FINAL RESEARCH Results REPORT

Coalition for Sustainable Egg Supply

CSES EXECUTIVE SUMMARY

Many consumers are requesting that the food they purchase have specific attributes related to animal welfare, environmental impact and more. In the case of egg production, the way in which the hens are housed can potentially influence these attributes. There is mounting pressure on brands to source eggs from particular hen housing systems, and governmental and non-governmental organizations have become involved in setting standards focused on regulating or eliminating certain types of hen housing. However, good data about the potential impacts and trade-offs associated with the overall sustainability of egg production have often not been available when setting these standards.

In 2008, the American Egg Board funded teams of experts to review the sustainability aspects of different hen housing systems. These reviews revealed gaps in existing knowledge. To fill these gaps with more holistic, commercial-scale research, the Coalition for Sustainable Egg Supply (CSES) was formed. The Coalition consists of leading animal welfare scientists, academic institutions, non-government organizations, egg suppliers, and restaurant/foodservice and food retail companies (http://www2.sustainableeggcoalition.org/).

In 2010, CSES initiated a project to evaluate the sustainability trade-offs of three different laying hen housing types – conventional cages, enriched colonies, and cage-free aviary (see the Project Overview for a detailed description). These houses were located on a commercial farm in the Midwestern United States. Using a holistic approach, multiple variables related to animal health and well-being, food safety, the environment, worker health and safety, and food affordability were evaluated by research teams from Michigan State University, University of California-Davis, Iowa State University, and USDA Agricultural Research Service. The research was conducted over a three-year period with two flocks of hens. The results provide insights into the impacts and trade-offs associated with each of these three hen housing systems, relative to each of the five sustainability areas:

- Animal health and well-being: Hens were able to perform the widest range of behaviors (e.g. flying, perching, nesting, opportunity to forage, dust bathing) in the Aviary, and also could perform more diverse behaviors (especially nesting, perching and opportunity for movement) in the Enriched Colonies than in Conventional Cages. Hen health issues occurred in all systems, but hen mortality in the aviary was double that in the other housing types. Aviary hens had the strongest leg and wing bones, which reduced the potential for breakage of these bones. Conventional Cage hens had the lowest leg and wing bone strength, with Enriched Colony hens intermediate. However, rib remodeling and fractures at the end of the keel (breastbone), which reflect the demands of egg production on the skeletal system, were most common in Aviary hens. Hens in all housing systems were overall in good physical condition, although in general when problems were evident the hens in the Enriched Colonies had problems that were intermediate in frequency and severity compared to Aviary and Conventional Cage hens.

Physiological measures did not indicate that hens in any housing system were experiencing short-term or long-term stress.

- Food safety and quality: Current USDA grade standards are accurate for all housing systems compared in the study since egg quality declined at a similar rate during cold storage. Hens in all housing systems were shedding *Salmonella* spp. at a similarly high rate, yet all types of eggs tested had very low prevalence of *Salmonella* spp. associated with the egg shells. Furthermore, results indicate that management strategies in the different systems can impact egg safety. Overall these results indicate that the eggs laid on system wire and within nest boxes, irrespective of housing system, were of high microbial quality at the time of collection.

- Environment: The continuous environmental monitoring of the three hen housing systems showed that comfortable thermal conditions can be maintained in all three houses through proper ventilation management. The Enriched Colony system performed the best in terms of indoor ammonia and particulate matter (dust) concentrations and emissions to the outdoor environment. Frequent manure removal from the houses helped to achieve low ammonia levels except for occasional higher levels in the Aviary house during cold weather. The Aviary house had the highest dust concentration and emissions, as a result of the hen activities on the litter floor. Future mitigation of ammonia emissions should focus on manure storage. Overall energy costs were similar among the houses. Greenhouse gas (GHG) emissions were small for all three housing types. The Aviary tended to have a higher carbon footprint, arising from poorer feed conversion. Most of the nutrients consumed in the feed were excreted in the manure, making the manure a valuable energy and fertilizer product. The manure from the Enriched Colony had the most nitrogen and the lowest moisture content, meaning that it was the best fertilizer source and had the lowest potential for environmental emissions.

- Worker health and safety: Workers were exposed to higher pollutant concentrations in the Aviary house than in either the Conventional Cage or Enriched Colony houses. On average, working in the Aviary house resulted in a greater decline in pulmonary function from the beginning to the end of the work shift compared to working in the other houses, although this was not statistically significant. The small number of workers studied may have contributed to a lack of statistical power to observe significant results. Respiratory protection is strongly recommended for workers in all barns. There were ergonomic challenges and risks in all housing types, but these varied according to the workers' tasks in those housing types. Significant ergonomic and risk issues identified in the Aviary house were mainly related to workers' collecting eggs from the litter floor and removing hens from the house, while in the Conventional Cage house and Enriched Colony house they were related mainly to placing hens in and removing them from the cages and colonies.

- Food Affordability: The Aviary was the most costly system per dozen eggs for all cost categories evaluated, with costs exceeding the Conventional Cage system by 30-40 percent. Costs of the Enriched Colony system were higher than the Conventional Cage system for labor and capital costs per dozen, but quite similar for feed costs, which account for more than half of all the costs of egg production.

Depending on the goals of each food system stakeholder, these trade-offs between housing systems may be weighed differently. Regardless of how they are weighed, the food system will benefit from the Coalition's science-based information on a range of sustainability factors to guide production and purchasing decisions.

It is important to note that this research represents a snapshot in time – it assesses elements of hen housing and egg production using a single hen breed/strain, in a particular region of the U.S., in these particular housing systems. While it therefore highlights the trade-offs involved and can assist in supporting informed decision-making, caution should be exercised in applying the specific results to other scenarios with different variables. Nonetheless, the approach taken by the CSES in identifying and evaluating these five sustainability areas provided valuable evidence and information, and can be used in subsequent research to evaluate other egg production systems.

PROJECT OVERVIEW

Today, society is scrutinizing agriculture and demanding increased accountability that practices used to produce animal products are sustainable, ensuring a wholesome, safe, environmentally- and socially- responsible, and inexpensive food source. Some non-governmental organizations have used legal means to set standards for farm animal welfare, specifically focusing on regulating or eliminating certain kinds of housing, particularly housing for egg-laying hens. However, the potential impacts of these changes on the overall sustainability of egg production in the U.S. have received limited research attention.

While animal welfare is an important issue, determining the true impact of different egg production systems also requires considering food safety and quality, the environment, worker health and safety and food affordability. In 2008, the American Egg Board provided funding for teams of experts to review the literature regarding the sustainability aspects of different hen housing systems. These reviews, which were published in the journal *Poultry Science*, revealed many gaps in knowledge. The Coalition for a Sustainable Egg Supply (CSES) study was therefore designed and conducted to provide needed scientific information about the sustainability of egg production in alternative hen housing systems from a holistic viewpoint. The goal was to identify sustainability tradeoffs to help food-system stakeholders make informed decisions about egg production and egg purchasing.

Three different housing systems were evaluated: conventional cages (CC), enriched colony housing (EC), and a cage-free aviary (AV). Diagrams of each system can be found at the end of this Project Overview. Interdisciplinary scientific teams were assembled from the University of California at Davis, Michigan State University, Iowa State University and the U.S. Department of Agriculture Agricultural Research Service to conduct research addressing the five sustainability areas. In brief, the research was conducted over the course of two flock cycles at a commercial egg production facility located in the upper Midwest. Hen and housing characteristics can be found in the table below. More information about the rationale for choosing these particular housing systems and the Lohmann LSL Classic White strain of hen, as well as related to aspects of management of the systems, can be found in the Frequently Asked Questions posted on the CSES website.

This report presents the results for each sustainability area, as well as an overall integration and discussion of the trade-offs identified. A brief description of the methodology used for each sustainability area is presented in the respective results sections. More detail can be found in the peer-reviewed scientific papers published from the study. The findings from the CSES research project are being disseminated on the CSES website and in peer-reviewed scientific journal publications. Listings of published work from this and related studies can be found in the reference section at the end of this document.

The results of the CSES project should be viewed as a "snapshot" of the sustainability trade-offs for these particular housing systems under the management conditions during the period of the study. Caution should be exercised in applying the research results to other scenarios with different variables.

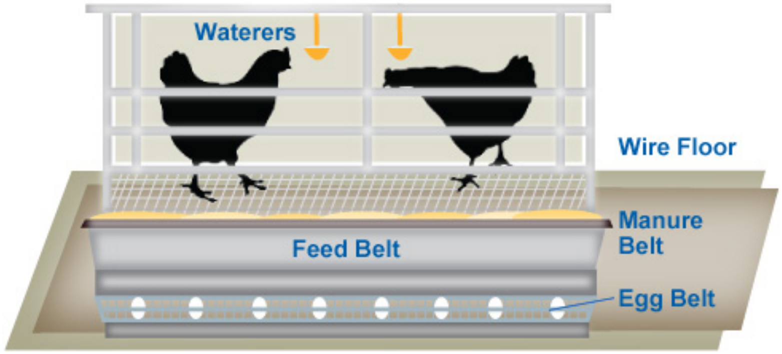
Management summary for two commercial flocks housed in different environments.

	Conventional Cage	Cage-Free Aviary	Enriched Colony
Hen genetics	Lohmann LSL Classic White		
Pullet rearing	Conventional cage	Cage-free aviary	Conventional cage
Hen population (Flock 1)	193,424	49,842	46,795
Hen population (Flock 2)	198,816	49,677	46,729
Hens per housing unit*	6	852/1,704 with 142 hens per colony unit	60
Designed space per bird, in^2	80	144	116
Enrichment options	N/A	Perch, nest area, litter access	Perch, nest area, scratch pad
Photoperiod	16L:8D		
Diet	Commercial diets formulated to maximize production efficiency		
Feeding schedule	2x/d	5x/d	2x/d, includes scratch auger
Ventilation type	Tunnel	Cross	Cross
Manure handling	Belt	Belt/litter	Belt
Manure removal	3-4 days	3-4 days/end of lay	3-4 days
Supplemental Heat	-	3 heaters	-

*the two numbers for the aviary reflect the hen numbers per pen in the inner and outer rows

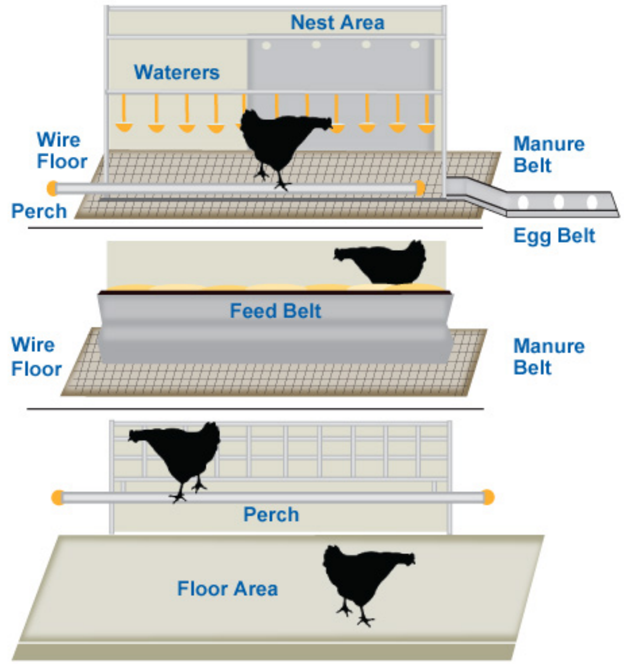
CONVENTIONAL CAGE HOUSING SYSTEM

- Hens are housed indoors (climate-controlled) in multilevel rows of enclosures with wire mesh floors
- Six hens per cage, 80 square inches per hen
- Hens have daily access to food and water
- A manure belt below the cages keeps manure away from birds
- The wire floors slope slightly so eggs roll down to an egg-collection belt



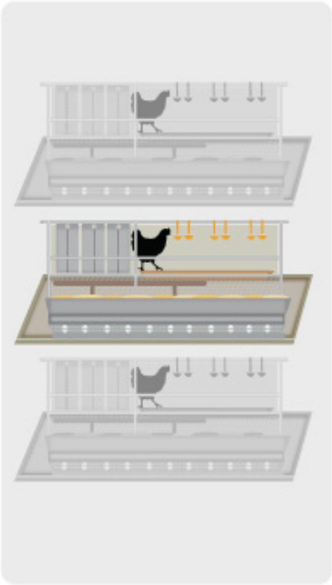
CAGE-FREE AVIARY HOUSING SYSTEM

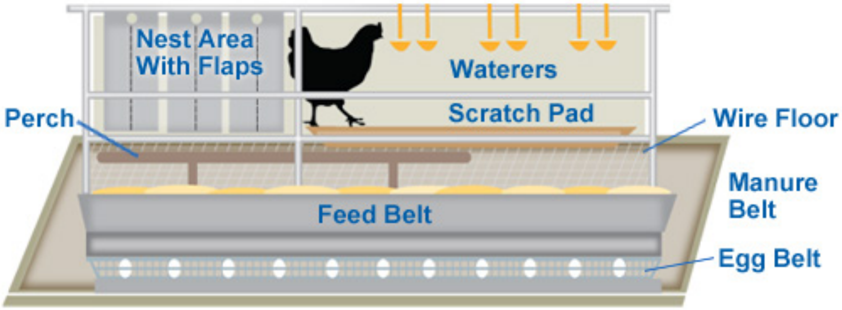
- Hens are housed indoors (climate-controlled) and allowed to roam freely in defined sectors of the building
- There is open floor space as well as multiple levels for hens to perform natural bird behaviors, like perching, scratching, dust bathing and nesting
- Aviary sections hold 1704 hens in the inner row, 852 hens in the outer row, with 144 square inches per bird
- Hens have constant access to food and water
- A manure belt below the cages keeps manure away from birds



ENRICHED COLONY HOUSING SYSTEM

- Hens are housed indoors (climate-controlled) in multilevel rows of enclosures with wire mesh floors
- 60 hens per cage, 116 square inches per hen
- There is enough space for each hen to stand, sit, turn around and extend her wings
- Each enriched colony allows for natural bird behaviors, like perching, scratching, dust bathing and nesting
- Hens have daily access to food and water
- Nesting hens have access to privacy curtains
- A manure belt below the cages keeps manure away from birds
- The wire floors slope slightly so eggs roll down to an egg-collection belt





RESEARCH FINDINGS: FLOCKS 1 AND 2

Results: Production Performance

- Overall performance in the three systems, all of which were stocked with beak-trimmed Lohmann LSL Classic White hens, improved from the 1st to the 2nd flock, with increased egg production and increased feed efficiency
- Hen-day production at 78 weeks was above the Lohmann LSL management guide (2013) of 77 percent for both flocks
- Average hen-day production for the two flocks was above the 86 percent Lohmann LSL management guide (2013) average, except for the AV Flock 1
- Cumulative hen mortality in AV was approximately double that of the other systems, with mortality in CC and EC being similar to the breeder expectations for this hen strain

Production performance is both an indicator of overall flock health and a major component of economic and environmental sustainability. Daily feed usage, water consumption, hen-day egg production (the percentage of hens in the flocks laying an egg that day), and mortality data were collected during each 28-day period of each flock cycle; a summary is provided in Table 1. The hen-day percentage production was above the calculated 86 percent management guide average from 19-78 weeks for hens in all three housing systems in both flocks. Hen-day production at 78 weeks of age (Figure 1) was also higher than the Lohmann LSL White management guide (2013) target of 77 percent for both flocks. Flock 2 overall performed better than Flock 1, showing an increase in eggs per hen housed, average hen-day production, and better feed conversion. Mortality is shown in Figure 2 and Table 5. The Lohmann LSL management guide (2013) reports that cumulative mortality should be around six percent for the flock; mortality in both the CC and EC was slightly lower than this in both flocks, but mortality in the AV was double that figure. Mortality in both the AV and CC were about the same in Flock 2 as they were in Flock 1. In the EC, however, mortality decreased from Flock 1 to Flock 2, resulting in EC mortality being similar to that of CC.

Results: Animal Health and Well-Being

- Perches were well-used by the hens in both AV and EC
- Nests were also well-used in the EC, although nest use in the AV was more variable, with generally high nest use but also periodic problems with eggs being laid in the litter area. Nest pads in both systems stayed clean throughout the laying cycle.
- Hens accessed the open litter area in the AV and dust-bathed there, whereas in EC the scratch pad was used infrequently for the intended purposes of dust bathing and foraging; this pad also became contaminated with manure

- Analysis of flights in the open litter area in the AV showed that 9-21 percent ended in failed landings, usually due to collisions with other hens
- There were system-related differences in foot health, keel bone (breast bone) abnormalities, and feather condition, with the EC hens generally having problems intermediate between those of CC and AV hens. Keel bone damage was already evident in AV-reared pullets when they were placed into the laying house.
- At placement, pullets reared in the AV rearing system had better bone quality of the humeri (wings) and tibiae (legs). This better bone quality was maintained throughout the lay cycle. At the end of lay, bone quality of the humeri and tibiae was better in EC than CC, although not as good as in AV.
- The most common causes of mortality in all systems as determined by post-mortem analysis were egg yolk peritonitis (due to leakage of egg yolk into the abdominal cavity) and hypocalcemia (low blood calcium). Egg yolk peritonitis was more common overall in CC and EC than in AV. Hypocalcemia was more common in AV than CC or EC in both flocks; in addition, AV hens that died were more likely to have been caught in the system, cannibalized, or pecked extensively than CC or EC hens. Rib remodeling and fractures at the end of the keel were also more common in AV hens, reflecting the demands of egg laying on the skeletal system.
- Physiological data (white blood cell counts, adrenal weights, heterophil to lymphocyte ratios) did not demonstrate the presence of acute or chronic stress in any housing system

The assessment of hen welfare involves an integrated evaluation of hen behavior, health, production and physiology. In many of the studies of hen welfare conducted prior to the CSES project, the various elements of welfare were assessed in separate studies or in non-commercial contexts (Lay et al., 2011). The CSES project took an integrated approach to studying hen welfare. The results presented in this section describe the research findings for resource use (e.g. litter area, scratch pads, nests, perches) by hens in AV and EC and evaluations of physical condition, physiological stress and health (including bone health) of hens in all three systems. Brief details of the methods used to collect the data are described in each section. Resource use in the AV and the EC could not be directly compared to one another statistically because the configuration of the AV limited the researchers' ability to observe hens using some of the resources that were located in the interior of the system.

RESOURCE USE

Enriched Colony. Resource use in the enriched colony cages was assessed at peak, middle, and end of lay for each flock cycle using both video recordings and in-person observations. All of the resources in the system were used, but the perches and nests were overall better-used than the scratch pad (Table 2). While there was consistent, low usage of perches during the day, perch use was much higher at night, although some hens (4-23 percent of the hens) roosted at night in the nests rather than using the perches. Use of the scratch pad for foraging and dust bathing was low, but hens did sit, stand and sleep on the pad. This particular pad type thus did not appear to be well-designed/managed to encourage foraging and dust bathing behavior.

Nest use was determined by counting the number of eggs laid both in the nest section and the rest of the cage. Use of the nest was high, with approximately 97 percent of eggs laid there. Cleanliness of the nest pad was assessed using a 0-7 point scale, with 0 being completely clean and 7 being completely dirty (i.e., the turf on the pad completely covered by hardened manure). Nest pads stayed very clean, with a median score of 1 for both flocks by 77 weeks. However, eggs that were not laid in the nest were usually laid on the scratch pad, which was dirtier, although there was variation between the two flocks in how dirty these pads became over time. Flock 1 pads got progressively dirtier, with a median score of 6 by 77 weeks. However, Flock 2 had a median score of 4 by 52 weeks, which then dropped to 2 by 77 weeks, suggesting that hens in Flock 2 were using the pads for foraging enough that they were more effective than Flock 1 hens in removing the manure by scratching on the pad. The presence of manure on the pads, and particularly the scratch pad, was associated with higher levels of microbial contamination (see Food Safety and Quality section below).

Aviary. Aviary resource use was also assessed at the same three time points across the lay cycle using both live and video observation. Again, resources appeared to be well-used (Table 3). Nest use was recorded in Flock 2 when hens were 19-36 weeks of age, and hens were found to lay their eggs in the nest 97.3 percent of the time. At other times, however, there were periodic problems with eggs laid outside of nests, either on the floor in the litter or in other areas of the tiered enclosure. As in EC, the nest pads stayed relatively clean.

In Flock 2, locations where hens perched within the aviary enclosure were recorded during both day and night. Hens used the internal perches extensively during the night, as well as during the day prior to the opening of the aviary. During both the dark and light periods hens preferred to perch in the top level of the enclosure, on the highest perch in the middle level, and on the flat metal ledge separating the first and second levels. At night, hens that were not observed roosting on perches were in the nest box or on the wire of the upper level. After aviary opening, hens used the outer perch to move down to the litter but also to perch.

More birds were observed in the open litter area during midday than at other times (except during the morning of peak lay of Flock 2 when hens first accessed the litter and occupied 95 percent of the open litter area). Hens used the open litter area to dust bathe most often in either afternoon or late morning. Hens were typically spread fairly evenly across the litter area, but were also seen to cluster there in large groups — with these ‘piles’ sometimes including as many as 229 hens and lasting for as long as six hours.

Hen flight and landing success in the open litter area were recorded at peak, middle and end of lay for both flocks. Hens flew less as they aged. Failed landings were observed for 9.1 percent of flights in Flock 1 and 21 percent in Flock 2. The proportion was probably higher in Flock 2 because the hens were observed on the first day of litter access, when an atypically large number of flights occurred. Though patterns were different across flocks and over time, most failed landings were due to collisions with other hens and occurred when hens were flying from the litter up to the outer perch.

HEN PHYSICAL CONDITION AND HEALTH

Physical condition of live hens. Physical condition of 100 hens in each housing system was evaluated at peak, middle, and end of lay for both flocks using the Welfare Quality Assessment protocol for poultry (2009). Flock 2 pullets were also evaluated when they were placed into the housing systems. Pullets were in good physical condition when they were placed regardless of whether they had been reared in an AV or CC pullet rearing system. Those reared in the AV system did have more keel abnormalities (15 percent of pullets) and dirtier feathers (21 percent of pullets) than CC-reared pullets (0 percent with keel abnormalities and 10 percent with dirty feathers), but also better foot condition as shown by less toe damage (2 percent of pullets from AV compared to 10 percent from CC) and shorter claws.

For hens evaluated at 52 and 72 weeks of age, external parasites, enteritis, respiration abnormalities/nasal discharge (indicative of respiratory infection), and panting (indicative of heat stress) were rarely or never observed. Table 4 illustrates the major differences in foot health, keel abnormalities, and feather condition between the housing systems. In general, these findings indicate that the CC and AV systems each have positive and negative effects on hen physical condition (e.g. a greater incidence of foot problems in CC but foot problems most severe in AV; dirtier feathers in AV but largest amount of feather loss in CC; highest incidence of keel abnormality in AV), with EC generally having intermediate effects.

Bone quality of humeri and tibiae. Laying hens housed in CC are prone to developing osteoporosis late in the laying cycle, which can lead to broken bones. This portion of the research aimed to evaluate the bone quality of the tibiae and humeri of AV- and CC-reared pullets at placement (19 weeks) and AV, CC and EC hens at end-of-lay (72 weeks). Bone samples were collected from 120 birds from each system and analyzed for bone quality using biochemical, morphological and biomechanical techniques. The bones of AV-reared pullets had better load-bearing capacity and were stiffer than those of CC-reared pullets, indicating better bone quality (Regmi et al., 2015). This better bone capacity was maintained in AV hens through 72 weeks. Bone quality of the tibiae and humeri was generally better in EC than CC at 72 weeks, although not as good as AV.

Necropsies. Hens that died daily (daily mortality) were dissected (necropsied). A cause of death was determined and the ribs and keel bones were assessed. The frequency with which necropsies were performed varied within and between flocks (Table 5).

The main causes of mortality (Table 6) in all housing systems were hypocalcemia and egg yolk peritonitis. Hypocalcemia was greatest in the AV for both Flocks 1 and 2, with more than three times more hens affected in AV than in CC and EC. Egg yolk peritonitis was more common overall in CC and EC than in AV. The AV had the most hens that died from being caught in the structure, had been vent cannibalized (pick out) or excessively pecked, or that were emaciated in both flocks, while the CC and EC were relatively equal in those categories. Compared to the CC and EC, the AV had many more hens (from six to 20 times more) excessively pecked or caught in the structure (from four to seven times more). Also of interest was that the number of birds that were too rotten to necropsy was greatest in the AV. This finding most likely reflects the difficulty that workers have finding dead birds within the more complex structure of the AV. Missed and rotten mortality could contribute to the incidence and spread of disease under some conditions.

During Flock 1, more pullets died from wing and leg fractures soon after placement in the EC (Table 7) than in the other houses. This was most likely due to the workers being inexperienced in placing pullets in this system, since this finding was not repeated in Flock 2. In an attempt to determine the calcium demand of egg production on a hen's skeleton, the junction of the ribs on the side of the bird as well as the distal end of the keel bone were examined during the necropsy. When the hen uses her skeleton to meet calcium demands, her rib ends become enlarged and cartilaginous and the last area of the keel to have the cartilage remodeled into bone becomes broken transversely or shows evidence of a remodeled transverse fracture. AV hens had more rib remodeling and keel bone fractures (Table 8) than hens from CC and EC.

PHYSIOLOGICAL STRESS

Blood samples were taken for assessment of heterophil to lymphocyte ratios and white blood cell counts at pullet placement and then at peak, middle and end of lay; in addition, the hens sampled were euthanized and their adrenal glands were weighed. Heterophil to lymphocyte ratios were within normal ranges for hens in all systems, but could be considered low for the pullets at placement (suggesting some type of stress). In contrast, total white blood cell counts were high for hens in all systems. No difference was observed in adrenal weights of hens across the three housing types during lay, indicating that there were no differences in long-term stress in the three systems, but this may be due in part to the fact that only a small number of birds were sampled (25 per housing type at each time point). The pullets reared in aviaries had lower adrenal weights at placement than those reared in cages (100 pullets sampled per rearing system). Overall, the physiological data are not suggestive of differences in long-term or short-term stress among the three housing systems.

Results: Food Safety and Quality

- Hens in all housing systems were shedding *Salmonella* spp. at a similar rate; the prevalence of *Salmonella* spp. on egg shells was very low and did not differ significantly between systems
- The highest environmental microbial levels were found in the AV litter area and on the EC scratch pad; AV floor eggs also had significantly higher levels of microorganisms than AV nest box and wire, EC nest box and wire, and CC wire-laid eggs
- Differences in egg quality between housing systems were found to be more likely related to nutrition than to the housing systems themselves
- Housing system did not influence the rate of egg quality decline during 12 weeks of extended storage, and thus current U.S. egg quality standards and grades are adequate for all three of the housing systems
- Hen antibody response to *Salmonella* was affected by season, but not by housing systems

Maintaining high levels of egg safety and quality is a critical aspect of a sustainable egg supply. Prior to this study, little was known about housing system effects on either egg safety or quality, and where information existed it was often contradictory (Holt et al., 2011). A comprehensive comparison of environmental and egg shell microbiology was therefore conducted during the second flock. Furthermore, a wide array of egg quality attributes was evaluated monthly in both flocks, and quality conditions during extended cold storage determined. In addition, hen *Salmonella* antibodies were measured to determine if housing system affected immunity.

EGG SAFETY

In each of the three housing systems, 20 sampling points were identified as replicates. During each of four sample times (egg-laying periods 9, 11, 13, and 15, as defined in Figures 1 and 2), environmental swabs and egg shell pools (3-6 shells each) were collected from each of the replicates (Table 9). The indicator populations of total aerobic organisms and coliforms were enumerated for up to 10 swabs/shell pools for each sample type by housing system combination each collection period. Total aerobes indicate the general microbial levels present in the production environment and on the shell surface of nest run eggs. Coliforms are indicators of fecal contamination and also are the class of microorganism containing many of the human pathogens. The prevalence (presence or absence) of *Salmonella* spp. and *Campylobacter* spp. was determined for every swab/shell pool collected during the study. Manure scraper swabs were only assessed for pathogen prevalence and were denoted per housing system proper and not assigned to unique sampling replicates.

The summary of overall microbial levels and pathogen prevalence can be found in Tables 10 and 11 (for full details see Jones et al., 2015). The AV drag swabs had the greatest levels of total aerobes and coliforms, followed by EC scratch pads, which is concerning since eggs can be laid on or come in contact with these surfaces. AV floor shells had the greatest levels of total aerobes and coliforms.

Aerobic organisms were also elevated on AV nest box and system shells. It has been found that total aerobe levels are greater on eggs produced in high dust environments; as reported below, dust levels were significantly higher in AV production systems. Coliform levels were low for all shell samples, excluding AV floor shells.

Hens from all three housing systems were shedding *Salmonella* spp. at a high rate as indicated by manure scraper swabs (89-100 percent). It is not uncommon for poultry to shed *Salmonella* spp. or other Enterobacteriaceae. Additionally, 69 percent of AV drag swabs were positive for *Salmonella* spp. Manure scraper swabs had low levels of *Campylobacter* spp. detection (0-41 percent), yet *Campylobacter* spp. were detected at high levels in wire swabs (63-74 percent) for all three housing systems. Again, AV drag swabs (100 percent) and EC scratch pad (93 percent) swabs had high levels of *Campylobacter* spp. recovery. The difference in *Campylobacter* spp. detection in the housing swabs and manure scraper samples can be attributed to the nature of *Campylobacter* spp. growth. The manure scraper blades are contained in the most arid portion of the housing systems, and since *Campylobacter* spp. prefer a warm, moist environment for growth they are more easily detected in samples collected from surfaces in direct contact with the hens. The prevalence of *Salmonella* spp. and *Campylobacter* spp. in shell pools was statistically similar for all egg types by housing system combinations.

The AV litter area and EC scratch pad management in the current study resulted in high levels of indicator organisms and monitored pathogens. Further research is needed to address these prominent growth niches to enhance the safety of eggs produced in AV and EC. It is also important to develop management strategies to encourage nest box usage and cleanliness in alternative housing systems for egg safety.

EGG QUALITY

Egg quality parameters measured included egg weight, shell dynamic stiffness (shell acoustical characteristics), static compression shell strength, Haugh unit/albumen height, yolk index, vitelline membrane strength and deformation (elasticity), and whole egg total solids. Egg quality is highly dependent on hen nutrient intake. The flocks in these studies were managed commercially and thus fed to maximize economic efficiency. As such, the monthly egg quality and egg production data were confounded. This required us to create statistical models to assess the impact of primary management components on egg production and egg quality parameters (for full details see Karcher et al., 2015). These models revealed complex effects. For example, the model developed for predicting egg weight suggests that there could be a level of crude fiber in the diet that results in diminishing egg weight. Overall, the models suggest that egg quality differences between systems are more likely related to nutrition than to the housing systems themselves.

For both flocks, once a quarter eggs were washed and stored at 4°C for 12 weeks. Egg quality was monitored to determine the rate of egg quality decline during extended cold storage and how it is impacted by housing system, with egg quality sampled at 28, 42, and 84 days of storage and compared to egg quality at 0 day of storage. These times were chosen to reflect approximately 30 and 45 days in retail and a period of time (12 weeks) for eggs to be in consumer refrigerators. There were no differences in the rate of egg quality decline between the housing systems (Jones et al., 2014). As such, currently utilized egg quality characteristics should adequately describe egg quality and egg grade throughout retail and consumer use for all three systems.

IMMUNITY TO *SALMONELLA*

In each flock, 20 laying hens per housing system were sampled monthly over the course of the flock cycle. Serum and crop lavage (washing) samples were collected and analyzed for the presence of *Salmonella* antibodies. This allows for the measurement of antibodies to *Salmonella* Enteritidis given in vaccines and to any *Salmonellas* that are present in the housing environment. Figure 3 indicates that between the months of June and July the immune response was low, likely due to temperature, but the AV birds mounted a higher immune response compared to the other housing systems from August to October. Figure 4 reports the accompanying crop washing indicating a response to what the birds are exposed to via the oral and gastrointestinal tract. Again, there are no differences among housing systems, but AV birds mounted a higher response from December to February. Therefore, no differences between housing systems were detected but a seasonal effect was evident.

Results: Environment

- Hen thermal comfort was generally maintained in all three housing types. The CC and EC houses had no supplemental heating, whereas the AV house did; a small amount of propane fuel was used for supplemental heating in AV during the 1st flock.
- Daily mean indoor ammonia concentrations were below 15 ppm for CC and EC, but occasionally exceeded 25 ppm in AV
- Particulate matter (dust) levels in the AV house was eight to 10 times those of CC and EC, which had levels similar to one another
- Farm-level ammonia emission (house plus manure storage) was lowest for EC and approximately half of that of CC or AV, presumably due to its lower stocking density and drier manure. About two-thirds of the farm-level ammonia emissions came from the manure storage.
- Particulate matter emissions were highest for the AV house, being six to seven times those of the CC or EC house, resulting from activities of the AV hens on the litter floor
- Greenhouse gas (GHG) emissions were small for all three housing types
- Energy costs (electricity and propane fuel) were similar for the three systems
- The estimated losses of all nutrients were higher in the AV house than in CC and EC. The EC house had the lowest nutrient losses.
- In the AV house, 77 percent of manure was deposited on the belts and the rest on the litter floor when hens had free access to that area
- Manure removed from EC was drier and had a slightly higher nitrogen content than that removed from CC or AV. Moisture content of the manure removed from the on-farm storage bays was similar for all three housing types.
- Overall, manure from the EC had more nitrogen and thus had a higher fertilizer value than that from CC or AV, and because it was drier than manure from CC or AV it had lower emission potential during storage

Environment is a critical component of a sustainable egg supply. Indoor thermal conditions (temperature, temperature, relative humidity – RH) and air quality (ammonia – NH_3, carbon dioxide – CO_2, and particulate matter – PM) directly impact the health and production performance of the hens, and potentially also the workers. Gaseous and PM emissions to the atmosphere affect the environmental footprint of the operation. Although literature on indoor air quality and air emissions exists for CC houses, environment impact associated with alternative egg production systems, i.e., AV and EC, is less understood, especially under U.S. production conditions (Xin et al., 2011). Thus, continuous environmental monitoring of all systems and their manure storage facility was carried out over both flock cycles using two state-of-the-art monitoring systems. In addition, feed samples were taken periodically to determine the nutrient composition. Moreover, properties of the hen manure removed from the houses and the storage were monitored. For detailed description of the monitoring systems and the results, refer to Zhao et al. (2015[b]) and Shepherd et al. (2015).

Thermal Environment. The indoor temperature was generally maintained between 76–80°F (24.6–26.7°C) in all three houses (Table 12). Although concerns have been expressed that it could be difficult to maintain desired house temperature during cold weather in the AV and EC houses because of the reduced bird stocking densities as compared to CC, the data showed that the indoor temperature in all three houses during wintertime was maintained above 68°F (20°C) (Figure 5), i.e., within the comfortable zone for laying hens, even without supplemental heat. Indoor RH was also similar among all three houses and generally in the acceptable range of 40 percent to 70 percent (Figure 6, Table 12). The reason that desired temperatures could be maintained in AV and EC was because, when there is no excessive indoor ammonia to deal with, as was generally the case (due to frequent manure removal), the function of minimum ventilation rate (VR) is to remove moisture produced by the birds and manure. Hence fewer hens in a house means lower minimum VR requirement, thus less cold air coming into the building. When a house is properly insulated, most of its heat loss is through ventilation air.

Ventilation rate (VR). The function of building ventilation is to provide fresh air while removing noxious gases and excessive moisture in winter and excessive heat in summer to maintain the proper house indoor environment. As expected, building VR showed clear seasonal patterns in all houses, higher on warm/hot days and lower on cool/cold days (0.2 to 4.8 cfm hen^{-1}, Table 12, Figure 7).

Indoor gas and particulate matter (PM) concentrations. Elevated NH_3 concentrations can have adverse effects on the hens' health and production performance. United Egg Producers (UEP) recommends NH_3 concentration not exceed 25 ppm (UEP, 2014). During the entire monitoring period, indoor daily mean NH_3 concentrations in CC and EC never exceeded 25 ppm, while daily mean NH_3 concentrations exceeded 25 ppm on 12 winter days of Flock 1 in AV (Figure 8). The higher NH_3 concentrations in the AV house arose from the accumulated floor litter coupled with lower building VR. The overall daily mean indoor NH_3 concentration was highest in AV, followed by CC and EC (Table 13). The values observed in the current study, while in the range of the literature data, are at the lower end of the range, which may be attributable to better manure management (i.e., frequent manure removal and drying of manure on the belt). Daily mean CO_2 concentration was consistently below 5,000 ppm (Permissible Exposure Limit set by Occupational Safety & Health Administration – OSHA) in CC and EC while it slightly exceeded this level in AV on the six coldest days encountered during the study (Figures 9 and 10). Methane (CH_4) concentrations were similar among the houses and were low (11-12 ppm) (Table 13).

Fine PM can be detrimental to the respiratory system. PM_{10} (PM with aerodynamic diameter ≤ 10 μm) and $PM_{2.5}$ (PM with diameter ≤ 2.5 μm) are of particular interest from the health and regulatory standpoints. The PM concentrations were significantly higher in AV than in CC and EC (Figures 11 and 12; Table 13). The high PM concentrations in AV resulted from activities of the hens on the litter floor. Diurnal PM_{10} variation shows the spikes of concentration coincided with the light-on time when the hens woke up and started the first feeding; then further increased during the litter access period, and sometimes exceeded the upper limit (20 mg m-3) of the PM monitoring device (Figure 12).

Gas and PM emissions. Gas and PM emissions can impact ecosystems through acidification and eutrophication (NH_3), global warming (GHG), and reduced visibility/health (PM). In particular, ammonia and PM emissions are subject to federal reporting or permitting requirement (e.g., the reportable quantity of 100 lb/day for ammonia emissions). Gas emissions from the hen houses and manure storage facilities were measured separately, and then totaled to yield farm-level emissions (Table 14). Farm-level NH_3 emission was higher for AV and CC (0.30 and 0.29 g/hen/d, respectively) than for EC (0.16 g/hen/d). The difference in farm-level NH_3 emission is believed to be driven by the manure-drying effectiveness in each house, and the littered floor of AV. As indicated by the manure properties shown later, the EC manure was considerably drier, probably due to the lower stocking density and thus more drying of the manure on the belt. The majority (60-72 percent) of the farm-level emissions were from the manure storage facility. Farm-level CO_2 emission was slightly lower for CC than for EC and AV. House-level CO_2 emissions (mainly from hen respiration) accounted for approximately 90 percent of the overall farm-level emissions. Farm-level methane (CH_4) emissions were quite low (0.10 g/hen/d) for all three systems, with the majority (70-80 percent) from the hen houses. AV had much greater PM emissions (PM_{10} and $PM_{2.5}$ of 100.3 and 8.8 mg/hen/day, respectively) than CC or EC (15.6 and 0.9-1.7 mg/hen/day, respectively).

Energy use. Electricity use was similar across the three housing types, averaging 0.25-0.26 kWh or two cents (based on 0.078 cent/kWh) per kg eggs. AV used a small amount of propane fuel for supplemental heating, averaging 0.0032 L or 0.11 cents (based on $0.35/L) per kg eggs. The majority (55-75 percent) of the total electricity was used by the manure belt blowers, while the rest was used by ventilation fans (6-32 percent) and others (13-22 percent, including lighting, automatic feeders, egg belts, etc.) (Figure 13). Electricity use spiked between June and August due to more fans running to achieve the higher VR (Figure 14). The small amount of propane used in AV occurred in wintertime of Flock 1. However, desired indoor temperature was maintained in winter during Flock 2 through better ventilation management, resulting in no propane use in AV (Figure 15).

Nutrient flow in feed, eggs and manure. Nutrient flow data allow the measurement and assessment of feed conversion efficiencies and manure production and properties, and also estimate the nutrient losses to the environment. The detailed results are shown in Figures 16-21 and Tables 15-19. Of the feed nutrients consumed, 28 percent of carbon, 58 percent of nitrogen, 68 percent of sulfur, 79 percent of phosphorus, and 89 percent of potassium were excreted in the manure. The estimated losses to the environment through air emissions were 54 percent for carbon, 8 percent for nitrogen and 6 percent for sulfur. The estimated losses of all nutrients were higher in AV than in CC and EC. The EC house had the lowest nutrient losses.

Properties of manure removed from hen houses and storage. Characterization of manure properties allows us to assess the nutrient value of manure as fertilizer and estimate the emission potential and impact. The manure removed from EC had a lower moisture content (MC, 46 percent, wet basis) than that removed from CC (54 percent) and AV (52 percent). The drier EC manure likely contributed to the lower NH_3 emissions from that system, as indicted earlier. Lower NH_3 emission would result in higher nitrogen (N) retention in the manure. In fact, manure removed from EC had a slightly higher N content (5.62 percent dry basis) than CC (5.56 percent) or AV (5.42 percent). In AV, 77 percent of manure was deposited on the belts and the remaining 23 percent on the litter floor when the hens had free access to that area. In comparison, 86 percent of total manure was deposited on the belts and 14 percent on the litter floor when the hens were kept inside the system (away from the litter) between 5-11 a.m. The manure removed from the storage bays had similar moisture content for all three housing types (43-45 percent, wet basis). The EC manure removed from the storage bay had a higher N content (6.23 percent, dry basis) than the CC (5.55 percent) and AV manure (5.35 percent). Detailed results are shown in Tables 20-25. Overall, manure from EC had more nitrogen and thus had a higher fertilizer value than that from CC or AV, and because it was drier than manure from CC or AV it had lower emission potential during storage.

Computer Models. Computer models were developed for analyzing and predicting the air temperature distributions in the house, ventilation rates and ammonia emission rates from CC, which was tunnel ventilated, under different bird stocking density and ambient environmental conditions. Simplified diagrams of the air flows in CC house are shown in Figures 22 and 23, indicating the pressure node locations and the names of various pieces of equipment included in the air flow model. Computer models were also developed for predicting ammonia emission rates from stored manure under different manure characteristics (pH, moisture content, ammonia content) and storage conditions (ambient temperature, air velocity over the manure surface, exposure surface area, and storage time). These models will be very useful tools for predicting changes in ventilation rates and ammonia emission rates from hen houses and manure storage when bird stocking density and climatic conditions change.

Results: Worker Health and Safety

- While working in the AV, workers were exposed to significantly higher concentrations of airborne particles and endotoxin (toxic components of bacteria) than when working in CC and EC; exposures in EC and CC were similar to one another.
- It was difficult to evaluate potential long-term system effects on worker respiratory health because of the small number of workers surveyed and because there was high mask use among all workers. However, short-term respiratory health was marginally worse (lower lung function and more respiratory symptoms) for AV than EC or CC.
- The task of gathering floor eggs in AV required workers to adopt extreme body positions for extended periods and exposed them to multiple respiratory and ergonomic hazards since they had to crawl and lie on the floor. Ergonomic challenges and health and safety risks in the CC and EC were mainly associated with the tasks required to place hens in, and remove them from, the cages and colonies.

Poultry workers inhale airborne particles and gases produced in layer barns throughout their work shift. Smaller particles are of particular concern because they can potentially be deposited deep into the lungs (Dockery and Pope, 1994). The combination of dust and ammonia can work in synergy to impair pulmonary function (Donham et al. 2002). Prolonged exposure without respiratory protection may lead to respiratory health problems, such as chronic bronchitis, wheezing and reduced lung function (Donham, et al. 2000;Schenker, 1998; Takai, 1998). Endotoxin is capable of inflaming workers' airways through allergic and non-allergic mechanisms (Kirychuk, et al. 2006;Larsson, et al., 1999; Senthilselvan, et al., 2011). At the time of the CSES project, worker health had not been studied in a way that allowed detailed comparison between different hen housing systems (Mench et al., 2011). In addition, there was no research on ergonomic challenges faced by workers in different hen housing systems.

BREATHING EXPOSURES

Workers' respiratory health and exposure to air pollutants in the three housing systems was assessed. Each worker wore a backpack holding exposure monitors during his or her work shift. The exposure monitors sampled ammonia, particles of all sizes that can be taken in through the nose (referred to as inhalable), and smaller particles (referred to as $PM_{2.5}$), which can travel deep into the lungs. Workers were assigned to work an equal number of days in a random pattern in each of the three barns for 13 to 15 days in each of three seasons: summer, winter and spring. A total of 124 sampling day air samples were collected. Workers' lung function and breathing symptoms before and after work were monitored on the same days that personal air sampling was conducted. From these measurements, changes across a shift in workers' respiratory symptoms and pulmonary function were recorded.

Inhalable particles, $PM_{2.5}$, and endotoxin concentrations, were significantly higher in AV than in CC or EC, while CC and EC were similar to one another (Figure 24). The higher levels in AV were most likely due to aerosolized litter (wood shavings and manure). In terms of ammonia, the National Institute of Occupational Safety and Health (NIOSH) recommends that the time-weighted average (TWA, averaged over an 8-hour work day) for worker ammonia exposure should not exceed 25 ppm. The TWA for ammonia measured at the normal standing height of the workers never exceed this threshold in any housing system. The actual percentage of the worker day that ammonia exceeded this limit was low in all systems, but significantly lower in CC.

LUNG HEALTH

Workers' lung function and breathing symptoms before and after work were monitored on the same days that personal air sampling was conducted. From these measurements we recorded changes across a shift in workers' respiratory symptoms and pulmonary function. We also recorded what percentage of the day workers wore respiratory protection (a N95 mask or respirator).

There was a slightly higher occurrence of respiratory symptoms in AV barn than in EC or CC (Figure 25). However, since there were few symptoms they could not be analyzed statistically for system differences. On average, workers wore masks more than 50 percent of each day, with the median percentage of time being 70 percent (Figure 26). As the masks filter out 95 percent or more of the particles and also filter out many gases, the workers' airways and lungs were not exposed to the concentrations of pollutants recorded by their air samplers. Workers used their masks more when the particle concentration in the AV increased.

Cross-shift changes in pulmonary function between the systems were compared adjusting for season (since both hen age and ventilation depend on the time of year), mask use and the individual worker. Differences between the systems in general were not statistically significant. However, the direction of changes suggested worse pulmonary function for workers when they were in the AV. For example, working in the AV was marginally worse than in EC for FEV_1 (forced expiratory volume in 1 second – a measure of airflow obstruction). It was also marginally worse than CC for FEV_6 (forced expiratory volume in 6 seconds – a measure of lung volume) (Figure 27). Workers who wore a mask more than 70 percent of the time had significantly better cross-shift FEV_6 changes. Average mask use was higher in the AV, which may have protected workers from any respiratory consequences.

WORKER ERGONOMICS AND SAFETY HAZARDS

Worker's tasks were classified into three categories indicating their level of risk due to body position. Three main ergonomic stressors - force, repetition and posture - were also assessed. A number of tasks stood out as possible risks. Loading and unloading cages in the CC and EC during hen population and de-population required extreme body positions, including squatting for an extended time. There was also significant twisting while "herding" the birds and standing on small diameter railings in these two systems. Gathering eggs that had been laid on the floor in AV was a risk, since it required extreme body positions such as squatting for an extended period of time. Extreme arm positions, over the shoulder and reaching to the side, as well as rapid and extreme hand and wrist positions were also observed. Crawling and lying on the floor to collect floor eggs also exposed the workers to potential respiratory hazards, especially if no respiratory protection was worn, as well as to potential infection hazards to the hands and the knees.

During population and depopulation of the EC and CC with hens, personnel were observed climbing to the cages and colonies on the higher tiers by using the small railings on the feeders to gain access to the door openings to the cages. This provided minimal traction for footing (no proper work platform) and caused personnel not only to use exaggerated body stress positions but to risk slipping and falling. In all systems, passages were blocked by transport modules when hens were being depopulated. The workers thus were in a narrow area which, in the event of an emergency, could lead to them being unable to exit the area. This problem was compounded in the AV because the workers had to secure themselves inside the cage structure within the AV to guide hens to the catchers while ensuring that the birds could not escape into the open litter area. There was very close tolerance once a worker was inside the system, severely limiting body movement in case of emergency where free movement is both desired and needed to exit the system safely.

Results: Food Affordability

- AV had total operating costs per dozen eggs that were 23 percent higher than CC, and EC had total operating costs per dozen eggs that were four percent higher than CC
- EC had lower feed and pullet costs per dozen eggs than CC
- Overall the AV was the most costly system for all cost categories. Costs of the EC system were quite similar to those of the CC system except the labor costs and capital costs, which were significantly higher.

Prior to the CSES study, U.S. cost comparison data for the three housing systems was lacking (Sumner et al., 2011). The egg cost of production data represent the first on-farm cost comparisons across three housing systems on a single farm, at the same location and employing the same accounting definitions and consistent cost measurement for each housing system. Farm managers provided specific cost of production data measured weekly, biweekly and monthly during commercial operations over the two flock cycles. The economic data provided were used to compare feed costs, labor costs, pullet costs, calculated energy costs, capital costs and miscellaneous operating costs and the sum of all available costs across the three housing systems. The results are shown in Tables 26 and 27.

Feed Costs. Feed costs were by far the largest cost item over the two flocks. The bulk of the feed costs derived from corn, soybean meal and distiller's dried grains (DDGs), with the share of costs in that order. The price of corn, soybeans and DDGs varied during the research project, and the cost difference over time reflected those market price variations. The amount of feed per hen and the average egg production per hen also varied over the life of the flocks. Most important for our analysis, feed per hen and per dozen eggs differed due to housing system. Feed costs per dozen eggs rose more over the flock cycle for AV than for CC and EC, due mainly to a greater decrease in eggs produced per hen for AV over the flock cycle compared to the other two housing systems. On average over the two flocks, hens in EC produced 4.8 percent more eggs per pound of feed than the hens in AV, but only about 1.5 percent more eggs per pound of feed than hens in CC.

Labor. Labor in the CC house cost about two cents per dozen, with little variation over the flock cycle. Labor costs per dozen for the AV rose over the flock cycle and were variable from one bi-weekly pay period to the next. The average labor cost rose from about six cents per dozen at the start of the flock cycle to more than eight cents per dozen by late flock. The largest specific labor cost item for AV was egg collection, which rose steadily to over three cents per dozen for the last half of the cycle. In addition, hen mortality and other hen health issues were greater in AV and contributed to the higher labor costs. The EC had labor costs between the two extremes, averaging more than five cents per dozen (three cents per dozen higher than CC). The EC had higher management labor costs than CC primarily because it used the same management hours for fewer hens.

Pullet Costs. Pullet costs also differed significantly between the AV and the other two housing systems, due to differences in rearing costs. The pullets entering the CC and EC systems were reared in the same conditions, in conventional cages. The AV pullets were reared in an AV, which was more expensive (with higher capital and labor costs). The AV pullets cost about $1.85 more per pullet than the CC and EC pullets. These initial costs were magnified by the end of the flock cycle because AV hens had higher mortality and produced fewer eggs than hens in CC or EC. The AV hens produced about five percent fewer eggs per pullet placed than the CC hens. By the end of the cycle, the flocks in the AV system lost 13.3 percent of the original pullets placed, compared to 5.2 percent in EC and 4.8 percent in CC. Over the full flock cycle, EC had about 3.3 percent more eggs per pullet placed than CC, resulting in pullet cost of 14.3 cents per dozen compared to 14.8 cents per dozen for CC.

Capital Costs. Capital costs per dozen eggs were calculated using data from the farm and some simple standard assumptions about interest and depreciation rates. Itemized capital outlay for land, buildings and equipment and the sum of capital invested for each house are shown in the top rows of Table 26. Because the CC house was built in 2004 while the AV and EC houses were built in 2011, we converted the original capital outlay for the CC house to 2011 prices using price indices for each cost category. Land costs comprised less than one percent of capital costs across the three systems. Building costs comprised 33 percent and equipment 66 percent of capital costs in the CC house. For the EC and AV, building costs were about 60 percent of capital costs, with equipment accounting for the other 39 percent. We converted capital costs into an equivalent annual flow using the same 10 percent base rate of interest and depreciation for each of the three houses. Because interest and depreciation calculations are typically considered on an annual basis, the average number of eggs produced per year of operation was calculated. Weekly data from the 61-week flock cycle were used, with the assumption that the house produces eggs for 51 weeks per year (about eight days for transition from one flock to another).

The flow rate of capital costs per dozen was estimated to calculate the sum of capital plus operating costs per dozen eggs. Using a 10 percent rate to account for interest plus depreciation, capital costs were about $0.058 per dozen for CC, about $0.162 per dozen for AV, and about $0.120 per dozen for EC.

Summary of Cost per Dozen.Table 27 shows a summary of the average across the two flocks of operating cost items and capital cost per dozen eggs. Feed costs were slightly higher for the AV than for the CC, and the EC had slightly lower feed costs than CC. Labor, which was a much smaller share of overall per dozen costs, differed greatly across the houses and comprised a larger share of average cost differences. Pullet costs also differed substantially. Energy costs and miscellaneous costs were very small shares of total operating costs and did not contribute to differences across the three housing systems. On average across the two flocks, operating costs were almost $0.139 (23 percent) higher for AV than CC. Operating costs were only $0.024 (about four percent) higher for EC than CC. The higher labor costs more than offset the slightly lower feed costs. Capital cost per dozen eggs was $0.104 (180 percent) higher for the AV and $0.062 (107 percent) higher for EC system than CC. The bottom line shows that the AV system had costs per dozen 36 percent higher and the EC had costs 13 percent higher than CC. Some of the cost differences may be associated with differences in scale between the three systems, especially related to labor and capital costs per dozen. During the time the study was conducted, scale and other technology, especially for EC housing, has evolved, which could affect costs per unit of production.

COALITION FOR SUSTAINABLE EGG SUPPLY

Research Results

The following summaries present the Coalition's overall research findings for each sustainability area, along with infographics showing both positive and negative impacts. In these infographics, the Enriched Colony (**EC**) and Cage-Free Aviary (**AV**) systems are compared to a baseline of the Conventional Cage (**CC**) system. The CC system was chosen as the baseline because it is the system in which approximately 95 percent of the laying hens in the U.S. are housed, and because it is the system for which there was the most existing data prior to the CSES project being initiated. There is also an interactive version of these infographics that contains additional information about the sustainability tradeoffs, and which can be found on the CSES website at **http://www2.sustainableeggcoalition.org/**.

The CSES researchers are aware that many egg producers are transitioning away from conventional cages as they install new systems. These summaries provide an overview of the sustainability tradeoffs that should be considered during this transition, and can assist in supporting informed decision-making. They should be evaluated in the context of the other final research materials, including the final research report and the peer-reviewed publications. They also represent a snapshot in time and particular conditions of management and housing design. As egg production systems continue to evolve, future research should focus on continuing to enhance the sustainability characteristics of those systems via advances in design and management.

Find more information at
www2.sustainableeggcoalition.org

COALITION FOR SUSTAINABLE EGG SUPPLY

Food Safety & Quality

Housing system type did not influence the rate of egg quality decline through 12 weeks of extended storage, and current U.S. egg quality standards/grades are adequate to describe eggs for all three of the housing systems. It is not uncommon for poultry to shed *Salmonella* spp. or other coliforms thus the prevalence (presence or absence) of *Salmonella* spp. and *Campylobacter* spp. were determined for every swab/egg shell pool collected from each system. Hens in all housing systems were shedding *Salmonella* spp. at a similar rate; the prevalence of *Salmonella* spp. on egg shells was very low and did not differ between housing systems. The AV had higher levels of environmental *Campylobacter* spp. recovery (drag swab). *Salmonella* spp. were detected at similar levels of prevalence in the EC and CC production environments however AV were more positive. The manure scraper had low levels of *Campylobacter* spp. recovery in all systems, but AV drag swabs and EC scratch pad swabs had high levels of *Campylobacter* spp. recovery. AV floor shells had the greatest levels of total aerobes and coliforms. Aerobic organisms were also elevated on AV nest box and system shells. Previous studies indicate total aerobe levels are greater on eggs produced in high dust environments. Eggs laid on litter (in AV only) have greater shell microbial levels than eggs laid on system wires or in nest boxes. Coliforms are indicators of fecal contamination which is linked to many human pathogens. In the EC system wire egg shell coliform levels were detected at levels similar to CC. The coliform level in AV nest box egg shells was similar to the EC. The coliform levels were low for all shell samples, excluding the AV floor shells, which had the highest levels of total coliforms.

**An infographic is not available for Food Safety and Quality.*

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COALITION FOR SUSTAINABLE EGG SUPPLY

Animal Health & Well-Being

Cumulative hen mortality in the EC and CC was slightly lower than the 6% Lohmann LSL management reference, but double that percentage in the AV. Major mortality causes in all systems were hypocalcemia and egg yolk peritonitis. More AV hens died from being caught in the structure, vent cannibalized or excessively pecked. EC and AV systems offered hens more behavioral freedom than CC with the nesting area and perches generally well used. In the AV the litter was used for dust bathing, but the EC scratch pad was not well used for dust bathing or foraging and accumulated manure. Nest use by AV hens was variable, with a proportion of eggs laid in the enclosure or on the litter. Bone health/strength measures indicate EC hens had more keel abnormalities than CC hens, particularly during late lay. AV reared pullets had more keel bone damage at placement than those reared in CC, and keel breaks were more prevalent in the AV hens during lay. Pullets in the AV rearing system had better bone quality at placement in their tibiae and femurs than pullets reared in the CC rearing system; this good bone quality was maintained throughout the lay cycle. Bone quality in CC and EC was not as good, although it improved somewhat in EC during the lay cycle. Measures of stress overall did not indicate acute or chronic stress. EC hens had slightly less feather loss than CC hens, while the AV hens had the best feathering. Feather cleanliness of EC and CC was similar, but AV hens had slightly dirtier feathers. EC hens had shorter claws and fewer foot problems (e.g. hyperkeratosis) than in CC, and no severe foot problems (e.g. bumblefoot). Incidence of foot problems in AV was lowest, but those problems were more severe. Air temperatures in AV and EC were similar to CC, and the hens were never observed panting. Indoor air quality (dust and ammonia) for EC was similar to CC but worse in AV. However, there were no signs of hen health problems associated with poor air quality in any housing system. Feed and water consumption by hens and body weights were similar across systems.

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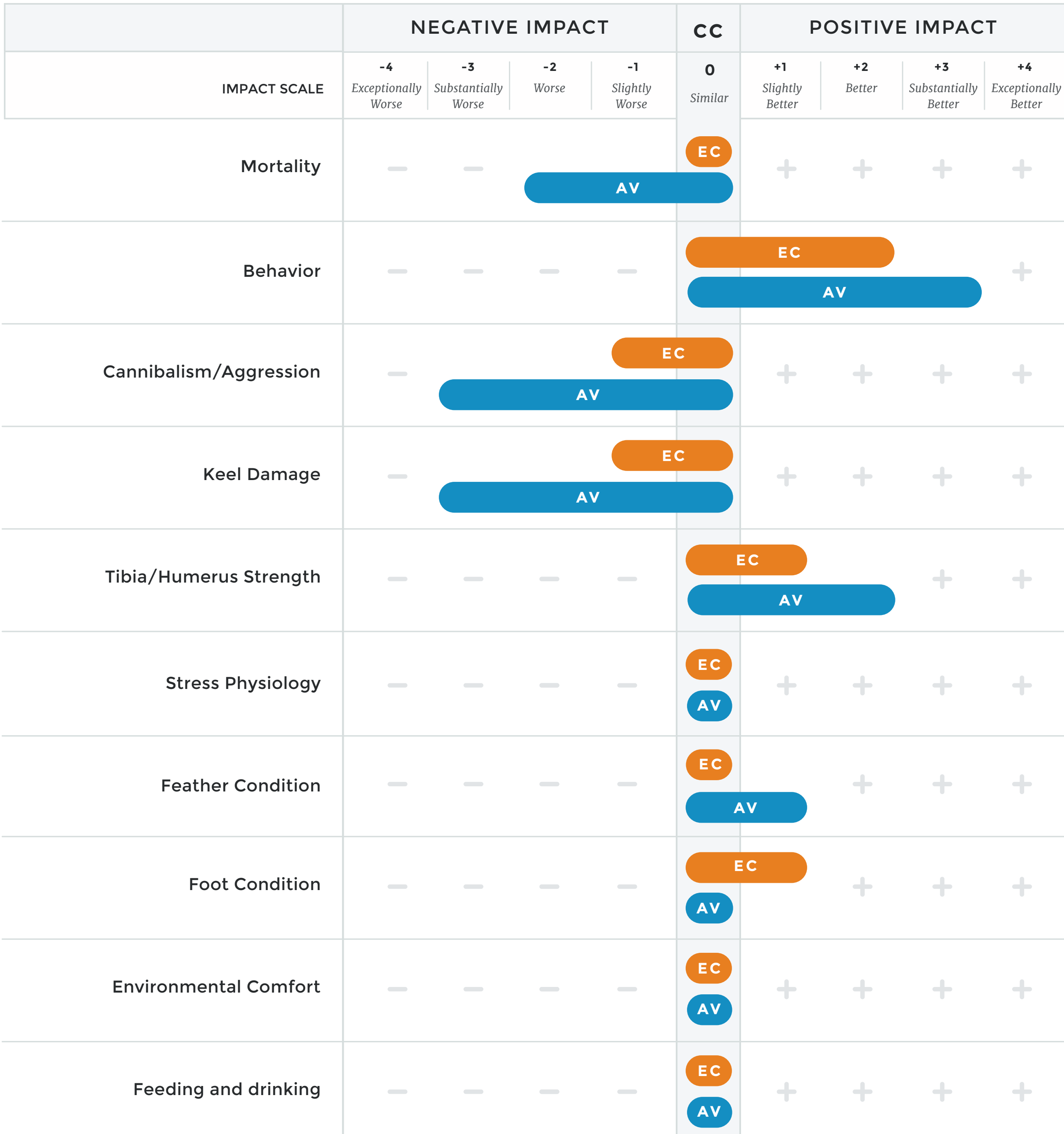
Animal Health & Well-Being

KEY: HOUSING TYPES EC *Enriched Colony* **(EC)** | AV *Cage-Free Aviary* **(AV)** | CC *Conventional Cage*



COALITION FOR SUSTAINABLE EGG SUPPLY

Environment

Ammonia and particulate matter (PM) concentrations were significantly higher in the AV house than in the EC or CC house. PM concentrations were roughly 8-10 times higher in the AV than either the CC or EC. PM emissions from the EC and CC house remained low and similar year-round, whereas the AV house had 6-7 times more PM emissions than the other two types of housing. The higher AV PM levels and emissions were caused by hens' behavioral activities on the litter floor. Poor indoor air quality may lead to eye and respiratory tract irritation in workers and hens. Farm-level ammonia emissions were lowest for the EC system, approximately half that of CC or AV, due to its lower stocking density and drier manure. Ammonia emissions from manure storage accounted for two-thirds of farm-level emissions. Greenhouse gas (GHG) emissions were low for all systems due to relatively dry manure. Manure removed from the EC house was drier and had a slightly higher nitrogen content than that removed from the CC or AV house. In the AV house, 77% of manure was deposited on the belts and the rest on the litter floor when hens had free access to the litter floor. Manure on the AV litter floor had to be removed separately, either mechanically or manually onto the manure belt. With respect to natural resource use, the EC house had similar energy use and feed efficiency to the CC house. The AV house may need supplemental heat during cold days, and when coupled with lower AV feed efficiency, creates a larger carbon footprint than EC or CC, as feed supply accounts for approximately 80% of total carbon footprint in the egg-supply chain. In addition, more natural resources are needed per bird space in the construction of AV houses.

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Environment

COALITION FOR SUSTAINABLE EGG SUPPLY

Worker Health & Safety

Airborne particulate matter (PM) can make its way into workers' airways, with smaller particles being deposited deep into the lungs. In the EC and CC houses, workers were exposed to significantly lower concentrations of airborne particles than when working in the AV house. Inhalable particle and PM 2.5 concentrations were higher in AV house due to the litter on the floor. The overall daily mean indoor ammonia concentration was well below the recommended limit of 25 ppm for the CC (4.0 ppm), EC (2.8 ppm) and AV (6.7ppm). Ammonia concentrations only exceeded 25 ppm in the winter of Flock 1 in each house but for less than 10% of the work shift. In the AV there was worker exposure to significantly higher concentrations of endotoxin than in CC or EC. High use of mask/respirator by workers, and similar concentrations of exposures in both CC and EC, was associated with similar cross-shift lung health outcomes. Average mask use was higher by workers in the AV protecting them from higher exposures and greater respiratory consequences. Ergonomic stressors assessed included force, repetition, and posture. Loading and unloading of cages in EC and CC systems required extreme body positions and significant twisting. Gathering floor eggs in AV required extreme body positions for extended periods and exposure to respiratory hazards. With respect to access, EC and CC systems posed significant hazards normally and at population/depopulation. EC workers stepped on the cage front instead of ladders to reach hens and worked from unapproved platforms and railings. There were no access issues in the AV. During unloading, the cage modules were placed in the aisles blocking them in the event a rapid evacuation was needed, and AV workers placed themselves inside the wire enclosures and locked the doors behind them, reducing the ability for a rapid evacuation.

Find more information at
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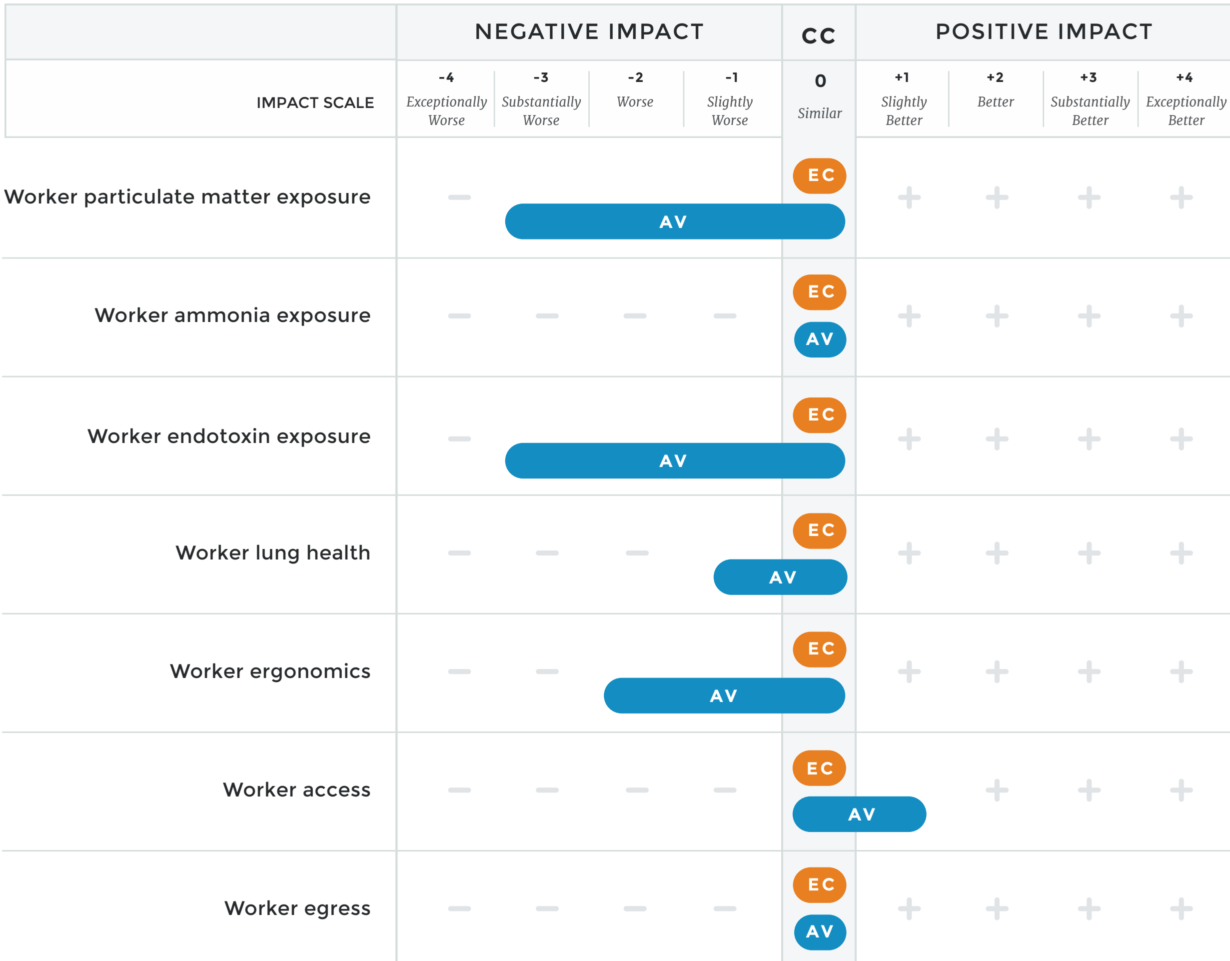
Worker Health & Safety

KEY: HOUSING TYPES EC *Enriched Colony* **(EC)** | AV *Cage-Free Aviary* **(AV)** | CC *Conventional Cage*



Coalition for Sustainable Egg Supply

COALITION FOR SUSTAINABLE EGG SUPPLY

Food Affordability

Feed for hens comprised the largest share of operating costs for each of the housing systems. Feed consumption per dozen eggs was similar across the systems, increasing somewhat over the life of the flock. Feed cost per dozen eggs produced in the AV was higher because production per hen placed in that system declined more over the life of the flock. The cost per dozen eggs for pullets placed in the AV were substantially higher than the other systems, due to higher rearing costs, higher hen mortality and lower production per hen in that system. The EC had higher weekly labor costs (per dozen eggs) than did the CC, though costs did not rise over the life of the flock as they did with the AV. An EC with more hens per house might be more efficient and reduce labor costs per dozen eggs produced. The labor costs per dozen eggs produced were highest in the AV, primarily due to greater labor costs for egg collection. Higher hen mortality and other hen health issues were also contributing factors. The EC had total capital costs per dozen eggs that were 107% higher than CC, largely the result of higher construction costs and fewer hens housed in comparison to CC. The AV had total capital costs per dozen eggs that were 179% higher than CC, largely the result of higher construction costs and fewer hens housed in comparison to CC. The EC had total operating costs per dozen eggs that were 4% higher than CC. Coupled with higher capital costs, EC had total costs per dozen eggs produced that were 13% higher than CC. The AV had total operating costs per dozen eggs that were 23% higher than the CC. Coupled with higher capital costs, the AV had total costs per dozen eggs produced that were 36% higher than the CC.

Find more information at
www2.sustainableeggcoalition.org

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Food Affordability

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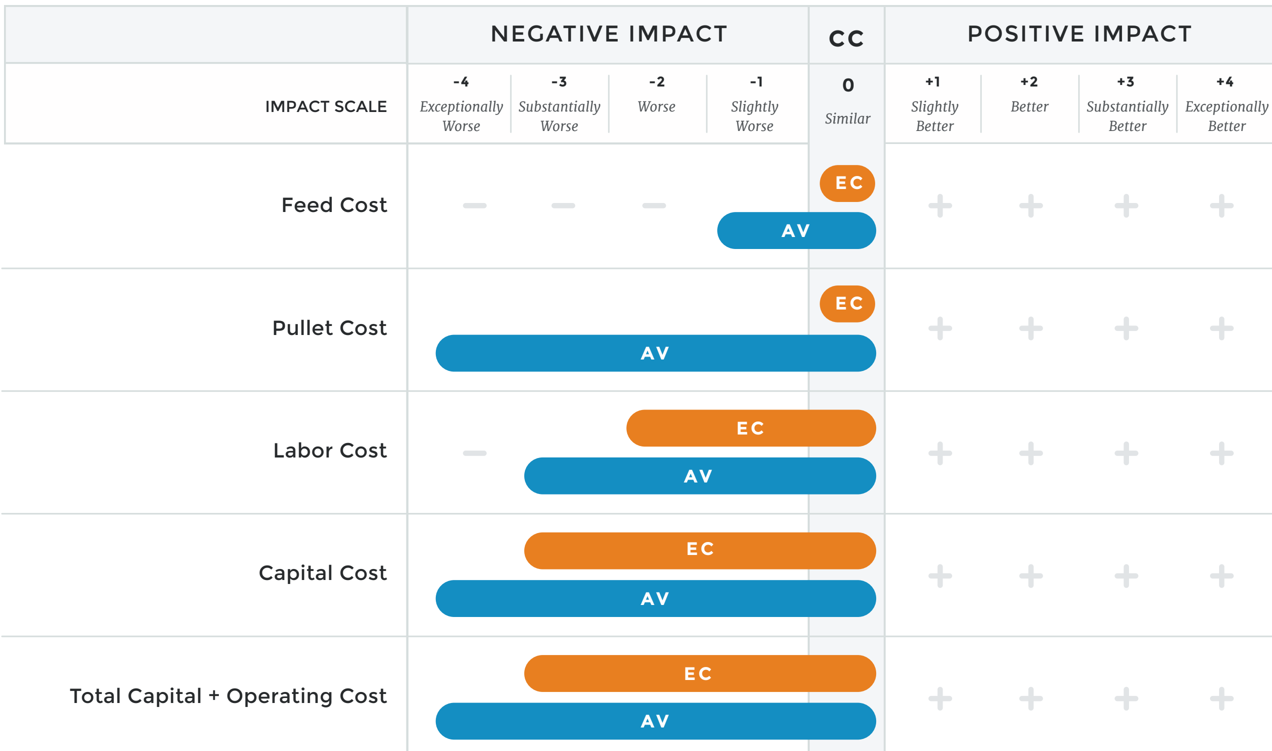

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