast, feed transport in 2009 was configured much differently with hogs not necessarily being grown within close proximity of the cropland growing their feedstuffs. Thus, the country was divided into three geographic regions based on the regions of most intensive pig populations (Corn Belt, Upper Midwest and Southeast). Feed transport in the Corn Belt and Upper Midwest is still local within the region where feedstuffs are grown so mileage was still considered five miles to the mill, however, trucks were considered to be a 40-foot grain hauling tractor-trailer combination. In the Southeast region, however, most of the feed must be transported in by rail from distant grain elevators. Rail transport was assumed to be 100-car unit grain trains composed of 100-ton capacity cars. Feedstuffs were transported one-way from Des Moines, IA to Charlotte, NC for off-loading and delivery. Local delivery from the railhead to the farm was also five miles. Transportation-related emission factors published by the WRI/WBCSD GHG Protocol Initiative were used in these calculations.

2.7.6 Processing

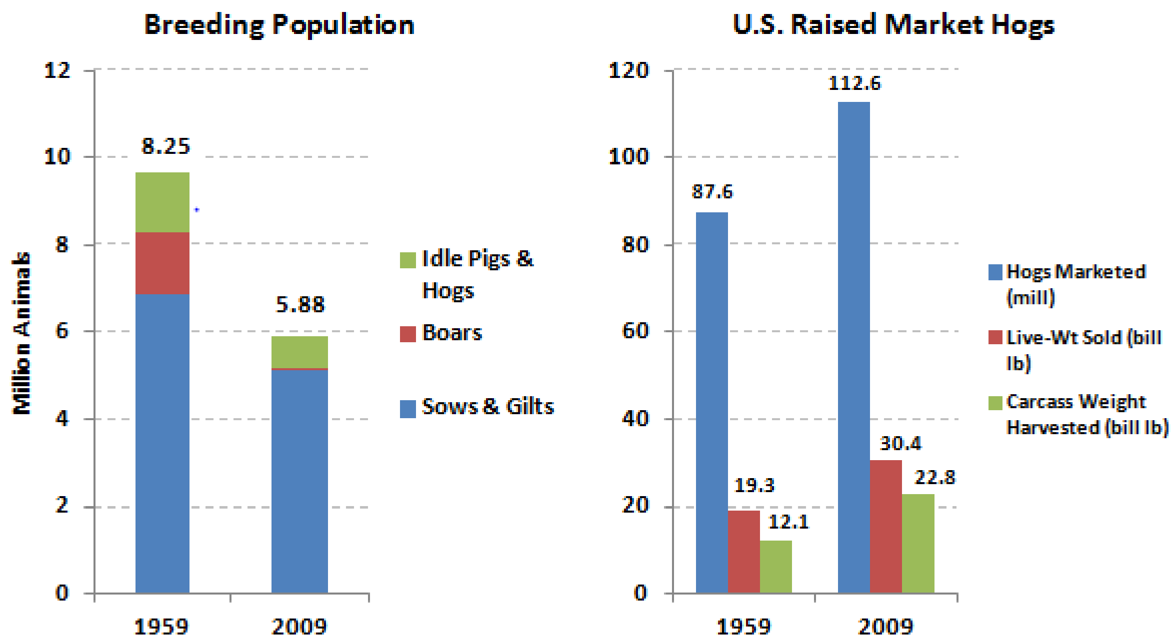
We estimated the greenhouse gas impact of drying corn feedstock in 2009 based on information provided via personal communication with Dr. Thoma of University of Arkansas, and reference materials associated with the University of Arkansas *"National Life Cycle Carbon Footprint Study for Production of U.S. Swine"*. We assumed processing of feedstock in 1959 was minimal and considered diminimus.

3 Results and Discussion

3.1 Swine Production

The U.S. swine industry produces pigs and pork far more efficiently today (2009) than in 1959. Referring to Figure 2, the number of hogs marketed has increased from 87.6 million to 112.6 million from a breeding herd that is 39% smaller. The efficiency gain is even more impressive when measured by the total weight of dressed carcasses harvested. Yield has nearly doubled in 50 years from 12.1 billion pounds to 22.8 billion pounds. This increase has resulted in an increase of 2,231 pounds (2.5x) of dressed carcass harvested annually per sow-year (Figure 3) in 2009.

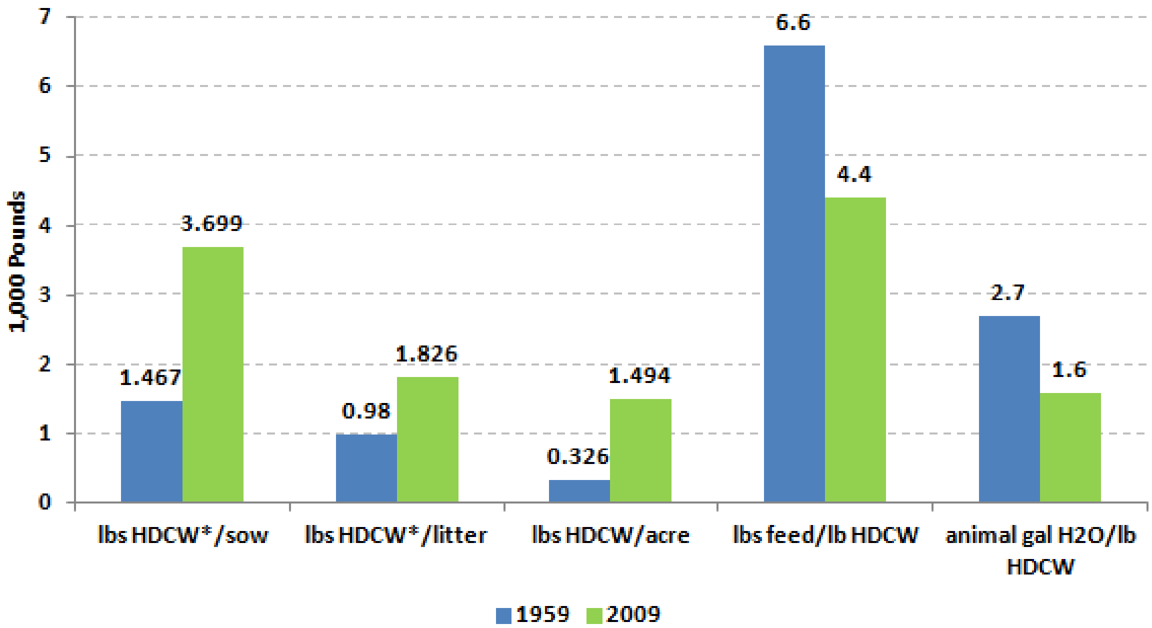
Figure 2: Breeding Population Distribution and Market Hog Summary



Source: Adapted from USDA-NASS, USDA-ERS & 1959 US Ag Census

Figure 3: Key U.S. Swine Industry Production Resource Measures

NOTE: *Hot Dressed Carcass Weight from U.S. born market pigs only; imported grower and feeder pigs excluded



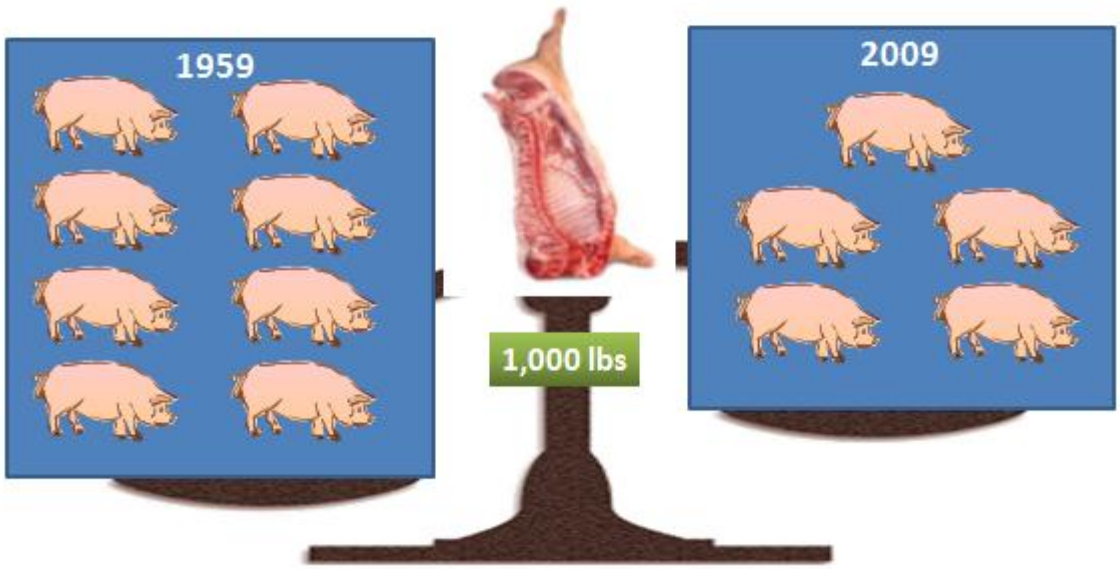
Improvements occurring in genetics (ADG, litter size, carcass composition and crop yield); management (nutrition, facilities, health and reproduction) and technology (ADG, carcass composition, crop management, animal health and reproduction) have combined to achieve this efficiency. Many key factors indicative of efficiency gains are summarized in Table 3. The overall increase in efficiency can be best summarized in Figure 4. Namely, overall, considering all hogs (breeding herd plus market hogs) in the population, it takes only five hogs today to produce the same 1,000 pounds of dressed carcass weight that required eight hogs in 1959.

Table 3: Key Pork Efficiency Factors 1959 – 2009

NOTE: *HDCW is an industry average after condemned carcasses have been removed from the total.

Key Performance Indicators	1959	2009	Δ	Δ%
Swine Industry Performance				
% Idle Hogs & Sows	17%	12%	-4%	-26%
No. Litters/Sow/Yr	1.49	2.03	0.54	36%
Average Litter Size @ Birth	9.1	11.9	2.8	30%
Average Pigs Sold/Litter	6.9	9.0	2.1	30%
Average Days to Harvest	210	180	-30	-14%
Average Live Weight at Harvest (lb)	237	270	33	14%
Average Daily Gain (ADG) (lb/d)	1.12	1.49	0.37	33%
Average hot dressed carcass weight (HDCW*)/hog (lbs)	149	202	53	36%
% HDCW* Yield	63%	75%	12%	19%
Crop Performance				
Corn Yield (bu/ac)	53.1	164.7	111.6	310%
Soybean Yield (bu/ac)	23.5	44.0	20.5	87%
Efficiency Measures				
Lbs Feed:Lbs HDCW	6.6	4.4	-2.2	-34%
Gal Water Intake:Lb of HDCW	2.7	1.6	-1.1	-41%
HDCW Pounds/Sow/yr	1,467	3,699	2,231	252%
HDCW Pounds/Litter	980	1,826	845	186%
HDWC Pounds/Acre	326	1,494	1168	458%

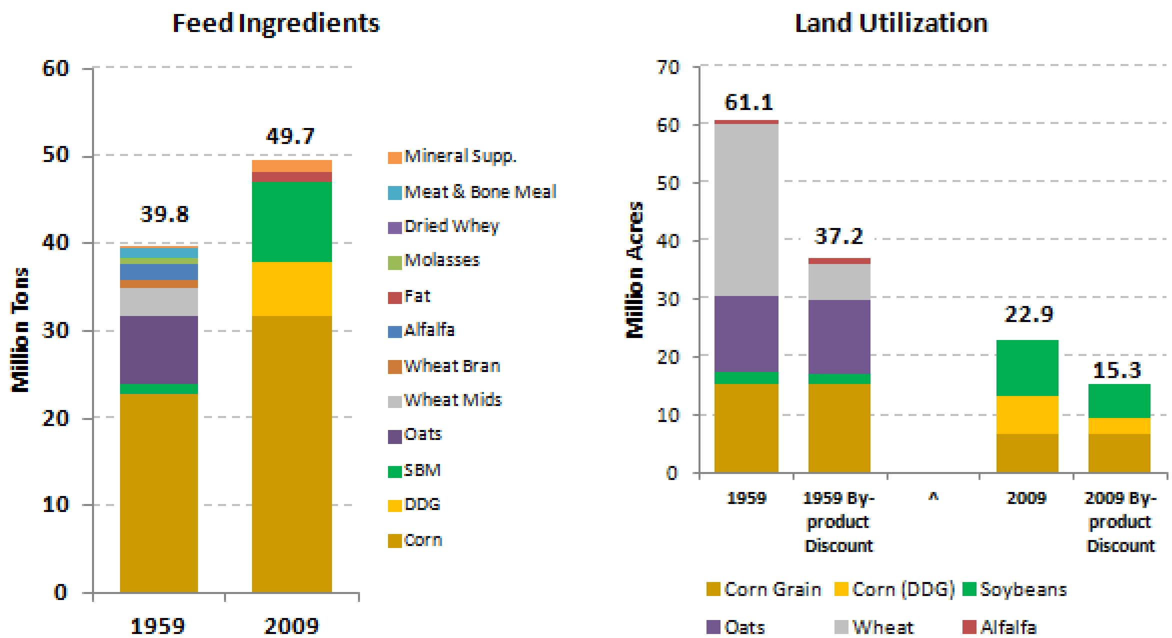
Figure 4: Reduced Environmental Impact Driven by Productive Efficiency



3.2 Feed Utilization and Production

A near doubling of pork output at the farm gate has only required a 25% increase in annual feedstuffs (including shrink) of 9.9 million tons. As a result, feed efficiency as measured over the entire population, including maintenance of the breeding herd, has improved 34% from 6.6 pounds of feed per pound of dressed carcass produced at the farm gate to just 4.4 pounds of feed (Figure 3). This increase is attributable to many factors including increased ADG, dietary changes, improved feed conversion, decreased size of the breeding herd and a decrease in the number of idle pigs in the breeding herd. As stated previously, genetics, management and technology have all played a role in these improvements.

Figure 5: Overall Feed Ingredients and Associated Crop Land Utilization



3.3 Land Use

An increase in the number of market hogs from 1959 to 2009 has increased feed demand (Figure 5). As discussed earlier, however, significant increases in hog production efficiency have significantly mitigated the increase in feed demand such that the amount of additional feed required is proportionally less than the increase in market hog numbers and carcass weight harvested. This has served well to increase land conservation. Despite this progress, reduced land base requirements are predominantly the result of improved crop yields, corn and soybeans in particular (Table 3). The total cropland base requirement to support the U.S. swine industry has been reduced by 59% since 1959, after discounting for feeding by-product feeds (37.2 million acres to 15.3 million acres) (Figure 5.). When combined with meat production, this means that over 4.5 times as much dressed carcass/acre was produced in 2009 vs. 1959, which is a 78% reduction in land demand per pound of dressed carcass. While land for pasture and farmstead obviously requires a land base regardless of year evaluated, the amount of land required for these uses was determined to be diminimus due to the northern geographic location of most swine production in 1959, which required significant periods of feeding harvested feeds and the predominance of enclosed intensive housing systems typical in 2009.

Another important point is that even though hogs are monogastric, they consume substantial amounts of by-product feeds. These by-products are the result of either processing food for human consumption, such as the wheat midds and bran in the 50’s, or from the conversion of corn into bio-fuels for human use, such as ethanol today or soybean meal from the manufacture of soy oils. Swine were initially domesticated some 6,000 to 8,000 years ago and because they are by nature scavengers, they did not compete for food sources with humans. They ate what humans could not or would not eat. Contrary to common public belief today, swine still play an important role in consuming nutritious by-products of human food and energy processing for which there is no human demand. Because of the by-product nature of wheat midds and bran, dried-distiller’s grains and soybean meal, the land demand for these products have been discounted to account for the primary product demand for wheat flour, ethanol respectively and soybeans for oil.

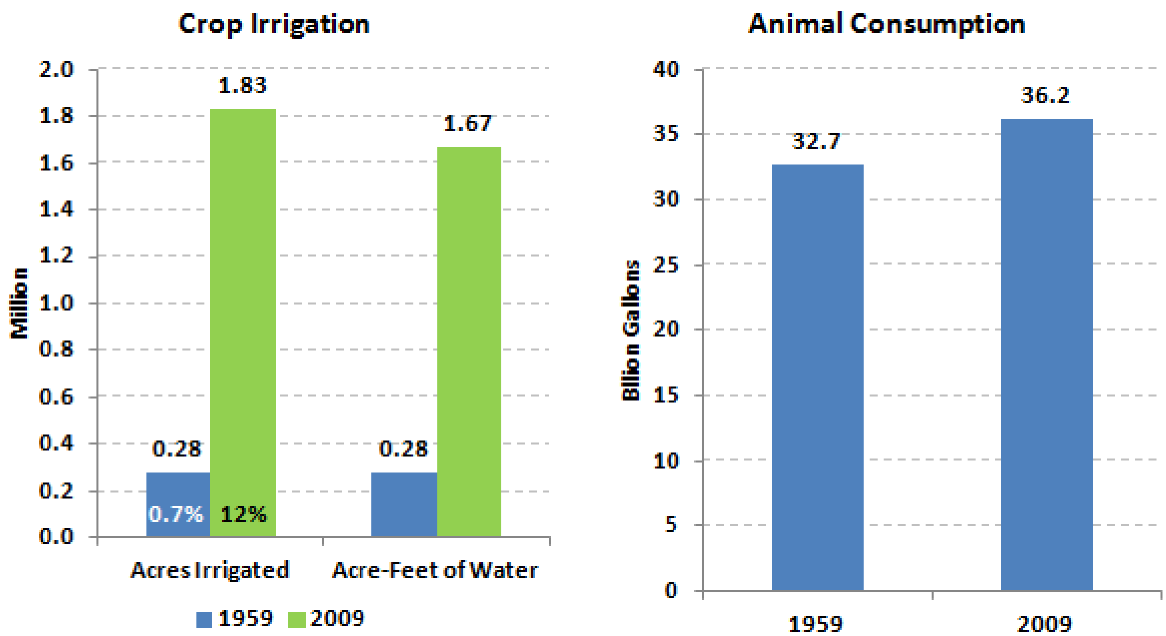
3.4 Water Use

Estimating a water footprint is a complex undertaking beyond the scope of this project. However, it was possible to estimate water consumption by the swine industry. Water consumption has been separated out into water intake by the hogs and water used for fresh water crop irrigation.

Much like feed consumption, despite the increased number of market hogs, total water demand for hog consumption has increased only 11% from 32.7 million gallons to 36.2 million gallons (Figure 6). This has resulted in water consumption dropping from 2.7 gallons per pound of dressed carcass to 1.6 gallons, a 41% improvement (Figure 3). Most likely this improvement is due to a change in the age-gender profile of the U.S. swine herd from 1959 to 2009 as well as the fewer days to market.

Data from the Census of Agriculture indicated that only 0.75% of cropland was irrigated in 1959 at an average rate of 1 acre-foot annually. While only 12% of U.S. cropland used for feedstuffs of the type used in swine rations (corn and soybeans) was irrigated in 2009 that represents a greater than 12-fold increase in irrigated acres, including those assigned proportionally to swine production and discounted for by-product feeding. The increase in irrigation water use for feedstuffs for swine was actually reduced because number of acres allocated to swine production declined by more half from 1959 to 2009. However, this still represents a 6-fold increase is water use for irrigation for pig feedstuffs in 2009 compared to 1959.The result is that water savings for hog consumption has been more than offset by the demand for crop irrigation.

Figure 6: Water Utilization



3.5 Carbon Footprint

The overall carbon footprint of the U.S. swine production industry to the farm gate in 2009 was 56.1 million metric tonnes (MMT) of CO_2e, as estimated by this project compared to a like-estimated carbon footprint for the 1959 swine industry of 42.7 MMT (Figure 7). While this is a 23% increase over the past 50 years, this increase must be put in context of the 88% increase in harvested carcass weight; meaning the U.S. swine industry has clearly instituted methods to reduce its environmental impact while increasing production. This can be seen quite clearly when comparing the carbon footprint per pound of dressed carcass weight (Figure 8.) between 1959 and 2009. The carbon footprint per pound of dressed carcass has been reduced 35% (Figure 1) from 3.8 kg in 1959 to 2.5 kg in 2009 (Figure 8). Comparing the 2009 estimate with the University of Arkansas report ("*Thoma et al. National Life Cycle Carbon Footprint Study for US Swine. Mar 2011*) is not straightforward because the Thoma report LCA boundary ended at the consumer versus the farm gate in this report. Furthermore, the functional units were different; a four-ounce serving of pork in the Thoma report versus 1,000 pounds of dressed carcass weight in this report. However, sufficient detail is provided in the University report that some rudimentary comparisons can be teased out. Converting carcass weight to boneless pork and comparing to the live animal production portion of the Thoma report and finally converting units, the estimates for carbon footprint of the farm sector (live animals plus crops) are remarkably similar, differing by less than 10% with the estimate in this report and falling well within the 95% confidence interval of the Thoma report. This is remarkable considering the difference in the two investigative strategies.

The reduction in carbon footprint per unit of meat produced has been achieved in several ways. Foremost among the practices has been the improvement in production efficiency for both swine production and crop yields. It simply takes far fewer resources to produce a bushel of grain and a pound of dressed carcass today than it did 50 years ago. These gains in efficiency have been well documented throughout this report.

Examining the breakdown in source of carbon emissions, some of the responsible factors are apparent. First and foremost would be the significant reduction in emissions from chemical application to crops. This is due to both fewer acres to provide feedstuffs and due to use of genetically modified (GMO) corn and soybeans that have genetic resistance to pests and herbicides. Thus, fewer tractor passes across cropland and less herbicides and pesticides are required to maintain crop health. This extraordinarily effective technology has had the effect of shifting the distribution of carbon source much heavier onto the animal production side.

Another noticeable shift in carbon emission source is the increase in manure related emissions despite a small 5% overall increase in total manure production over 50 years. The primary reason is the adoption of lagoons and other modern methods of manure management. Many of these systems are anaerobic which convert organic carbon to methane (CH_4) which has a 23 to 25 times greater global warming potential than CO_2.

In conclusion, the U.S. swine industry has made major strides in minimizing the environmental impact of meeting increased demand for pork over the past 50 years. Resource use and environmental impact per 1,000 pounds of dressed carcass weight produced has been greatly reduced, an average of nearly 50% across the board. This noteworthy achievement has only been possible because of tremendous increases in production efficiency. Pigs go to market on average 33 pounds heavier and 30 days younger today than in 1959. As a result, five pigs today produce the same 1,000 pounds of dressed carcass weight compared to eight pigs in 1959.

Figure 7: U.S. Swine Industry Carbon Footprint (CO_2e)

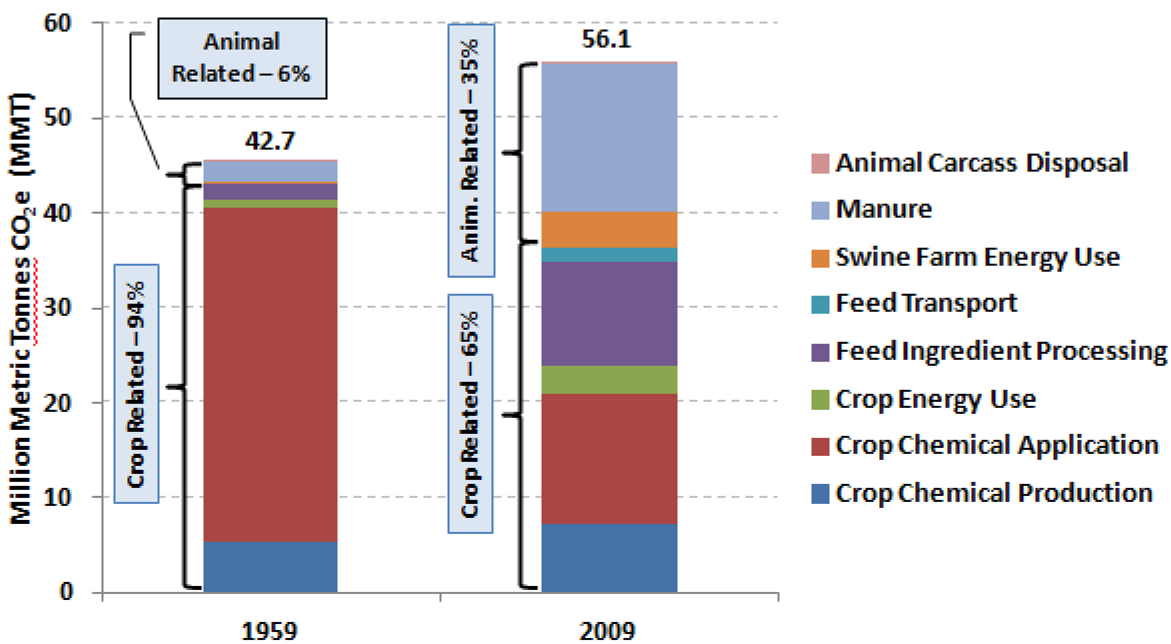
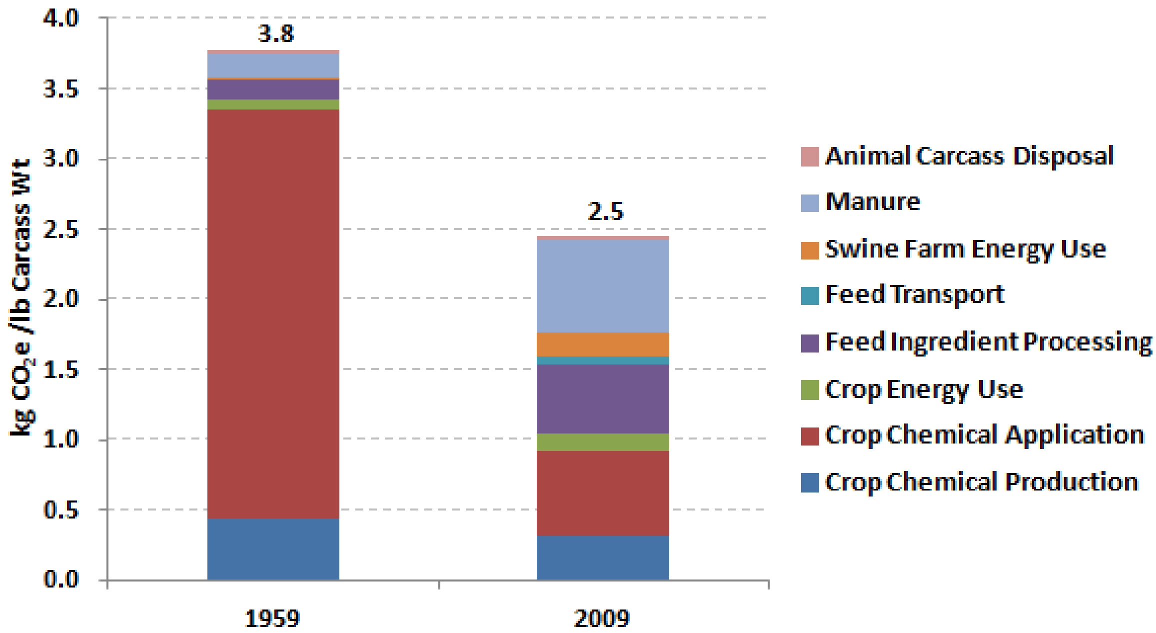


Figure 8: U.S. Swine Industry Carbon Footprint (CO_2e) per Pound of Hot Dressed Carcass Weight



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