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Changes in Cotton Gin Energy Consumption Apportioned by 10 Functions

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ABSTRACT

The public is concerned about air quality and sustainability. Cotton producers, gin owners, and plant managers are concerned about rising energy prices. Both have an interest in cotton gin energy consumption trends. Changes in cotton gin energy consumption during the past 50 yr, a period of significant increase in labor productivity, were estimated to determine if replacing man-hours with machinery resulted in increased energy use. Data from recent audits and monitoring studies were combined to estimate energy consumption in total and for each of 10 processing or materials-handling functions. These values were compared to similar data published nearly 50 yr ago, by region and across the U.S. Bale formation energy consumption had increased because gins now press bales to nearly twice the density compared to the early 1960s. Other processing categories decreased significantly. Most materials-handling categories did not change much, but trash handling had decreased despite the increasing energy burden of more stringent emissions regulations. In total, electrical energy consumed per unit of cotton processed decreased by 19% to 34% even as gin processing rates increased three to six fold and mechanization has made labor four to six times more productive. This is welcome news when consumers are concerned about the carbon footprint of their apparel.

Generating electricity consumes nonrenewable energy resources and results in air pollutant emissions. The fossil fuel required and the mass of each pollutant (proportional to the generation of a kilowatt-hour (kWh) of electricity) varies by state and region (Funk, 2010). Power plant emissions are undesirable in all locations. Thus, it is not just cotton producers, gin owners, and plant managers, who are concerned about rising energy prices and interested in cotton gin energy consumption trends. The general public wants to reduce pollution and increase energy security. Both are therefore interested in gin energy consumption trends

Labor productivity in cotton gins has increased steadily as technological innovations have been adopted and processing rates have increased. Labor has primarily been replaced by machines powered by electric motors. This paper reports on the energy consumption impact of rising labor productivity in the cotton ginning industry.

By 1945 cotton gins had largely abandoned steam power in favor of diesel, gas, and electric motors, which took less man power to operate (Bureau of the Census, 1946). At that time machinery was powered by flat belts connected to a main line shaft turned by a single motor. In the 1950s and 1960s gins added lint cleaning machinery to better clean a crop that was becoming increasingly mechanically harvested (Hughs et al., 2008). Cotton gins were becoming bigger to take advantage of economy of scale and were also becoming fewer in number as gins consolidated and served a larger cotton growing area. Between 1940 and 1960 the average connected load more than doubled as individual gins increased processing throughput capacity (Watson and Holder, 1964). At the same time that the cotton crop converted to mechanical harvest, newly constructed gins were converting to individual electric motors on each machine (Watson et al., 1964). Moving away from single-motor main line shafts to individual machine drives added flexibility and convenience as individual machines could be shut off for maintenance or repair without stopping the entire gin plant (Wilmot et al., 1967). This change not only reduced maintenance labor requirements, it was safer. Due to the difficulty of restarting equipment in a line shaft gin, ginners tended to attempt to clear chokes in equipment while the equipment was still running, resulting in frequent, serious injuries.

In the late 1950s changes were made to saw-gin stands that resulted in much higher ginning rates (cre-

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ating high-capacity gin stands). Gin stands were built with larger diameter and/or larger numbers of saws set closer together. Seed roll agitation was added. These modifications doubled gin-stand processing rates without changing their outside dimensions. The use of high-capacity gin stands necessitated changes in practically all complementary seed cotton cleaning, lint cleaning, and bale press equipment. Seed cotton cleaning equipment was often replicated, as it could take two parallel overhead systems to supply an adequate quantity of seed cotton to high-capacity gin stands (Wilmot and Watson, 1966).

By 1961 more than half the cotton crop was mechanically harvested (USDA, 1974) and gin plants began to resemble those in use today. Each machine had, and still has, an individual electric motor. The configuration and type of machines used has hardly changed with three exceptions. First, cotton harvesters now form modules or transfer raw seed cotton to module builders instead of trailers. This has reduced on-farm labor requirements. It has also decoupled harvesting from ginning by circumventing the limiting availability of trailers for seed cotton storage and transport. Gins have responded by replacing trailer suction unloading systems with, or adding, module feeders. Gins have benefited as this has reduced the labor required to bring raw material into the gin, and it has increased the intake rate. Second, automation has been added in several places, such as seed cotton drying and gin-stand feeding, which has contributed to higher processing rates. Automation of the bale strapping, handling, weighing, and bagging functions has reduced labor and increased the processing rate of the bale press system; this has followed replacement of modified flat-bale presses with gin universal-density bale presses. Third, increases in processing rate have been realized elsewhere by increasing the size, loading rate, and number of machines. For example, average high-capacity saw-gin stand processing rates in the 1960s were about eight bales per hour per stand. Twenty or more bales per hour per stand were routinely accomplished in the gins sampled in the 2010s (authors' data). Similarly, seed cotton cleaning formerly took place in inclined cylinder cleaners that were 5 to 8 ft wide (Stedronsky, 1964). Current practice has two or more series of cleaners in parallel, each from 8 to 12 ft wide (Cherokee Fabrication, 2011; Lummus Corporation, 2004) and to operate them fully loaded, near the manufacturer's recommended 2.5 bale hr^{-1} ft^{-1} (Hardin et al., 2011).

As gin plant throughput has increased, the number of workers required has remained constant or decreased slightly. Current labor productivity is higher compared to that of 50 yr ago. The average man-hours required per unit processed has declined significantly, to as little as 25% to 15% of that required in 1962, depending on region (Table 1).

Table 1. Average labor required to process a bale of cotton in 1962 and 2010.

Region	1962^z (man·h bale^{-1})	2010^y (man·h bale^{-1})
Beltwide^x		0.42
Southeast		0.53
Mid-South	1.83	0.39
Southwest	2.78	0.42
West	1.65	0.42

^{z} From a sample of 32 gins (Cable et al., 1965)

^{y} From a sample of 126 gins (Valco et al. 2012)

^{x} Weighted average based on bales processed.

This analysis examined the change in cotton gin energy consumption during the past 50 yr, a period of significant increase in labor productivity. The objective was to answer the questions: "Has replacing man-hours with machinery resulted in increased energy use," and, "Has cotton ginning's carbon footprint changed?"

MATERIALS AND METHODS

Audits and Monitoring Studies. An energy audit is like a photograph in that it captures a situation at a single moment in time. An energy monitoring study is like a video in that it captures a succession of observations over a period of time. Because audits required less effort (a typical gin energy audit required approximately 4 h) it was possible to compare more facilities, gaining insight into the impact that design differences had on energy consumption. Energy monitoring studies provided sequential information through an entire season and made it possible to compare the impact that operation differences had on energy consumption (Hardin and Funk, 2012). This paper combined data collected during the past 3 yr from both energy audits and energy monitoring studies to provide a larger sample. Combined data acquired recently was compared to data compiled in 1962 through 1964 to determine changes in energy consumption over five decades. Now, as 50 yr ago, the data available was from a relatively small sample of the total number of gins in operation in the U.S. This comparison was limited statistically to presenting energy consumption trends. There were not enough gins sampled, then or now, to assert that these numbers exactly represented the industry as a whole.

Energy Audits. Energy audits were performed at 20 U.S. cotton gins in six states. Gins were selected to represent a broad range of capacity and annual throughput. A single measure was made of the current drawn by one phase of each motor (multiple readings were recorded for motors with fluctuating loads). Current measurements were made with a clamp-on Greenlee CM-600 ammeter (Rockford, IL; ±2.5%). Hourly energy consumption was calculated as the product of current, voltage, power factor, and the square root of three (because all motors were three phase). The product was normalized to energy consumption per bale by dividing by the processing rate at the time of the audit. This typically was higher than the processing rate averaged over the season as it did not include down time for cleaning and maintenance. Data from 1962 through 1964 also appeared to be based on audits.

Energy Monitoring Studies. Energy monitoring studies were performed at 7 U.S. cotton gins in four states. Current drawn by one phase of each motor (four gins), or each motor over 7.5 kW (10 hp) (three gins: but this captured 85% of the energy consumed) was sensed continuously for one or two seasons. The majority of motor loads were monitored using loop powered, 4-20mA output, selectable current range (0-30/60/120 amps) split-core current transducers (Hawkeye 921, Veris Industries, Portland, OR). Larger motors were monitored with similar but single range transducers, sized to match the load (Hawkeye 221, 321, or 421, Veris Industries, Portland, OR). Mains were monitored to capture total current, voltage, and power in cases where some of the smallest motors were not monitored. Values corresponding to motor current were recorded using data loggers (model 34970A with 34908A switch units, Agilent Technologies, Santa Clara, CA) or a modular data logging system (model CR1000, Campbell Scientific, Logan, UT). Each value was recorded at frequent intervals (from 2-6 sec).

More extensive monitoring system details are available in Hardin and Funk (2012). Systems were started at the beginning of the ginning season. Calibration was performed by stepping through each data logger channel, comparing the displayed reading to the value shown at that moment by a hand-held clamp-on ammeter. Procedures used during measurement of live 480-volt circuits were published by Funk and Hardin (2012). Calibration was repeated twice during the season. Memory cards were swapped out after a short interval (less than 1 wk) to verify operation of each channel by comparing logged values to expected values based on calibration and gin operating status. The memory cards were left for longer intervals once systems were confirmed to be fully operational. Figure 1 illustrates the design of the USDA-ARS data logger used in the energy monitoring studies.

Figure 1. A USDA-ARS data logger (with the cover removed) near a motor control center.

Data Analysis from Monitored Gins. Raw data files were converted to spreadsheets. Where a gin had more than one motor control center the spreadsheets were combined to synchronize logged data. Macros were used to: 1) remove bad values (occasionally an out-of-range value coincided with a motor starting event); 2) determine the completion of each bale using press pump current maxima; 3) average all data recorded during the interval since the previous bale; 4) cull bales that were formed when the gin was not running or that were significantly out of range for the gin's capacity; and 5) convert logged values to motor currents and save the results as separate spreadsheets. To minimize the influence of outliers, the seasonal median current value for each motor was used to calculate energy. First, motor power (kW) was calculated by:

$$P\ (kw) = V * I * \sqrt{3} * pf \qquad (1)$$

Where V was the RMS line-line voltage (average between phases 1-2, 2–3, and 3-1), I was the current (amps) averaged during the measurement interval, $\sqrt{3}$ was the square root of three (for three-phase motors), and pf was the power factor. Power factor was recorded in real time at some gins. At others, it was measured once using a hand-held instrument (model CW240, Yokogawa, Tokyo, Japan). In those cases, the gin's average power factor was used. Energy consumption per bale was then estimated by integrating power over the elapsed bale formation time and normalizing to standard 217.7-kg (480 lb) bales, where bale weight data were available. A constant bale weight was assumed based on seasonal average. Upland bale weights averaged 219 kg (482 lb) in 2010 and 226 kg (499 lb) in 2011. Pima (roller gin) bale weights averaged 219 kg (484 lb) in 2010 and 225 kg (495 lb) in 2011. It was deemed unnecessary to hand enter more than 100,000 actual bale weights because both bale weight and energy consumption were aggregated over the season.

Previous Study. Research published nearly 50 yr ago divided gin processing into 10 functions (Wilmot and Watson, 1966). These categories were grouped as either processing or materials handling. To facilitate comparison, the same categories were used. From that publication, only high-capacity cotton gins were quoted—gin facilities with equipment similar to that used today (though present capacities are much greater). The 10 categories were:

Processing or Value Added:

1. Seed cotton drying (adds value by improving cleaning).
2. Seed cotton cleaning (included extractor-feeders, and vacuum droppers driven by cylinder cleaner motors, if cleaners were so constructed).
3. Ginning (included seed-roll agitator, huller-front and air-blast fans in saw gins, and cooling fans associated with high-speed roller-gin stands).
4. Lint cleaning (included flow-through lint cleaner booster fans if so constructed).
5. Packaging (included battery condenser, moisture restoration systems, lint conveyor, tramper, press, strapper, bagger, and bale-incline and scale conveyors).

Materials Handling:

6. Seed cotton unloading (included the elevator fan, unloading separator, steady-flow feed, and steady-flow vacuum dropper; this study added the entire module feeding system).
7. Seed cotton conveying and overflow (included the conveyor-distributor, overflow hopper feed and vacuum dropper, overflow fan and overflow separator and vacuum dropper, and any independently driven vacuum droppers associated with seed cotton cleaners).
8. Lint conveying (battery condenser and lint cleaner fans only).
9. Seed conveying (augers, belts, seed plug, and positive-displacement blower).
10. Trash conveying (included trash, hulls, and mote conveying, and mote cleaner and mote press).

RESULTS AND DISCUSSION

Seventeen high-capacity gins in three producing areas were surveyed by Wilmot and Watson (1966); six in the Mississippi Delta (1962), and 11 in the Texas High Plains and the San Joaquin Valley (completed in 1964). These study areas were not replicated exactly, but monitoring data were collected in areas with similar production practices: Mississippi and North Carolina (South and Southeast); Lubbock, Texas (Southwest); and New Mexico and West Texas (West). Energy audits were performed in Arkansas, Missouri, and Mississippi (South and Southeast); Texas (Southwest); and California and New Mexico (West). Valid energy and/or connected power data were available from 22 gins from 2009 through 2011. These data are presented by region and, in the case of saw gins, for the U.S. Data are tabulated first by energy consumption per bale (Table 2), then by total connected power (Tables 3a and 3b).

Energy Consumption. Wilmot and Watson (1966) wrote, "Opinions differ among ginning engineers as to the proper categorization of certain fans." They added that dryer push-pull fans are more a part of processing than materials handling. Machinery would be stacked to allow for gravity flow throughout the seed cotton system if drying was never necessary. Drying seed cotton adds value because it increases the effectiveness of seed cotton cleaning (Anthony and Mayfield, 1994). To be consistent with the earlier study for comparison purposes, the same classification rules were followed. If an airstream could be heated, all fans associated with it were placed in the seed cotton drying category whether or not the burner was on that moment or that season. Electrical energy consumption associated with moving seed cotton through drying systems fell by half or more per processed bale over the past half century. The trend has been to build driers with more spacing between shelves and fewer shelves, reducing total pressure drop.

Table 2. Energy consumption (kWh bale^{-1}) by gin function; by regions and total; 1960s and 2010s.

(kWh bale^{-1})	West[z]		Southwest[z]		South and Southeast[z]		Saw Gins	Roller Gins
	1960s	Present	1960s	Present	1960s	Present	Present	Present
1) Seed Cotton Drying	14.56	7.22	15.91	4.94	12.03	5.54	5.53	10.28
2) Seed Cotton Cleaning	2.52	3.38	4.79	3.01	2.69	2.36	2.60	4.17
3) Ginning	9.11	5.94	8.16	6.79	9.08	6.52	6.38	8.40
4) Lint Cleaning	4.68	2.79	4.58	2.22	4.26	2.20	2.21	2.02
5) Bale Press	1.34	4.26	1.41	3.68	1.56	4.16	3.98	6.59
Value Added	*32.21*	*23.60*	*34.85*	*21.46*	*29.62*	*20.84*	*20.98*	*31.47*
6) Seed Cotton Unloading	5.47	3.54	8.23	0.90	5.88	1.89	1.56	3.56
7) Seed Cotton Conveying	2.00	1.70	1.62	1.89	1.45	1.83	1.79	5.50
8) Lint Conveying	4.98	5.33	4.34	4.58	4.08	4.33	4.65	7.38
9) Seed Conveying	0.73	1.25	0.63	0.65	1.31	1.44	1.11	1.78
10) Trash Conveying	7.50	6.01	6.28	3.59	5.16	4.62	4.43	5.92
Materials Handling	*20.68*	*17.79*	*21.10*	*11.61*	*17.88*	*14.10*	*13.53*	*24.15*
Total (kWh bale^{-1})	52.89	41.37	55.95	33.07	47.50	34.94	34.50	55.61
Processing Rate (bale h^{-1})	8.8	26.7	8.3	50.6	7.2	39.1	44.2	25.1
Sample Size[y]		3		4	6	8	15	4

[z] 1960s from Wilmot and Watson (1966).

[y] Seventeen gins were sampled between 1962 and 1964 but apportionment between the San Joaquin Valley and West Texas was not published. Twenty-two gins were sampled between 2009 and 2011 but not all sampled gins had complete energy consumption data.

Table 3a. Connected power (kW) by gin function; by regions and total; 1960s and 2010s.

(kW)	West[z]		Southwest[z]		South and Southeast[z]		Saw Gins	Roller Gins
	1960s	Present	1960s	Present	1960s	Present	Present	Present
1) Seed Cotton Drying	190	313	210	384	122	263	337	384
2) Seed Cotton Cleaning	66	153	107	216	61	129	176	180
3) Ginning	155	201	145	510	116	309	394	268
4) Lint Cleaning	85	128	67	182	57	115	153	80
5) Bale Press	56	165	40	397	34	256	318	206
Value Added (kW)	*552*	*960*	*568*	*1689*	*389*	*1072*	*1378*	*1117*
6) Seed Cotton Unloading	72	104	98	91	60	107	94	112
7) Seed Cotton Conveying	27	89	25	145	22	102	120	164
8) Lint Conveying	57	177	48	277	34	219	259	214
9) Seed Conveying	17	40	18	51	19	66	60	57
10) Trash Conveying	95	210	83	287	54	204	251	166
Materials Handling	267	*621*	271	*852*	187	*699*	*782*	*714*
Total (kW)	819	1581	839	2541	576	1771	2160	1831
Processing Rate[y] (bale h^{-1})	8.82	25.84	8.3	48.53	7.22	39.04	44.24	26.72
Sample Size[x]		3		5	6	7	15	4

[z] 1960s from Wilmot and Watson (1966).

[y] Small differences in processing rates in Table 2 and Table 3a for 2009-2011 were due to three audited gins being omitted due to incomplete connected power data, and a different three gins being omitted due to incomplete energy consumption data.

[x] Seventeen gins were sampled between 1962 and 1964 but apportionment between the San Joaquin Valley and West Texas was not published. Twenty-two gins were sampled between 2009 and 2011 but not all sampled gins had complete connected power data.

Table 3b. Connected power (hp) by gin function; by regions and total; 1960s and 2010s.

(hp)	West[z]		Southwest[z]		South and Southeast[z]		Saw Gins	Roller Gins
	1960s	Present	1960s	Present	1960s	Present	Present	Present
1) Seed Cotton Drying	255	420	281	515	163	353	452	515
2) Seed Cotton Cleaning	89	205	143	289	82	173	236	241
3) Ginning	208	270	194	684	155	415	529	359
4) Lint Cleaning	114	171	90	244	76	154	205	107
5) Bale Press	75	221	54	533	45	343	426	276
Value Added (hp)	*740*	*1287*	*762*	*2265*	*521*	*1438*	*1848*	*1498*
6) Seed Cotton Unloading	96	140	131	122	80	144	126	150
7) Seed Cotton Conveying	36	119	34	195	29	137	161	220
8) Lint Conveying	77	238	64	371	45	294	347	287
9) Seed Conveying	23	53	24	69	25	88	80	77
10) Trash Conveying	127	282	111	385	73	274	336	223
Materials Handling	358	*833*	364	*1143*	251	*937*	*1049*	*957*
Total (hp)	1098	2120	1125	3408	772	2375	2897	2455
Processing Rate[y] (bale h^{-1})	8.82	25.84	8.30	48.53	7.22	39.04	44.24	26.72
Sample Size[x]		3		5	6	7	15	4

[z] 1960s from Wilmot and Watson (1966).

[y] Small differences in processing rates in Table 2 and Table 3b for 2009-2011 were due to three audited gins being omitted due to incomplete connected power data, and a different three gins being omitted due to incomplete energy consumption data.

[x] Seventeen gins were sampled between 1962 and 1964 but apportionment between the San Joaquin Valley and West Texas was not published. Twenty-two gins were sampled between 2009 and 2011 but not all sampled gins had complete connected power data.

Classifying the majority of fans in the drying category resulted in some present-day gins having relatively small unloading energy consumption. Because current practice in some gins was to use a hot-box pick up at the module feeder and two stages of inclined hot-air cleaning, seed cotton was transported by the drying system or gravity from the module feeder to the conveyor distributer. The other reason electrical energy consumed by seed cotton unloading was reduced significantly was through the use of module feeders. The majority of seed cotton arrived at the gin in modules; some facilities no longer accepted trailers at all. Average module feeder energy consumption was less than 1 kWh $bale^{-1}$. This was a significant savings over the suction unloading elevator fan energy consumption of the early 1960s, which by itself was more than 4 kWh $bale^{-1}$ (Wilmot and Alberson, 1964).

Seed cotton cleaning energy consumption per bale has remained fairly constant in most of the cotton belt. However, it has decreased somewhat in the stripper-harvested Southwest (Texas High Plains and Oklahoma). Stripper harvesters with effective field cleaners were tested in the late 1960s as they became commercially available (Kirk et al., 1972). Modern field cleaners having cleaning efficiencies of 50% to 60% result in less trash being brought to the gin (Wanjura et al., 2009). Stripper-harvested seed cotton processed by Southwest gins now contains roughly 160 kg $bale^{-1}$ (350 lb $bale^{-1}$) of trash compared to 320 kg $bale^{-1}$ (700 lb $bale^{-1}$) typical of the early 1960s. Gin energy consumption was displaced because there was less total seed cotton material to handle in gins processing field-cleaned stripper cotton compared to 50 yr ago when stripper-harvested cotton was not field cleaned; overall gin processing rate probably improved as well. Sherwood (1973) reported a 13% increase in ginning rate with field-cleaned cotton at one gin.

Without knowing transport distances, it is difficult to estimate the net benefit of field cleaning (extraction) today in terms of total energy or carbon footprint. However, relative changes to subsystems are available based on a 1969 study measuring the economic impact of field cleaning on each component of harvesting and processing systems. Changing to harvesting with field cleaning resulted in a 15% increase in harvester fuel consumption, but energy consumption transporting seed cotton to the gin decreased 25%, gin energy consumption decreased 11.5%, and energy requirements to haul and spread trash decreased 50% (Sherwood, 1973).

The data show gin-stand energy consumption per bale decreased by about 30%. Much of the change was due to advances in technology resulting in greater economies of scale and better equipment utilization. Gin-stand capacities have increased dramatically during the past 50 yr, from about 8 bales h^{-1} to more than 20 bales h^{-1}. Other innovations, such as electronic gin-stand controls and overflow automation, help the gin stands run at full capacity a greater portion of the time. Hardin and Funk (2012) reported that the operating efficiency of gin stands at four monitored facilities was 91.65%, compared to an operating efficiency of 84.2% reported by Watson and Holder (1964). A smaller contribution might come from the cotton itself. Selective breeding during the past half century has focused on increasing lint percent, fiber length, and fiber strength. For example, the average length of U.S. Upland cotton in 1961 and 1962 was 26.4 mm (33.3 staple) (USDA, 1963). In 2010 and 2011 it was 28.2 mm (35.5 staple) (Cotton Inc., 2012). Studies have shown significant variation among cultivars for gin-stand energy usage. Boykin (2007) observed that cultivars with reduced gin-stand energy had increased gin turnout (or lint percent), increased strength, and reduced short fiber content; but no trend was observed with fiber length. Boykin et al. (2012) observed that cultivars with reduced gin-stand energy had reduced fiber-seed attachment force, reduced strength, and reduced length; but no trend was observed with lint percent or short fiber content. These findings support the notion that selective breeding over time has affected ginning energy, but there is no direct evidence. Ginning not only separates fibers from seed, but also extracts ginned fibers from the seed roll. Resistance to the gin saw includes fiber-seed separation, fiber-fiber friction, fiber breakage, and seed-roll friction. In theory, increased fiber length reduces fiber-seed separation force on a per mass basis, but there appears to also be an increase in fiber-fiber friction with increased length.

The lint cleaning energy category included flow-through lint cleaner (SuperJet™) booster fans found in some roller gins. Lint cleaning energy consumption has decreased during the past 50 yr as fewer unit lint-cleaner stages are used. Where once two or three stages of lint cleaning were common practice, only one or two were used in the audited and monitored gins. This is in response to research that has shown that gains in leaf grade from additional lint cleaning are offset by losses in fiber length and bale weight (turnout). A second stage of lint cleaning might decrease waste during spinning, but it does so at the cost of additional card web neps and lower yarn strength. For these reasons a second stage of lint cleaning is reserved for late-season, more trashy or Light Spotted cottons in both spindle and stripper-harvested regions (Anthony and Mayfield, 1994).

The only processing or value added category that has seen an increase in energy consumption per bale was packaging. The biggest change came about in the 1970s as gin universal-density bale presses replaced modified flat-bale presses. The new gin universal-density bale presses formed a finished bale that was about twice the density, 448 kg m^{-3} (28 lb ft^{-1}), compared to bales formed by modified flat-bale presses. This increased press energy consumption by a factor of eight (Anthony et al., 1980).

Though forming gin universal-density bales required a significant capital investment and more operating energy, the new bales were economical because they did not require recompressing at the warehouse to become compress universal-density bales. Gin universal-density bales saved, at that time, $3.00 in compression fees and $1.00 in bagging and ties (Shaw and Ghetti, 1977). Eliminating a second stage of pressing by shifting the work done at the compress to the cotton gin has possibly reduced total energy consumption by the industry. Displacing warehouse-based steam-powered pressing with gin-based electric/hydraulic pressing likely has greatly reduced the carbon footprint of this operation. Unfortunately, energy consumption of compress operations were not published, so quantification was difficult. The other benefit of forming higher density bales at the gin occurred at the transport level. Trucks transporting cotton bales from the gin to the warehouse now need make fewer trips. This has likely reduced motor fuel consumption and air pollution, though again, published data are lacking.

Comparing ginning energy consumption per bale over the past half century, there was approximately a 32% decrease in processing energy consumption. Materials-handling energy consumption per bale also decreased, about 22%, though most subcategories did not change much in the past 50 yr. Seed cotton conveying and overflow, lint conveying, and seed conveying energy consumptions did not change significantly. Savings have come through decreases in trash conveying energy consumption—despite including mote cleaning and pressing in that category. The West continues to have the greatest energy requirement for trash handling, possibly due to more stringent emissions control regulations in that region (though small sample size and the smaller size of sampled gins might also influence this statistic). Comparing the present study to results published from the 1960s, total energy consumption per bale decreased approximately 34% over the past 50 yr—a significant savings. These savings have been realized even as gin processing rates have increased three to six fold, and as manual labor has been replaced by mechanization.

Connected Power. This three- to six-fold increase in processing rates has not meant a commensurate increase in connected power (Table 3a, SI units, and Table 3b, English units). Connected power has only increased two to three fold. The most significant increase in processing power has been at the bale press. The next largest processing increase in connected power has been on gin stands, but the increase in connected power has been less than the increase in processing rate (as reflected in the decrease in unit energy consumption). With materials handling the trend is similar. Materials-handling connected power has increased, but this increase has not approached the rate of increase in processing rate. Table 4 compares the ratio between average power actually consumed and connected power based on the sum of motor nominal rated power. This was calculated for value added, materials handling, and total, by region, for the two time periods. Motor utilization has improved, from about 60% in the 1960s to about 70% at present. Motor utilization usually is less than 100% because of the margin of safety required in systems with fluctuating loads (to avoid overloading components when a surge of excess material enters the process stream). However, trimming that margin helps gins reduce capital and operating costs, and might slightly improve the facility's power factor.

Roller Gins. Roller gins were not included in the 1962 through 1964 studies. Roller gins were typically used only on Pima cotton, a small percentage of the U.S. crop. Today better quality upland cottons are increasingly being processed with high-speed roller gins (Armijo and Gillum, 2010). Roller gin statistics are presented here for comparison with saw gins. The connected power tends to be a bit less, but energy consumption per bale processed is more. This might partly be due to the lower processing rate and greater age of the roller gins sampled in this study. Also, roller gins typically have more gin stands, between 12 and 32, compared to saw gins, which typically have two to six. Other differences are not great enough to explain the disparity.

Study Limitations. Regional and nationwide averages from 2009 through 2011 were weighted by processing rate, not by total bales processed. This skews the data to represent larger gins more heavily, even if they did not process a large number of bales in the year studied. Gins were selected for audits and monitoring based on logistics considerations (proximity to transportation or other facilities being audited), not just based on how well they represented the "typical" gin of a particular size or age. And as mentioned above, audits are useful for apportioning energy consumption between functions, but they underestimate total energy consumption per bale because the audit is conducted while the gin is running; energy that is used during cleaning and repairs is excluded.

Table 4. Ratio between actual power consumed and connected power.

	Value Added		Materials Handling		Total	
	1960s[z]	Present	1960s[z]	Present	1960s[z]	Present
West	0.544	0.632	0.695	0.737	0.593	0.673
Southwest	0.528	0.606	0.653	0.670	0.568	0.628
South & Southeast	0.596	0.758	0.715	0.800	0.635	0.774
All Saw Gins		0.673		0.765		0.707
All Roller Gins		0.753		0.904		0.812

[z] 1960s from Wilmot and Watson (1966).

For these reasons the present study was compared to the results of a 2010 cost-of-ginning survey (Table 5). This provided a means of comparing these results to results from a larger sample of U.S. gins from the same time period. The survey energy consumption data are for the entire season and include down time for clean-up and in-season repairs (something the 1960's audits did not include). Some gins had seed house drying fans on the same power meter as the gin, so survey results in a few cases show more than just ginning energy consumption. Because the 1960's data did not include everything, and the survey data in some cases included more than just ginning, this comparison might be considered conservative.

Anonymous survey data provided by the USDA Office of Cotton Technology Transfer were parsed for missing values and seasonal average energy consumption per bale for each gin was weighted based on total bales ginned by that facility. Survey data, which included down time and in some cases seed drying, indicated about 18% more energy per bale compared to energy audits and monitoring data. Comparing survey results to audit data from the 1960s, the cotton ginning industry is using 81% the energy it once did, while processing at 3.4 times the rate.

CONCLUSION

The U.S. cotton ginning industry has experienced many changes over the past half century. Bale compression density has approximately doubled, displacing work from the warehouse compress to the gin. Harvest methods have changed, shifting labor from the field to the gin and, in the case of stripper-harvested cotton, moving some energy consumption to the field. Environmental regulations governing dust emissions have resulted in increased materials-handling energy requirements as well as capital expense (e.g., more stringent regulations required adding cyclones to lint cleaner exhausts, so vane-axial fans with small motors had to be replaced with centripetal fans with larger motors). At the same time, the ginning industry has developed new technology and adapted innovations from other industries. The overall result has been a remarkable increase in labor productivity—from four to seven fold. Even as machines have done an increasing proportion of the work—making gin employment safer as well as better paying—there has been a decrease in electrical energy consumed per unit of cotton processed. Comparing audit data from the 1960s to survey data from 2010 or to audit and monitoring data from the present reveal the same trend—electrical energy consumption has decreased by 19% to 34%. This is welcome news when consumers are concerned about the carbon footprint of their natural fiber clothing.

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DISCLAIMER

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Table 5. Comparison between present study and 2010 survey data from 106 U.S. gins.

	West		Southwest		South & Southeast		Beltwide	
	2010 Survey[z]	Present Study	2010 Survey[z]	Present Study	2010 Survey[z]	Present Study	2010 Survey[z]	Present Study
kWh/bale	49.46	41.37	41.31	33.07	35.93	34.94	40.62	34.5
bales/hour	23.0	26.7	29.1	50.6	27.4	39.1	27.8	44.2
Sample Size	13	3	50	4	43	8	106	15

[z] Data from Valco et al. (2012); weighted average results computed by authors.

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