An Engineering Review of Feasibility of a Producer Owned Ground Straw Feedstock Supply System for Bioethanol and Other Products

Prepared for

Grant 4D Farms

October 2006

CH2MHILL
Boise, Idaho

Contents

Section **Page**

Summary **1**
Introduction **2**
Project Description **2**
Report Review Details **2**
Section 1—Introduction 2
Section 2—Cost Methodology for Bulk Supply System Analysis 3
Section 3—Straw Contracts and Supplies 3
Section 4—Harvest 3
Section 5—Collection of Harvest Data 4
Section 6—Scheduling and Dispatching 4
Section 7—Baling Operations 4
Section 8—Roadsiding Bales 4
Section 9—Field Quality Assurance 5
Section 10—Inventory Management and Field Storage 5
Section 11—Grinding Operations 5
Section 12—Transporting Ground Feedstock 6
Section 13—Weighing and Accounting 6
Section 14—Unloading Ground Feedstock 6
Section 15—Plant Quality Assurance 7
Section 16—Plant Feedstock Storage 7
Section 17—Storage to Reactor Transportation 8
Section 18—Management Systems 8
Section 19—Permitting 8
Section 20—References 8
Section 21—Appendices 8
Additional Review Areas **8**
1. Dust Control 8
2. Financial Escalators 9
3. Fire Protection 9
4. Fuel Depot 9
5. Fuel Contract 10
6. Footprint 10
7. Lighting 11
8. Security 11
9. Employee Parking 11
10. Electrical Loads 11
11. Environmental Permits 12
12. Shift Schedule 12
13. Waste Streams 13
Areas of Concern **13**
Recommendations **14**

Summary

The report "A Model for a Lignocellulosic Biomass Feedstock Assembly System for Wheat and Barley Straw" provides a detailed description of the process for collected, processing, delivering and staging straw feedstock for an ethanol reactor proposed for siting in Idaho Falls, Idaho. The report focuses heavily on the equipment, man-power and logistics required for the enterprise from contracting for straw through delivery to the reactor mouth. A very thorough job was done in preparing the report with detailed research and experimental data supporting many of the elements. An equally detailed Excel spreadsheet based financial model was also developed to supplement the narrative, capturing capital, operation and maintenance and labor costs associated with each step of the process.

A two-part review of the model was done by CH2M HILL. Part one reviewed the report and spreadsheet for flaws in approach, assumptions or conclusions and errors in calculations. Part two evaluated thirteen aspects of the model that had not been addressed in the report. There are numerous minor comments on various aspects of the report as detailed in the body of this review. However, there were only five main areas that the reviewers felt could impact the viability of the model as shown in the report. Those five areas were as follows:

1. Ability to contract for the required quantity of straw. This is a requirement for the ethanol reactor and not just the supply model.
2. Logistics of delivering the material to the interim storage facility. The complex scheduling and optimization of the system has virtually no float in it to allow for equipment breakdown or weather delays.
3. Ability to use a silo storage system with straw while complying with the International Fire Code. Initial review of the Code suggests that this approach may not be allowable.
4. Ability of the conveying system to move the necessary volume at the required rate. The light unit weight of the material presents a design challenge that can only be addressed by conveyor designers.
5. Ability to support the field fueling requirements. In order for field fueling to be practical day tanks that support the two shift operation will probably have to be included with each grinding team and Saturday deliveries may be problematic.

While item 1 above is a problem for the entire ethanol plant from a capacity stand point the remaining issues are all resolvable. The restrictive scheduling can be adjusted with additional equipment, which will increase costs but ultimately be more believable as an operating model. There are alternatives to the silo storage concept that could lower costs associated with the silos and reduce the conveyor problems but that would have offsetting space, equipment and environmental control requirements. The conveying problems may be solved by custom design approaches, an alternate conveyance method or by eliminating the silos. The field fueling issue can be addressed by adding day storage tanks to the equipment.

Overall the report was well thought out and well researched. Excluding the availability of the required supply, none of the issues identified would qualify as a fatal flaw in the concept as all can be addressed. The supply question impacts the reactor size, which is set

by the ethanol reactor developer, so for the purposes of this model and review should not be considered limiting.

Introduction

Grant 4D Farms, working with the Idaho National Laboratory, has developed a model for supplying raw feedstock to an ethanol refinery. The model is described in the report "A Model for a Lignocellulosic Biomass Feedstock Assembly System for Wheat and Barley Straw." Grant 4D Farms has contracted with CH2M HILL to provide a review of the report seeking fatal flaws in the approach, addressing potential improvements and areas that were previously identified as being inadequately defined.

Project Description

This project is a collection, processing and delivery model for supplying raw feedstock to a proposed ethanol refinery to be developed by others in Idaho Falls, Idaho. The proposed ethanol refinery is based on processing lignocellulosic biomass obtained from wheat and barley straw. The model calls for a distributed collection and processing concept where the straw is collected and stored, in bales and stacks, where it is harvested. The straw will be ground to user requirements on an as needed basis on location and transported in a ready to use state to a centralized collection and supply point adjacent to the ethanol refinery. The refinery requires 800,000 tons of straw per year, collected from farms within a 100-mile radius of Idaho Falls. Plant capacity requires operation 24 hours a day for 350 days a year.

The critical success factors for this model include the following:

- Ability to contract sufficient straw, of required quality, within specified distance from the refinery.
- Capability to field grind required annual quantity of straw to customer's specifications.
- Capability to transport ground straw at a rate that meets refinery demand.
- Ability to design a transfer facility that can accommodate the inflow of material, with short term storage, while accommodating refinery demand.

Report Review Details

The report consists of 21 sections covering each aspect of the model. Each section was reviewed independently with comments as shown in the following sections. A summary of the overall process was then developed from the individual sections. The 13 areas identified as needing additional input are discussed in individual sections.

Section 1—Introduction

This section provides the basic assumptions used in the model, outlines the requirements for an optimized biomass supply enterprise and provides a brief summary of the biomass market in southern Idaho today. There were no comments on this section.

Section 2—Cost Methodology for Bulk Supply System Analysis

This section describes the basic approach to determining capital costs for the different aspects of a biomass supply enterprise and provides detail on the economic approach used for establishing the costs of operations and maintenance for capital equipment. An accepted methodology from the American Society of Agricultural Engineers was employed. This methodology is repeated in subsequent sections for each phase, covering the required capital equipment. The majority of the phases are described in terms of dollars/year, although other units are also used. For overall evaluation it would be best to establish a single unit. For the purpose of assessing the most economic approach to the design of the enterprise a cost per year is a sound approach. However, cost should also be translated into two other forms for other audiences; a cost per ton of finished feedstock that will show if the approach is economic for the refinery and a cost split into up front capital investment plus annual costs to demonstrate the investment requirement to realize the enterprise.

Section 3—Straw Contracts and Supplies

This section describes the approach to securing contracts for the required 800,000 tons of straw a year, plus 10 percent extra for contingency, including the range of contract size and contract criteria.

The size distribution indicates that the predominant farm size supplying straw will be 1,170 acres and the smallest farm included in the contract mix will be 234 acres. Using the numbers provided in this, and other sections, indicates the average contracted acreage is 672. While large farms in much of the region can skew the average size up it appears that the size assumption is aggressive. Data should be included to support the numbers in this section. Even with the assumptions in this section, 766 contracts are required to meet the demand, which will create a logistical and organizational challenge.

Growers' responsibilities as listed in this section should be restricted to those that are critical to delivering contracted straw. Additional requirements that increase labor or cost for the producers will make these contracts less desirable than the dairy market, especially among the smaller size of farms.

Section 4—Harvest

This section describes the historical levels of grain production in the focus area of the study, within 100 miles of Idaho Falls, the timing of the harvest, and the distribution of different barley and wheat types.

While we find no problems with the data as presented in this section, the overall assumption of the section, which impacts the entire enterprise model, is very aggressive for planning. To meet the production goals the enterprise will have to capture 88 percent of the available straw market in eastern Idaho and 90 percent of the harvest within the targeted 100-mile radius. The dairy industry, which is the state's fastest growing agricultural market, currently takes 500,000 tons, or 50 percent of the supply, per year, which produces an apparent demand of 138 percent on the market. The natural tendency of demand outstripping supply is to drive prices up. In addition, if the dairy industry contracting requirements are less stringent than ethanol, there is a natural tendency to lean towards the easier money.

Section 5—Collection of Harvest Data

This short section describes the straw buyer function in collecting data in the field. No comments were made on this section.

Section 6—Scheduling and Dispatching

This section describes the process for dispatching field grinding units to appropriate bale storage locations based on desired feedstock characteristics from the refinery and weather related priority areas.

A basic premise in minimizing operational costs for a complex transportation model like this enterprise is to optimize trips. In this case that would include grinder trips and material transportation trips, loaded and unloaded. Software and methodologies for this kind of optimization are readily available. However, adding variables such as plant demand for a certain straw type and an emphasis on grinding the most severe winter weather areas first, greatly complicate the model and will not necessarily result in the optimum transportation model in terms of fuel cost and time.

The assumption that all staff begin and end their shifts at the site in Idaho Falls creates inefficiency as well. With a 100-mile radius for activities, crews at the extreme edge of the harvest area will commute 200 miles each day adding at least four hours of non-productive time to the schedule. In winter months and in areas where access is via secondary and gravel roads, the time will be even longer. Geographically dispersed operations yards with equipment and local crews should be considered within the harvest area. Towns such as Ashton, Driggs, and Pocatello at the mid point of the radius, 50 miles from Idaho Falls, are likely candidates.

Section 7—Baling Operations

This section describes the model bale size and normal farm operations for baling. Baling is part of the farmer's responsibility in this model and therefore the costs should be left out of the financial model. Any baling-related costs will be reflected in the negotiated price per ton of straw.

Section 8—Roadsiding Bales

This section describes the standard farm practices for baling straw and the optimized approach using select equipment based on test runs. It also develops the cost associated with the optimized equipment on an annualized basis. As stated in the section, the roadsiding operation is the responsibility of the farmer, as is the previous baling operation. As with the previous section, the costs for this operation should be reflected in the cost per ton of straw. While the optimized equipment approach is well researched and makes sense from an efficiency standpoint, it does not appear relevant to the model. There is no data presented here, or elsewhere, that indicates bales left in the field for a period of time are more prone to degradation than those in stacks so there would appear to be no reason for highly efficient stacking using specialized equipment. Coupled with this is the fact that stack collection will take place throughout the entire calendar year. The first straw required by the model will need to be stacked quickly and available for the grinding operation. The last straw collected will not be ground until the start of the following year's harvest. Given

that the supply to the refinery is a constant rate the median time between harvest and use is approximately six months. Each of the over 700 individual farms required in the model will handle their own roadsiding and, although inefficient from a model perspective, will undoubtedly meet the stacking requirements.

Section 9—Field Quality Assurance

This section describes the methodology and equipment required for collecting and analyzing straw samples in the field from bales. The equipment includes pickup trucks for Straw Buyers, which are already included in Section 3. The requirement to store 3 years of samples, which will be 6,000 samples, will require some kind of storage rack system with catalogue software to manage storage and retrieval.

Section 10—Inventory Management and Field Storage

This section describes the management of stacks in the field prior to grinding and contains detailed research information on weather impacts on stored bales. Several minor inconsistencies were noted in this section:

- The assumptions paragraph provides numbers which lead to an average yield of 1.875 tons/acre of straw, Section 4 specifies the production assumption is 1.71 tons/acre, and the narrative on the top of page 31 says 1.88 tons/acre, a range of almost 10 percent. Although the range of numbers can be used to conservatively estimate different requirements, it appears inconsistent without explanation.
- Similarly, the facilities paragraph specifies 1.4 acres of storage per 1,200 tons while Table 5 shows 1.12 acres for the same quantity.
- The cost analysis includes the bale insurance. This is included in the farmers' responsibility in the Contracts section and will be reflected in the price per ton of straw.

Section 11—Grinding Operations

This section describes in detail the in-field grinding approach using custom made Diamond Z mobile grinders. Fairly extensive field testing was done to optimize the grinder configuration in terms of particle size, energy consumption and bulk density. Several areas of the section require additional evaluation:

The number of grinders, seven, is based on production rates and full shifts. However, it is unlikely that any mechanical equipment can be available 100 percent of the time. In addition, the crew shifts start and stop at the site in Idaho Falls and, depending on grind location, there could be up to four hours of lost time in commuting. Therefore, it is not reasonable to expect the seven grinders can actually support the required output. It is also practical to have a spare available in the event there is a long-term outage on one of the production machines.

The time required to move grinders between sites will also detract from the theoretical production time. Since the grinders will be oversized loads, they will move in transport at lower average speeds than the straw hauling trucks. There are also multiple layers of requirements on moving oversized loads in addition to the permit requirement. After day light and winter hour movements may be restricted in some locations and some road

sections may have additional site specific requirements, all of which will detract from the theoretical grinding capacity.

The grinder cost does not appear to be included in the summary cost information for the grinder operation components although it does appear to be in the summary of installed capital costs. This should be clarified.

Section 12—Transporting Ground Feedstock

This section describes the operating scenario, equipment requirements, and cost of transporting the ground feedstock to the transfer site adjacent to the refinery. The approach seems well thought out, the only comment on this section is that over-the-road trucks, even though hauling agricultural products, are not qualified for fuel tax exemption.

Section 13—Weighing and Accounting

This section describes the assumptions, equipment and facilities for weighing the straw delivered to the transfer site. The technical approach is sound but we note that for a single weighing operation all of the transport vehicles will have to have a tare weight certification, adding slightly to the annual cost and record keeping effort. The approach is based on payment per ton of delivered straw, which is different from the contracting approach outlined in Section 3, which specifies payment per ton in windrows. Since tonnage in windrows can't be measured, it will have to be based on accepted yields per acre. If the payment approach is Section 3 is followed then the scales will not have to be certified and will be used for through put control and monitoring rather than accounting and payment.

Section 14—Unloading Ground Feedstock

This section describes the system planned for unloading trucks, transporting straw to interim storage and then on to the reactor throat. The system is based on conveyors to move the unloaded material from truck dump pits to top loaded silos and then bottom fed to the reactor. The narrative correctly points out that the low unit weight of the material to be conveyed creates a considerable sizing problem for the conveyance system. In order to meet the feed rate of the reactor in tons, the volumetric rate of material becomes very large. Although the researchers have found manufacturers showing models of conveyors that advertise moving the required quantities it is not clear that they will function as expected. The conveyors are built around moving grain, which has a much higher unit weight than the ground straw in transit. The En Mass conveyor systems specified are the logical approach. However, there is concern that the motor sizes used on these machines, coupled with the low unit weights will create the phenomenon of pulling the paddles through the material while leaving a large amount of the material moving much more slowly around and above the paddles. This will give a belt speed and theoretical rate that achieves the goal but in practice does not deliver the desired volume. A review of design standards and manufacturer guides found little precedence for such low unit weight material. Screw type conveyors would be preferred for the material characteristics but are size limited to achieve the required rates. There are no readily apparent answers to this problem but three potential approaches: manufacturers will have to be engaged to provide a custom design solution, the number of each conveyor will have to be increased or a positive air pressure conveyance system can be explored that may have capacity to move the volume required. Custom

design solutions could include use of belt conveyors, which will require more space but can be designed to greater unit rates per foot, or custom design of motor sizes with existing systems based on the unit rates required. This leaves the limiting factor the vertical bucket conveyors. Multiple conveying systems can reduce the rates per conveyor to something more standard but will take more room, additional unloading pits, modified silo loading and modified silo distribution. Air systems have the advantage of not needing mechanical belts and buckets, with attendant sizing problems, but would need to be evaluated for feasibility.

Section 15—Plant Quality Assurance

This section reviews the laboratory requirements for quality assurance testing. It makes use of the same lab equipment and staff as the field quality assurance described in Section 9. The approximately 500 hours a year for field testing and the approximately 500 hours per year for sample archiving should be added to the expected annual labor hours of the lab staff.

Section 16—Plant Feedstock Storage

This section describes interim storage at the site using cylindrical concrete silos coupled with the positive feed system provided by a eurosilo mechanism. The high bridging characteristics of the ground straw require a method of feeding the material through a silo other than gravity. Based on a literature review the eurosilo appears to provide this method. Storage in a silo minimizes space requirements, provides environmental control of the material and aides in the control of particulate matter during processing. However, a review of International Fire Code (IFC) requirements appears to limit the quantity of straw that can be stored in a silo or other structure to quantities far below the required amount, 2,500 cubic feet according to section 2904.6 (attached in appendix) as opposed to the planned 565,200 cubic feet. While the IFC treats grains as an explosive material it treats straw and hay as both explosive and combustible, therefore limiting the storage volume. However, the International Building Code appears to allow a storage facility under the S1 occupancy category if sprinkled. Coordination with local building officials in the jurisdiction will be required to properly interpret the sections.

An alternate plan, not included in the report but provided in sketch form by the authors, eliminates the use of silos. This alternative uses bulk bale storage on site with multiple tub grinders to direct feed the reactor. There appear to be multiple advantages to this approach, the bale stack configuration is compliant with IFC requirements, the expensive concrete silo with eurosilo system is eliminated, the problematic conveyor system for the unloading process is mostly eliminated and fewer total grinders are required. Offsetting those advantages are the additional space requirements, about 19 acres, with attendant increases in paving, fencing and security requirements. This alternative also loses the advantage provided by field grinding in the environmental permitting area. Control of PM 2.5 and PM 10 particulate pollution will require extensive effort to meet air quality requirements and most likely will not be able to stay below the minor source limit of 100 tons per year. The 19 acre storage area will also require additional stormwater control measures and add snow removal and management expense to the operation. A second alternative could be evaluated using an open storage pit, or pits, and auger type conveyors to feed the reactor. This would require some evaluation of the impacts of wind, rain and snow on ground straw

or use of a pole barn type structure that provides some protection while not enclosing the storage mass.

Section 17—Storage to Reactor Transportation

This section describes the methodology for transporting ground straw in interim silo storage to the reactor. En Masse conveyor systems are proposed here as with Section 14. Similar problems are anticipated in this process step in matching transfer rates to conveyor technology. The approach to addressing these issues is the same as in Section 14.

Section 18—Management Systems

This section describes the organization structure of the enterprise and was not reviewed for technical detail.

Section 19—Permitting

No information was included in this section. Environmental permitting considerations are addressed in this report in another section.

Section 20—References

No review performed.

Section 21—Appendices

No review performed.

Additional Review Areas

1. Dust Control

With grinding done in the field by mobile grinding equipment there will be a greatly reduced dust control requirement at the facility. Grinding straw in a field is considered a fugitive emission source. The source is considered fugitive because of an open environment process in which particulate emissions do not pass through a common stack or vent. Grinding straw on-site would likely be performed inside an enclosed structure or a closed environment process in which emissions would pass through building vents. A stationary source is defined as *any building, structure, facility, emissions unit, or installation which emits or may emit any air pollutant. Fugitive emissions shall not be considered in determining whether a permit is required unless required by federal law (IDAPA 58.01.01.006.100).* An air quality Permit-to-Construct is only required for stationary sources.

The off-loading process from pit dumping of the trucks though the conveying system into and out of the silos will produce straw dust. The conveying process is entirely enclosed, which effectively eliminates the need for additional controls. The truck unloading area will be the single point of potential particulate pollution and will require a covered operation with a baghouse structure to ensure that particulate levels stay below the 100 tons per year requirement for minor source status. There is no base line data for estimating straw dust from the unloading process so it is difficult to estimate the size of the required unit. Based

on total tonnage of straw, 800,000 tons per year, an enclosed baghouse structure will cost on the order of $500,000.

2. Financial Escalators

The financial model attached to the report made use of a number of indices for adjusting costs for future years, including data from the Bureau of Labor statistics and Chemical Engineering magazine for labor costs and plant operational costs. No escalators were provided for construction because the actual site construction was not covered in this report. Attached in the summary cost report are costs for basic building and site construction in 2006 dollars. Because of the volatility of the construction materials market over the past two years it is recommended that forward pricing of construction services and materials be based on a local data base rather than a national one. The American General Contractors (AGC) branch in Idaho is the best source for near and mid term forecasting of construction related expenses. Electricity prices in Idaho have been fairly stable for many years and typically never outstrip the rate of general inflation as measured by the CPI. Fuel prices are the most unstable elements of the model and do not have a good index for forward pricing based on today's market. Fuel cost assumptions should be revisited when the model is finalized.

3. Fire Protection

Fire protection for the receiving facility, covering operations from the gate to the reactor throat were not included in the report. The theoretical site footprint was developed in Paragraph 6, Footprint.

The recommended fire protection design consists of a 300,000 gallon fire tank with a 2,000 gpm diesel powered fire pump. A valve house adjacent to the tank houses the pump and valves. The system has an 8-inch ductile iron header run underground. The header serves four above ground hydrants around the processing area on a maximum spacing of 300 feet. The silos and all conveyors are equipped with spray nozzles and the buildings with standard sprinkler protection. Costs for building sprinklers are captured in the building cost estimates. The installed cost of the fire protection system in 2006 dollars is estimated at $657,500. See Project Cost Estimate Reports attached. Given the proximity to town and the added difficulty of having a small fuel tank for non-diesel vehicles it is recommended that none be provided.

4. Fuel Depot

An on-site fuel depot will be required for the fleet of straw hauling trucks. There are 28 trucks in the model, averaging 6 miles per gallon fuel efficiency. Based on the trip scenario described in Section 12 the truck fleet will drive 17,290 miles per day over the two shift operation, consuming 2,882 gallons of fuel per day. Typical on-site depots are sized based on fleet consumption and standard fuel delivery quantities. A standard fuel delivery module is 10,000 gallons and the weekly consumption of the fleet is approximately 20,172 per week so the planned depot will be a 10,000 gallon above ground storage tank with delivery system. Two bulk deliveries per week will be required. The total estimated cost for the above ground tank and delivery system in 2006 dollars is $100,000. See Project Cost Estimate Reports attached.

5. Fuel Contract

Critical to the field grinding scenario is in-field fueling of the grinders and support equipment. A grinding team consists of a grinder and a bale loader. Between them they consume 408 gallons per 16 hour day or 2,856 gallons for the operation. In field fueling services are typically provided on a price per gallon basis with the service charge built into the unit price. Fuel is delivered in 2,000 or 10,000 gallon tankers and the larger tankers expect to fuel day tanks rather than equipment. Since the built in tanks on the equipment may not support a single fueling per day, larger day tanks would have to be provided as part of the support equipment. Prices checked with suppliers in eastern Idaho in late summer 2006 ranged from $2.959 to $3.00 per gallon with all costs factored in.

6. Footprint

Since no site layout was provided an assumed footprint for the site was developed using the following site elements.

Element	Space
Employee parking for 110 vehicles	39,600 ft^2
Maintenance shop	3,200 ft^2
Office	3,520 ft^2
Lab	2,000 ft^2
Silos	15,700 ft^2
Fuel Depot	3,200 ft^2
Truck unload, scales, pit access/egress road	40,000 ft^2
Truck, trailer and equipment parking/storage	33,600 ft^2
Setback & Circulation	49,000 ft^2
Total	189,820 ft^2

The itemized features of the site total 4.4 acres. For a conservative approach to sizing fire protection and fencing a 5-acre site was selected as the default.

For a site this large, with a small amount actually covered by structures it is probably not cost effective to pave the entire site. The cost of preparing the site with a designed gravel surface is about 57 percent of the cost of paving. With a paved site the stormwater runoff quantity will be far greater than with an unpaved area, leading to much higher costs for stormwater detention basins. A more practical approach would be to pave the employee parking lot and areas around the buildings and fueling depot, leaving the rest as a gravel pad. This provides good wear in the high traffic areas while minimizing costs and runoff concerns in the rest of the site.

7. Lighting

Lighting for the facility was not included in the report. For sizing the lighting requirements the same site footprint was used as developed in the fire protection review. Outside operations at the site are primarily limited to unloading the trucks and refueling as needed. During non-daylight hours the lighting level will be sufficient for general navigation and safety but will not provide task level intensities. Lighting was broken into four areas at the site, parking area, equipment areas, open areas and localized. The parking area is supported by mast mounted lighting typical for public parking, lighting around equipment is sufficient for safety and security purposes, lighting in open areas is provided by mast mounted lights at less intensity than parking and localized lighting at silos, unloading area and fuel pumps will have to be designed for each task. The total cost for the site lighting in 2006 dollars is approximately $96,200. See Project Cost Estimate Reports attached.

8. Security

Security systems were not included in the report. The 5-acre site model developed for fire protection was used for the security estimate. Based on sites with similar purpose and features a security plan calling for an 8-foot chain link fence topped with three strands of barbed wire is proposed. The fence will have a single motorized 20-foot vehicle gate at the main entrance and two personnel gates at various locations. Supplementing the fencing will be a camera system that provides coverage of the gates, fence line and key work areas such as the fueling station, unloading pits and silos. The cameras will be monitored from two locations, probably the main gate house and an office space in the office building. There will also be a recording system to archive security film. The total estimated installed cost of fencing, gates and camera system in 2006 dollars is $141,550. See Project Cost Estimate Reports attached.

9. Employee Parking

The enterprise model assumes a staff of between 100-110 employees per shift with all employees starting the work shift at the site. Therefore, parking has to be provided for approximately 110 vehicles. This parking is assumed to be separate from short term parking adjacent to the office and other buildings, which is included in the building design. Based on a standard 360 square foot per vehicle allowance for sizing parking lots the required lot size will be 39,600 square feet or approximately 1-acre. This sizing factor provides allowance for the individual parking slots and circulation within the parking lot. The parking lot can either be an improved gravel lot or a paved one. Gravel has a lower installed cost but presents problems when snow removal is required and generally requires more routine maintenance than a paved lot. For a 1-acre parking lot in 2006 dollars paving would cost approximately $170,000 and gravel only would cost approximately $97,000.

10. Electrical Loads

The proposed facility concept is fairly simple with minimal processing steps. The electrical load for the facility consists almost entirely of large electric motors on the conveyance systems. Based on the equipment described in the report the facility would most likely be designed for 1000 kVA service from the local utility. For purposes of this review it is assumed that the facility is located within the Idaho Falls city limits and the utility is Idaho

Falls Power. Service would be provided by direct feed from the closest distribution line. Because the rate of delivery is critical to meeting plant demand the facility should have either a loop feed to prevent isolated power outages taking the plant down or a back up diesel generator system. Given the reliability of the local system, based on historic availability numbers, the expense of a backup system is not recommended. The loop feed will provide a level of redundancy except in the case of a city wide black out, which is historically unlikely. The order of magnitude construction cost for 1000 kVA service, including transformer, switchgear and distribution system in 2006 dollars is $200,000.

11. Environmental Permits

Siting new industrial facilities in Idaho requires a review on environmental permits, which was not done in the report. The primary permit of concern for all facilities is an air permit. Air permits fall into three primary categories: minor source, major source and Permit of Significant Deterioration (PSD). The cost and complexity of each type of permit goes up with the level. The advantage to the enterprise model is that it has grinding done off-site as part of the harvesting operation, which is exempt from air permitting requirements. Since there is no other processing involved on the site other than straw transfer the only pollutant of concern is the small amount of particulate matter from the unloading and transfer of the ground straw, which is inherently dusty. An enclosed unloading point with baghouse is proposed and the conveyance scheme consists entirely of enclosed conveyors so the expectation is that this plant will be sited as a minor source, less than 100 tons per year. There is no appreciable use of water on the site so no waste water discharge, other than normal municipal connection requirements is expected. With a five acre site and fueling depot a Stormwater Pollution Prevention Control (SPPC) plan will be required. These are typically done as part of the site design and consist of design and operational elements that ensure stormwater does not enter surface waters of concern. The fuel tank system will be required to have a secondary containment design that ensures no leaks can follow the stormwater path. A list of typical environmental permits is attached in the appendix.

12. Shift Schedule

The enterprise model from field grinding though delivery to the storage system is based on two back to back eight hour shifts, with half hour lunch breaks in each. The portion of the model that feeds the reactor is expected to be three 8-hour shifts per day. However, the limited number of tasks required on the plant side may allow use of automation to the point that the third shift is not required. Plant production models often make use of 24-hour day shift work to minimize capital equipment investment. However, numerous studies correlate work on late shifts with decreased productivity and increased safety problems. This trend is exacerbated by shifts with relatively few work breaks. See attached report in Appendix. With the expected storage volume in the model there is no strong driver for a 24-hour approach to the field processing work. In addition there are practical limits to such activities. The noise and light pollution from night time operations would be an annoyance to straw suppliers whose bales were near their farm residences and to non-farm residences in the effected area. While the Right-to-Farm law in Idaho allows such activities it still causes frequent problems in areas where farm land abuts residential developments. The extended use of an overtime schedule is also problematic. Workers can typically adjust to periods of 6-day week work but a regularly scheduled 6-day week for the full year is harder

to accept. A cost trade off should be done to evaluate the impact of adding another grinder and dropping the Saturday shift. This also fits the field fueling model better as some suppliers have indicated they don't deliver on the weekends.

13. Waste Streams

Waste streams at the facility were not evaluated in the report. The enterprise as described in the report does not process or manufacture anything, it transports product through an interim storage point to the processing location. Waste streams from processing therefore are non-existent. That being said, all sites have the potential to generate waste streams of some type. At this site the waste stream falls into four general areas: particulate air pollution; stormwater runoff; fuel leaks and laboratory chemical waste. Air pollution and stormwater are discussed in the environmental permit section and fuel leaks are covered in the SPPC plan. The laboratory on site has a number of chemicals in storage and use as part of the testing program. A list of chemicals and quantities is attached. A review of these chemicals and quantities against the reporting requirements indicates that the levels are below reporting thresholds. However, during laboratory design the actual on-hand quantities will need to be determined for a final determination on reporting. Reporting of lab chemicals is a normal part of lab operations and not considered an environmental permitting issue.

Areas of Concern

There are five areas of primary concern with the enterprise as described in the report "A Model for a Lignocellulosic Biomass Feedstock Assembly System for Wheat and Barley Straw."

1. The model assumes the ability to capture approximately 90 percent of the straw available in the target area, a 100-mile radius of Idaho Falls, ID, and 88 percent of the market in eastern Idaho. This concern is actually independent of the enterprise model and applies directly to the reactor. With the dairy industry already consuming approximately 50 percent of the available straw in eastern Idaho the projected demand is 138 percent of supply. In a classic supply vs. demand scenario this condition will result in higher unit costs for the raw material. In addition, the ethanol model requires farmers to maintain the feedstock for up to a year, provide all weather access, be responsible for meeting quality requirements and reporting their farming plans each year. The competing dairy industry will require none of these, potentially making them look more attractive, even at a slightly lower price.

2. The logistics of moving the required volume of straw are daunting. Assumptions related to the quantity of equipment required and amount of work that can be done each shift may be optimistic. The difficulty of accessing some of the stockpiles in winter months, problems moving oversized loads, loss of productivity due to crew commute times and unplanned equipment downtime all indicate a more conservative approach to how much equipment is required to move the 800,000 annual tons from field to transfer site.

3. An initial review of the International Fire Code (IFC) suggests that storing the desired amount of ground straw is not possible in silos or other enclosed spaces. However, the International Building Code, which should work in conjunction with the IFC, would

appear to allow for sprinkled storage under building occupancy code S1. Interpretation assistance will be required from local jurisdictions.

4. The conveyor scheme planned for unloading the trucks and transferring feedstock into and out of storage may not be practical. This is a special circumstance outside the realm of experience of plant process engineers and requiring custom design analysis by conveyor manufacturers.

5. Field fueling services operate most efficiently in large unit quantities. In order to ensure that field fueling can be done economically the grinding equipment may need to have day tanks added so that only one fueling operation is done per day at each site. Day tanks would have to have 16 hours of fuel. Additionally, several of the service providers indicated that they only work five days a week.

Recommendations

Four specific recommendations have been developed as a result of the foregoing review:

1. Revisit the expected price per ton of straw as a result of higher demand.

2. Revise the enterprise model to allow for distributed equipment yards, allowing grinding equipment and employees to be closer to the field locations and eliminated part of the long daily commute between the Idaho Falls site and grinding sites.

3. Revise the total quantity of grinders, balers and trucks in the model to allow for unscheduled outages.

4. Look at alternates to the Eurosilo interim storage concept. This will eliminate the fire code issue with storage and may also alleviate the conveyor problem between unloading and supply.

Appendix A

CLIENT:	**Grant 4D**	**CH2M Hill**	PRINT DATE: 15-Sep-2006
PROJECT:	**Straw Storage**	**LOCKWOOD GREENE**	09:34:46
LOCATION:	**Idaho Falls, Idaho**	**PROJECT COST ESTIMATE - ORDER OF MAGNITUDE**	31 Area Summary (4.1)
JOB NO:	**347973**	**AREA SUMMARY REPORT**	
BY:	**SJK**		
EST. DATE:	**9/13/06**		
REV.			

CODE	DESCRIPTION	MATERIAL	LABOR HOURS	LABOR RATE	LABOR	CONST EQUIP	SUBCONT	PREPURCH EQUIP	TOTAL
	Project	$0			$0	$0	$1,587,250	$0	$1,587,250
02	Sitework	$0			$0	$0	$853,400	$0	$853,400
	Fencing	$0			$0	$0	$95,900	$0	$95,900
	Fire Protection	$0			$0	$0	$657,500	$0	$657,500
	Fuel Station	$0			$0	$0	$100,000	$0	$100,000
13	Special Construction	$0			$0	$0	$592,000	$0	$592,000
	Administration Building	$0			$0	$0	$304,000	$0	$304,000
	Maintenance Building	$0			$0	$0	$288,000	$0	$288,000
16	Electrical	$0			$0	$0	$96,200	$0	$96,200
	Site Lighting	$0			$0	$0	$96,200	$0	$96,200
27	Instrumentation	$0			$0	$0	$45,650	$0	$45,650
	Site Security	$0			$0	$0	$45,650	$0	$45,650
	DIRECT COST						$1,587,250		$1,587,250

Appendix B

CLIENT:	**Grant 4D**	**CH2M Hill**		PRINT DATE: 15-Sep-2006
PROJECT:	**Straw Storage**	**LOCKWOOD GREENE**		09:36:21
LOCATION:	**Idaho Falls, Idaho**	**PROJECT COST ESTIMATE - ORDER OF MAGNITUDE**		31 Area Unit Detail (4.1)
JOB NO:	**347973**	**AREA DETAIL REPORT**		
BY:	**SJK**			
EST. DATE:	**9/13/06**			
REV.				

CODE	DESCRIPTION	QTY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR HOURS	LABOR RATE	LABOR	CONST EQUIP	SUBCONT UNIT	SUBCONT TOTAL	PREPURCH EQUIP	PREPURCH TOTAL
02 Sitework														
Fencing														
01	***FENCING***	0		$0.00	$0	0			$0	$0	$0	$0	$0	$0
01	Fencing Around Site, 8' High, 3 Strands Barb Wire	2100	LF	$0.00	$0	0			$0	$0	$42	$88,200	$0	$88,200
01	Gate, Sliding, Motorized, 20' Wide	1	EA	$0.00	$0	0			$0	$0	$6,500	$6,500	$0	$6,500
01	Gate - Personnel	2	EA	$0.00	$0	0			$0	$0	$600	$1,200	$0	$1,200
				SUBTOTAL	$0.00				$0	$0		$95,900	$0	$95,900
02 Sitework														
Fire Protection														
02	***FIREPROTECTION***	0		$0.00	$0	0			$0	$0	$0	$0	$0	$0
02	Excavation/Backfill	1480	CY	$0.00	$0	0			$0	$0	$16	$23,680	$0	$23,680
02	Storage Tank, 300,000 gal	1	EA	$0.00	$0	0			$0	$0	$310,000	$310,000	$0	$310,000
02	Diesel Pump, 2000 gpm	1	EA	$0.00	$0	0			$0	$0	$75,000	$75,000	$0	$75,000
02	Pump House	800	SF	$0.00	$0	0			$0	$0	$100	$80,000	$0	$80,000
02	Valve House	96	SF	$0.00	$0	0			$0	$0	$120	$11,520	$0	$11,520
02	Valves, Backflow Preventer, Shut Off Etc.	1	LS	$0.00	$0	0			$0	$0	$12,000	$12,000	$0	$12,000
02	8" Pipe, U/G, D.I.	1800	LF	$0.00	$0	0			$0	$0	$48	$86,400	$0	$86,400
02	8" Pipe, U/G, D.I.	18	EA	$0.00	$0	0			$0	$0	$550	$9,900	$0	$9,900
02	8" Post Indicater Valves	5	EA	$0.00	$0	0			$0	$0	$2,500	$12,500	$0	$12,500
02	8" Fire Hydrant	6	EA	$0.00	$0	0			$0	$0	$2,400	$14,400	$0	$14,400
02	Pipe, Make Up Water	100	LF	$0.00	$0	0			$0	$0	$40	$4,000	$0	$4,000
02	Fire Protection Silo's	2	EA	$0.00	$0	0			$0	$0	$5,000	$10,000	$0	$10,000
02	Fire Protection Conveyors	200	LF	$0.00	$0	0			$0	$0	$23	$4,600	$0	$4,600
02	Electrical	1	EA	$0.00	$0	0			$0	$0	$3,500	$3,500	$0	$3,500
				SUBTOTAL	$0.00				$0	$0		$657,500	$0	$657,500

CODE	DESCRIPTION	QTY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR HOURS	LABOR RATE	LABOR	CONST EQUIP	SUBCONT UNIT	SUBCONT TOTAL	PREPURCH EQUIP	PREPURCH TOTAL
02 Sitework														
Fuel Station														
02	10,000 gal Fuel Tank, 60 gpm Pump, & Dispensing Equipment.	1	LS	$0.00	$0	0			$0	$0	$100,000	$100,000	$0	$100,000
			SUBTOTAL		$0.00				$0	$0		$100,000	$0	$100,000
13 Special Construction														
Administration Building														
13	Aministration Building	3200	SF	$0.00	$0	0			$0	$0	$95	$304,000	$0	$304,000
			SUBTOTAL		$0.00				$0	$0		$304,000	$0	$304,000
13 Special Construction														
Maintenance Building														
13	Maintenance Shop	4800	Sf	$0.00	$0	0			$0	$0	$60	$288,000	$0	$288,000
			SUBTOTAL		$0.00				$0	$0		$288,000	$0	$288,000
16 Electrical														
Site Lighting														
16	Lighting - Parking Area 65,340SF	7	Pls	$0.00	$0	0			$0	$0	$5,800	$40,600	$0	$40,600
16	Lighting - Around Equipment	3	Pls	$0.00	$0	0			$0	$0	$5,800	$17,400	$0	$17,400
16	Lighting - Open Areas Of Site	4	Pls	$0.00	$0	0			$0	$0	$5,800	$23,200	$0	$23,200
16	Lighting - Localized - Top Of Silo's, Unloading, & Fuel Pumps	1	LS	$0.00	$0	0			$0	$0	$15,000	$15,000	$0	$15,000
			SUBTOTAL		$0.00				$0	$0		$96,200	$0	$96,200

CLIENT:	**Grant 4D**	**CH2M Hill**		PRINT DATE: 15-Sep-2006
PROJECT:	**Straw Storage**	**LOCKWOOD GREENE**		09:36:21
LOCATION:	**Idaho Falls, Idaho**	**PROJECT COST ESTIMATE - ORDER OF MAGNITUDE**		31 Area Unit Detail (4.1)
JOB NO:	**347973**	**AREA DETAIL REPORT**		
BY:	**SJK**			
EST. DATE:	**9/13/06**			
REV.				

CODE	DESCRIPTION	QTY	UNIT	MATERIAL UNIT	MATERIAL TOTAL	LABOR UNIT	LABOR HOURS	LABOR RATE	LABOR	CONST EQUIP	SUBCONT UNIT	SUBCONT TOTAL	PREPURCH EQUIP	PREPURCH TOTAL
27 Instrumentation														
Site Security														
27	***SECURITY-EXTERIOR ONLY***	0		$0.00	$0	0			$0	$0	$0	$0	$0	$0
27	Camera	7	EA	$0.00	$0	0			$0	$0	$850	$5,950	$0	$5,950
27	Monitor	2	EA	$0.00	$0	0			$0	$0	$675	$1,350	$0	$1,350
27	Hardware, DVR Recorder, Set & Test	1	LS	$0.00	$0	0			$0	$0	$8,200	$8,200	$0	$8,200
27	Wire, Conduit, Trenching, Etc.	4500	LF	$0.00	$0	0			$0	$0	$7	$30,150	$0	$30,150
			SUBTOTAL		$0.00				$0	$0		$45,650	$0	$45,650
			DIRECT COST									$1,587,250		$1,587,250

Appendix C

Permit Type	Requirement	Agency	Format/Req'd Info	Prep Time	Typical Review Time	Project Timing	Est. Cost [1]	Analysis
EIS	NESHAP	EPA		>1 Year	>1 Year	Prior to starting construction	N/A	Not required. Only in cases of public funding or use of public lands.
Air Quality Construction Permit	IDAPA 58.01.01.200 et al – requires a permit to construct be issued for any stationary source, prior to commencement of construction.	EPA/IDEQ	Contents of the permit application are described in IDAPA 58.01.01.202. Two basic parts – IDEQ application forms and descriptive support documentation. A general list of application follows: Site information, plans, descriptions, specifications, and drawings showing the design of the stationary source, facility, or modification, the nature and amount of emissions and the manner in which it will be operated and controlled. Estimates of ambient concentrations of criteria and toxic pollutants based on the applicable air quality models. Must demonstrate compliance with: 1) all applicable local, state or federal emission standards; 2) national ambient air quality standards (NAAQS); and, 3) applicable toxic air pollutant carcinogenic increments and toxic air pollutant non-carcinogenic increments.	Approximately 30 days including air modeling, internal reviews, etc. Note that this assumes the facility design is set. Changes in facility design and operations will delay the completion of the application. Assumes plant will not be a major facility.	Regulatory timeframe is 30 days for a completeness review and then 60 days for technical review (IDAPA 58.01.01.209. Delays may occur if additional application data is required by the IDEQ. Assumes plant will not be a major facility. (Backlogs in Idaho have created review times up to 6 months)	Permit to construct must be received prior to commencement of construction (defined as physical on-site construction activities which are of a permanent nature (IDAPA 58.01.01.006.20). Note that there are other regulatory options for minor sources that may allow construction before a permit to construct is issued.	IDEQ just implemented permit application fees. Assuming plant is a minor source, fees are as follows: Application Fee: $1,000 Processing Fee: $5,000 Preparation Est. $15,000 to $50,000	Based on our experience with other malting facilities in Idaho the plant can be designed to ensure that it is considered a minor source (synthetic) which greatly simplifies the construction and operating permits.
Air Quality Operating Permit	IDAPA 58.01.01.400 et al – Assumes the facility will be a minor source (synthetic) and therefore need a Tier II Permit.	EPA/IDEQ	No separate application will be required, the PTC application is comparable and will be used (compare IDAPA 58.01.01.202 & 58.01.01.402). Note that a Tier II operating permit application is required for existing sources. The IDEQ will issue a Tier II Operating Permit for the facility at a later date.			Prior to starting commercial operation		Assume that the facility will be a minor source (synthetic) and therefore not be required to have a Tier I Permit.
Drinking Water Connection	City Code, Section 8-4-11	City of Idaho Falls	Simple permit with expected consumption, address etc.	1 day	2 weeks	Prior to connection	$750 - $1,000	Service connection fee and meter agreement required.
Fire Service Connection	City Code, Section 8-4-40	City of Idaho Falls	Detailed plans of fire service piping, pumps, etc. in plant.	1 week following design completion	2 weeks	Prior to connection	$2,000 - $4,000	All fire service connections between water mains and property lines shall be installed and maintained by City at expense of the Owner.
Water Rights	Idaho State Law	IDWR	Standard form indicating ownership, location, quantity etc.	1 day	1 month	Prior to well drilling	$3,000	May not be required
Proof of Beneficial Use	Idaho State Law	IDWR	Test following commercial operation showing actual quantities used versus quantities asked for.	1 week following full operation	1 – 2 weeks	After commercial operation	$1,000	May not be needed depending on restrictions placed in water right.
Well Construction Permit	IDWR Policy	IDWR	Standard form and submittal of design drawings for well construction, lining, pumps, tanks etc. Must comply with state standards.	1 week	1 – 2 weeks	Prior to well construction	$1,000	Always required but not complicated.
Waste Water Discharge	Idaho Falls Ordinance 2223 & 2357, 12/22/99 Section 8-1	City of Idaho Falls	Simple permit with description of discharge type, quantity and timing, if any. Design detail of connection.	1 week once design parameters are established.	2-4 weeks	Prior to connection	$1,000	Very detailed requirements in City Code. Nature of effluent influences application process, i.e. – whether or not pre-treatment is required etc.
Stormwater Pollution Prevention Plan (NPDES)	Clean Water Act (33 U.S.C. 1251)	EPA	Notice of Intent (NOI), 1-page permit application. Stormwater Pollution Prevention Plan (SPPP) detailing engineering controls during construction.	NOI - 1 day, SPPP – 1 week after basic design is established	NOI - N/A SPPP – 2-4 weeks	48 hours prior to start of construction	$2,000	Required on all sites of 5 acres or more.

Permit Type	Requirement	Agency	Format/Req'd Info	Prep Time	Typical Review Time	Project Timing	Est. Cost [1]	Analysis
Sewer Connections	Idaho Falls Ordinance 2223 & 2357, 12/22/99 Section 8-1	City of Idaho Falls	Simple permit with description of discharge type, quantity and timing, if any. Design detail of connection.	1 week once design parameters are established.	2-4 weeks	Prior to connection	$1,000	Covered by wastewater permit.
Spill Prevention (SPCC)	40 CFR, Part 112	EPA/IDEQ	Standard template. Includes site description, materials description, design and operational controls to prevent spills from reaching waters.	2 weeks	2 months	Required prior to commercial operations	$5,000	
Waste Management Commercial Waste Landfill Waste	 City Code 8-6-10 Variable	 City of Idaho Falls Landfill Operator	 Simple request for service for commercial waste service. Variable	 1 day Variable	 1 week Variable	 Prior to starting service Prior to starting service	$1,000 - $10,000	Commercial waste is a simple contract with City Sanitation Department. Landfill material depends on quantity and nature of waste and is negotiated with landfill operator.
Planning & Zoning/Land Use	City code 10-3-1, Ordinance 2224	City of Idaho Falls	Description of property, use and impacts including traffic, number of employees and visual impacts both during construction and operations.	1 month	1 month or more depending on community reaction	Prior to starting construction	$2,500 - $10,000	
Construction Impacts	City Code	City of Idaho Falls	Contained in Planning and Zoning application			Prior to starting construction	Included above	This area will be covered in the Planning & Zoning approval process.
Easements	State Law	Landowners				Prior to starting construction	Unable to estimate	Public Right of Way is governed by City Ordinance, 8-7-5.
Building Permits	City Code	City of Idaho Falls	Numerous standard forms with design drawings as supporting documentation.	2 weeks following development of sufficient design detail.	2 weeks	Prior to starting construction	$4,000	
Siting & Utilities	City Code 8-5-5	Idaho Falls Power	Plans showing conformance to IFP standards, Uniform Building Code, Fire Codes, etc.	1 week after sufficient design detail is established	1 –2 weeks	Prior to connection	$3,000	
Railroad Spur								
Construction in navigable airspace	49 CFR Part 77	FAA	Plans showing location of construction, height above ground. FAA Form 7460-1.	1 week after final design is established	30 days	30 days prior to construction	$1,500	Only required if any part of construction is >200' tall.
Access to highway								
Runoff/grading	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Covered by NPDES Permit

Notes:

1 Cost are estimated based on typical scenarios. Many items can vary considerably depended on complexity or permit request, amount of coordination with granting agency and other issues.

2 Construction projects in Idaho Falls are covered by Idaho Falls Code of Ordinances, which has adopted by reference the following standard codes:

- Building Code – Uniform Building Code (International Conference of Building Officials)
- Administrative Code – Uniform Administrative Code (International Conference of Building Officials)
- Mechanical Code – Uniform Mechanical Code (International Conference of Building Officials)
- Electric Code – National Electrical Code (National Fire Protection Association)
- Fire Code – Uniform Fire Code (International Fire Code Institute)
- Energy Code – Model Energy Code, 1986 Edition (Council of American Building Officials)
- Building Conservation Code – Uniform Code for Building Conservation (International Conference of Building Officials)
- Each referenced code has local modifications described in City Ordinances. CH2M HILL will ensure all referenced ordinances are followed in the design of the plant buildings and equipment, including third party equipment from Seginsa.

Appendix D

Occupational Medicine 2003;**53:**95–101
DOI: 10.1093/occmed/kqg047

IN-DEPTH REVIEW: SHIFT WORK

Shift work, safety and productivity

Simon Folkard and Philip Tucker

Abstract The arguments in favour of introducing shift work clearly depend on productivity and safety being maintained at an acceptable level. However, the evidence reviewed in this paper clearly indicates that both productivity and safety may be compromised at night. More specifically, safety declines over successive night shifts, with increasing hours on duty and between successive rest breaks. The only known way to minimize these problems is to improve shift systems with respect to these factors. However, these factors need to be considered in combination with one another since, for example, a long night shift that includes frequent rest breaks might well prove safer than a shorter night shift with less frequent breaks.

Keywords Circadian rhythms; fatigue; performance; productivity; safety; shift work; sleep.

Received 1 December 2002

Revised 1 January 2003

Accepted 1 February 2003

Introduction

Efficiency and safety on shift systems is a topic of major concern for two main reasons. First, a number of 'headline' incidents, such as Bhopal, Three Mile Island, Chernobyl, the Rhine chemical spillage and the Exxon Valdez, all occurred at night, and have drawn attention to both the risk and cost of impaired safety on shift systems. Secondly, shift work is frequently introduced for purely economic reasons in order to maximize the use of costly equipment. While many shift work researchers would argue that this practice should be discouraged in view of the health and well-being costs to the individual shift workers, the economic arguments in favour of introducing shift work clearly depend on productivity and safety being maintained at an acceptable level. An impairment of individuals' performance efficiency on a shift system may thus seriously undermine any potential economic benefit derived by introducing it.

'Real-job' trends in productivity

Unfortunately, the direct study of productivity and safety on shift systems is fraught with problems. As regards productivity, both the number of people at work and the nature of their work often vary across shifts, with, for example, 'long runs' frequently being saved for the night. Supervision is normally reduced at night, and there may be no maintenance personnel available to ensure that equipment is running efficiently. Despite these complications, three early published studies managed to obtain relatively continuous, 'real-job' measures of speed or accuracy over the 24 h day covered by a variety of continuous shift systems, and these showed similar trends to one another. The precise measures obtained in these three studies varied considerably. They were: (i) the delay in answering calls by switchboard operators [1]; (ii) errors in reading meters [2]; and (iii) the time taken by 'spinners' to tie broken threads in the textile industry [3]. The averaged results from these studies (based on Z scores) are shown in Figure 1 in order to give an 'overall picture' of the effect of time of day.

Two major points emerge from inspection of this figure. First, there was a relatively massive 'dip' in these efficiency measures during the course of the night shift, i.e. from ~22:00 h to 06:00 h, with the trough occurring at 03:00 h. Indeed, these measures had fallen below average levels (i.e. below a mean Z score of zero) by 23:00 h and did not climb back up to average until after 06:00 h. Secondly, there was clear evidence of a secondary 'dip' in the measures shortly after 12:00 h. This secondary dip has commonly been described as the 'post-lunch' dip, although close inspection of Figure 1 suggests that these measures started to decline considerably earlier than normal lunch times, i.e. from ~10:00 h. Indeed, there is

Body Rhythms and Shiftwork Centre, Department of Psychology, University of Wales Swansea, Swansea SA2 8PP, UK.

Correspondence to (current address): S. Folkard, Laboratoire d'Anthropologie Appliquée, UPRES Ergonomie, Université René Descartes-Paris V, 45 rue Saints-Pères, F-75006 Paris, France. E-mail: S.Folkard@Swansea.ac.uk

© Society of Occupational Medicine; all rights reserved

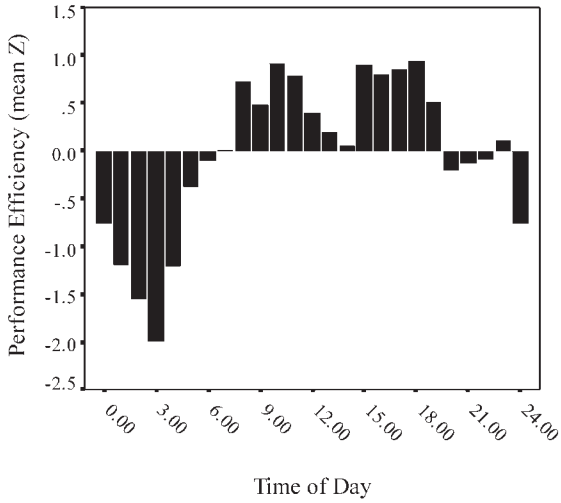

Figure 1. Industrial performance efficiency over the 24 h day.

reasonably good evidence that this 'post-lunch' dip is only partially dependent on the ingestion of food [4]. An alternative way of viewing the results shown in Figure 1 is that these 'real-job' speed and accuracy measures are only above average between 07:00 h and 19:00 h, at all other times efficiency is likely to be relatively impaired, especially so during the early hours of the morning.

There appear to be few other studies of productivity on shift systems that have successfully overcome the problems of differences in the workforce or work practices. However, an extremely carefully controlled study by Vidacek *et al.* [5] examined the number of capacitors produced by individuals in an electronics component factory over five successive, 8 h, morning, afternoon and night shifts. This particular job demanded a very high level of manual dexterity and was extremely repetitive, with the workers concerned each producing an average of >100 capacitors per hour. As might be expected from Figure 1, overall productivity was highest on the afternoon shift, and was on average ~5% lower at night. However, there was also clear evidence of an interaction between the type of shift and successive shifts. Productivity on the morning and afternoon shifts was relative constant across the five successive shifts, while that on the night shift rose substantially over the first three nights but then declined slightly over the subsequent night shifts. Clearly, there is a need for further studies of productivity in this area to determine whether the trends obtained in this study hold good for other work situations.

'Real-job' trends in safety

Unfortunately, as indicated above, in many industrial situations, the a priori risk is not constant across the day and night. This means that accident or injury rates often cannot be legitimately compared across the shifts since fewer 'incidents' might be expected on the night shift. (Note that the term 'incidents' is used from here on to refer to both accidents and injuries.) Indeed, even in those few industrial situations where the a priori risk of incidents would appear to be constant across the 24 h day, there remains the problem that the probability of actually reporting an injury or accident that occurs may vary. Thus, for example, in a recent unpublished study of injury rates in an engineering company, where the a priori risk of injuries appeared to be constant, we discovered that substantially fewer injuries were reported on the night shift than during the day. Further investigation revealed that when members of the predominantly male workforce reported an injury during the day, they were treated by a female nurse at the on-site occupational health clinic. However, this clinic was closed at night, when first-aid cover was provided by the male security guards at the gatehouse situated at the entrance to the works. It seems highly probable that this dissuaded many members of the workforce from reporting less serious injuries on the night shift. Indeed, the nursing sister at the occupational health clinic also commented that the number of injuries reported during the day varied substantially depending on which nurse was on duty!

When these contaminating factors are controlled for, there appear to be a number of reasonably consistent trends in incidents associated with aspects of shift systems.

Risk across the different shifts

The first consistent trend relates to the relative risk of incidents on the morning, afternoon and night shifts on 8 h shift systems. There are five studies of which the authors are aware that are based on relatively large numbers of incidents and that appear to have overcome the potential confounding factors [6–10]. It should be noted that while in some of these studies there were equal numbers of shift workers on each shift, in the others, the authors had to correct the data to take account of any inequalities. In addition, three of the studies report two separate sets of data, for different areas or types of incident, giving a total of eight sets of data across the three shifts. For the purpose of this review, the incidents were summed across the eight data sets and the risk on the afternoon and night shifts was expressed relative to that on the morning shift. Risk was found to increase in an approximately linear fashion across the three shifts, showing an increased risk of 18.3% on the afternoon shift and of 30.4% on the night shift, relative to that on the morning shift, and this is shown in Figure 2. The conclusion to be drawn from this figure would appear to be that in situations where the a priori risk would appear to be constant across the three shifts, there is a consistent tendency for the relative risk of incidents to be higher on the afternoon shift than on the morning shift, and for it to be highest on the night shift.

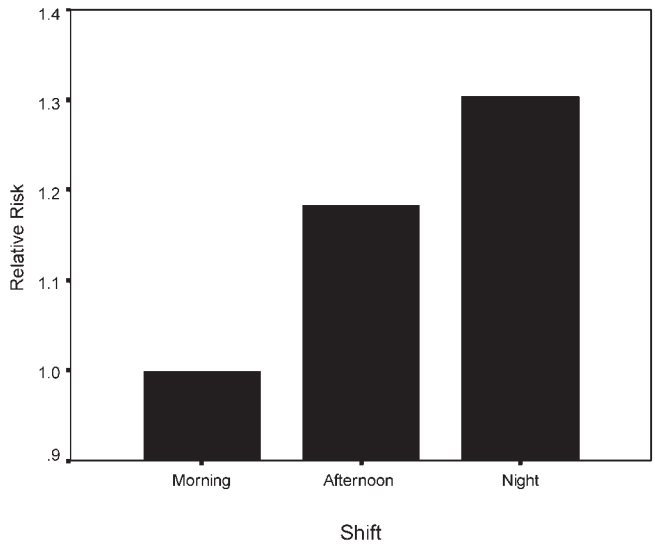

Figure 2. The relative risk across the three shifts.

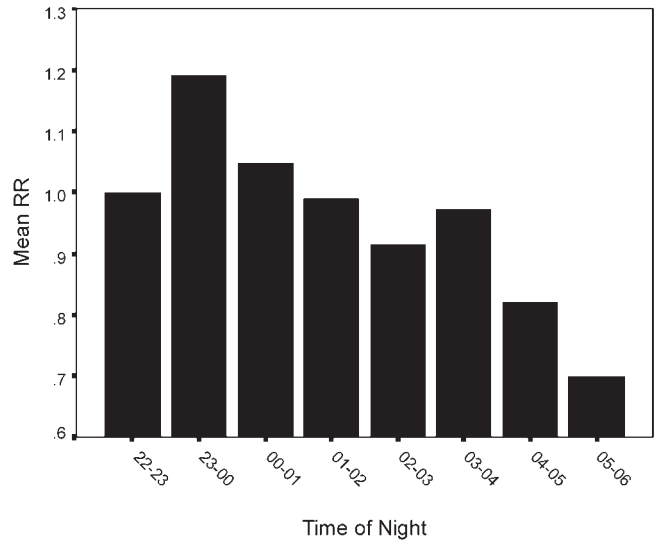

Figure 3. The relative risk over the course of the night shift.

Risk over the course of the night shift

The second reasonably consistent trend in risk is that over the course of the night shift. In 1923, Vernon [11] reported one of the earlier studies in this area. He reported that injury rates declined substantially over the first few hours of the night shift, and that this trend could not readily be explained in terms of changes in productivity levels. A number of more recent studies have also provided hourly incident rates over the course of the night shift [9,10,12–18]. As before, the incidents were summed across all 10 studies and the risk expressed relative to that during the first hour of the night shift. Using these summed values, risk rose by ~20% from the first to second hour, but then fell by a total of ~50%, and in an approximately linear fashion, to reach a minimum at the end of the shift, and this is shown in Figure 3. It is notable that there was a slight increase in risk between 03:00 and 04:00 h, when industrial efficiency is at its lowest ebb (see Figure 1), but this effect was relatively small compared with the substantial decrease in risk over most of the night.

Risk over successive shifts

The third consistent trends in risk are those over successive shifts. The authors are aware of a total of seven studies that have reported incident frequencies separately for each night over a span of at least four successive night shifts [7,9,14,17–20]. Note that the study reported by Monk and Wagner [21] was not included, since the data reported in that paper was a subset of that reported by Wagner [14]. As before, the frequency of incidents on each night was summed across the studies and then expressed relative to that on the first night shift. On average, risk was ~6% higher on the second night, 17% higher on the third night and 36% higher on the fourth night (see Figure 4).

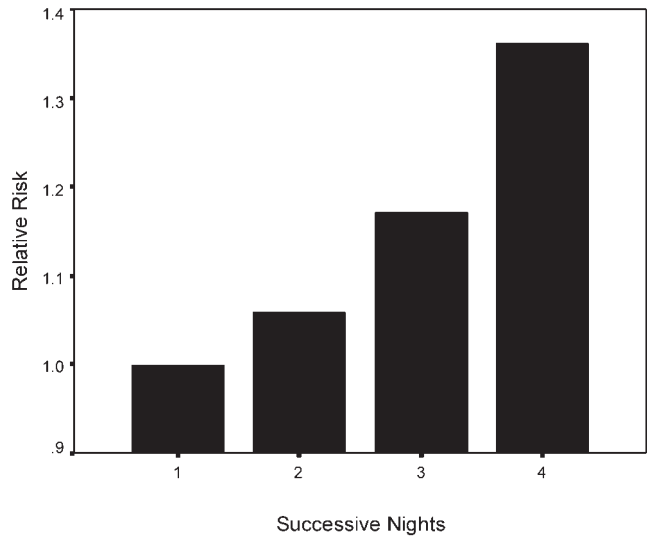

Figure 4. The relative risk over four successive night shifts.

Two important questions arise regarding this substantial increase in risk over four successive night shifts. The first is what happens to risk over longer spans of successive night shifts, but there is a paucity of data relating to this. While the increase in risk over four successive nights is difficult to reconcile with the finding of Vidacek *et al.* [5], that productivity increased over the first three nights, it would nevertheless be of great interest to determine whether risk, like productivity in Vidacek *et al.*'s study, reduced over longer spans of successive night shifts. However, while it is has to be admitted that this might occur, there is as yet no good evidence to indicate that this is the case.

The second question is whether the increase in risk over successive shifts is confined to the night shift, or whether it might be general to all shifts and represent an accumulation of fatigue over successive workdays. Of the seven studies that examined risk over successive night shifts, five also reported the risk over successive morning or day shifts [7,9,17,18,20]. As before, the frequency of incidents on each shift was summed across these five studies and then risk expressed relative to that on the first morning/day shift. The results are shown in Figure 5; note that the same scale has been used for this figure as that used in Figure 4 so that direct comparisons can be made. On average, risk was ~2% higher on the second morning/day, 7% higher on the third morning/day, and 17% higher on the fourth morning/day shift than on the first shift. Clearly, there was some evidence that risk did increase over successive morning/day shifts, but this increase was substantially smaller than that over successive night shifts (compare Figures 4 and 5).

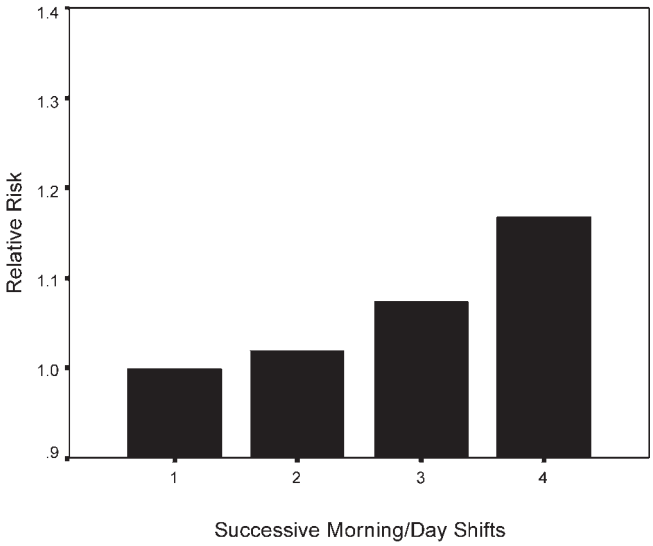

Figure 5. The relative risk over four successive morning/day shifts.

Risk over hours on duty

There appear to be four studies that have reported the trend in risk over successive hours on duty and that have managed to correct for exposure in some manner [15,22–24] (see also the review by Nachreiner [25]). However, the study by Folkard [22] was based on a statistical combining of several relatively small studies, and made various assumptions in deriving an overall trend. Since the remaining three studies were all based on substantial numbers of injuries/accidents and report fairly similar trends to that derived by Folkard [22], the latter was omitted from consideration in deriving an averaged trend. The three studies considered all examined trends in national accident statistics and corrected for 'exposure' in some manner. By setting the mean risk in each study for the first 8 h at one, it was possible to calculate hourly relative risk values for each study. The values were then averaged to derive an averaged trend, and this is shown in Figure 6. It is clear from this figure that, apart from a slightly heightened risk from the second to the fifth hour, risk increased in an approximately exponential fashion with time on shift such that in the twelfth hour it was more than double that during the first 8 h. The increased risk from the second to the fifth hour is considered in more detail by Folkard [22] and Tucker *et al.* [26].

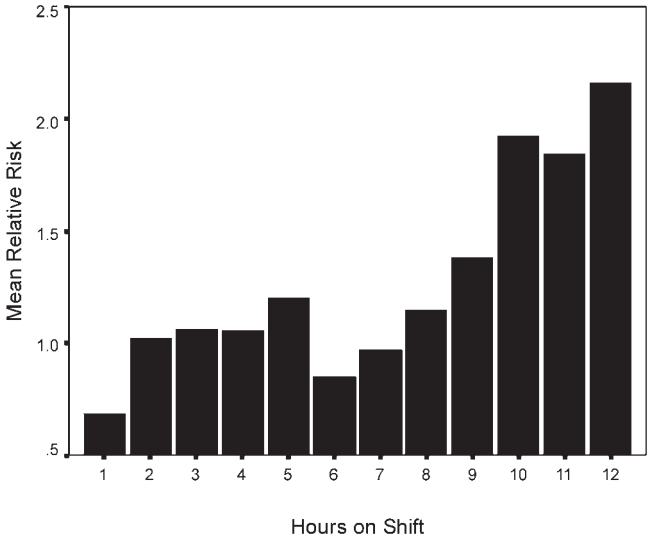

Figure 6. The mean relative risk over hours on duty.

Risk as a function of breaks

The trend for hours on duty shown in Figure 6 does not control for the influence of breaks during a duty period, and indeed one possible explanation for the decrease in risk after the fifth hour may be that it reflects the influence of rest breaks. Although a number of studies on the effects of breaks have been conducted [27–29], there appears to be only a single, very recent study that has examined their impact on the risk of incidents [30]. This study examined industrial injuries in an engineering plant in which a 15 min break was given after each period of 2 h of continuous work. The number of injuries within each of the four 30 min periods between breaks was calculated, and the risk in each 30 min period was expressed relative to that in the first 30 min period immediately following the break. The results are shown in Figure 7, from which it is clear that risk rose substantially, and approximately linearly, between successive breaks such that risk had doubled by the last 30 min period before the next break. It is also noteworthy that there was no evidence that this trend differed for the day and night shifts, or for the three successive periods of 2 h of continuous work within a shift.

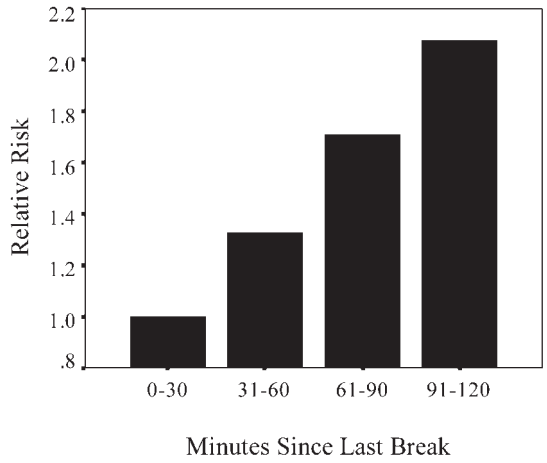

Figure 7. The trend in relative risk between breaks (from [30]).

Underlying factors affecting productivity and safety

Impaired safety and productivity on shift systems will almost certainly reflect the combined influence of a large number of factors; the psychosocial factors and physical health effects typically associated with abnormal work hours are discussed in other reviews in this issue [31–33]. It has long been recognized that people's efficiency at performing various tasks is not constant, but varies over the course of the normal waking day. Early theorists attributed this to either a build-up of 'mental fatigue' over a period of wakefulness [34] or an underlying rhythm in 'sleepiness' that was independent of whether people had actually slept [35]. More recent studies have confirmed that both these factors contribute to circadian variations in performance [36]. Indeed, a number of authors have developed mathematical models based primarily on these two factors [37–40], and these have proved relatively successful in predicting variations in alertness and performance on various laboratory tasks on both normal and abnormal sleep/wake schedules [41,42]. These models essentially assume that productivity and safety are low at night because (i) the circadian rhythms in performance are at a low ebb at this time and (ii) they remain relatively unadjusted over normal spans of successive night duties.

Unfortunately, while these mathematical models might be able to account for the trends in productivity described above, they have great difficulty in accounting for the trends in risk. Thus, while the models would predict that safety should be lowest at night, they would also predict that it should be highest on the afternoon shift, which it is clearly not (see Figure 2). Likewise, these models would predict that risk would be highest at ~04:00 h in the morning, while in fact risk is substantially lower then than at ~00:00 h (see Figure 3). Finally, the models would predict that risk should stay constant or reduce slightly over successive night shifts rather than show the substantial increase illustrated in Figure 4. The reasons for these large disparities between the predictions made by current models and the objectively determined trends in risk are as yet unclear, but may reflect on additional, as yet unidentified, factors that need to be incorporated into the models, and/or the possibility that risk is not linearly related to alertness and performance on laboratory tasks.

Other, mainly laboratory, studies have shown that the trend in performance over the day varies according to the nature of the task under consideration. In general, it would appear that the speed (and in some cases the accuracy) with which simple perceptual–motor tasks are performed tends to increase over much of the day and, with the possible exception of a 'post-lunch dip', parallels changes in body temperature [43,44]. In stark contrast, short-term memory, and in particular that for the information presented in prose, has been found to be at its maximum in the morning (between ~08:00 and 11:00 h) and to decrease over most of the day [43,45]. In this context, it is noteworthy that Monk and Embrey [46] found that process controllers made fewer errors at night in entering codes into a computer, presumably reflecting on the fact that their task was essentially one of short-term memory for alphanumeric codes. However, it seems unlikely that the failure of the mathematical models to account for the trends in risk reflects on the memory load involved since most of the studies of risk were based on highly repetitive perceptual–motor tasks.

Conclusions

The main conclusion to be drawn from the studies reviewed in this paper is that both safety and productivity are reduced at night. This reduction probably reflects on a number of underlying factors, including impaired health, a disturbed social life, shortened and disturbed sleep, and disrupted circadian rhythms. Despite the fact that current mathematical models of alertness and performance have difficulty in accounting for the precise trends in risk associated with various features of shift systems, it is clear that these trends could be used to try to reduce the risks associated with working at night. More specifically, it would seem that in order to minimize the overall risk on a shift system we need to consider the number of successive night shifts, the length of the night shifts and the provision of breaks within them. Finally, however, it is clear that these factors need to be considered in combination with one another since, for example, a 12 h night shift that included frequent rest breaks might well prove safer than a shorter 8 h night shift with only a single, mid-shift break. Likewise, the length of the night shifts and the number of successive night shifts involved in a shift system will act in combination to determine the overall risk on that system.

References

1. Browne RC. The day and night performance of teleprinter switchboard operators. *Occup Psychol* 1949;**23:**121–126.
2. Bjerner B, Swensson A. Shiftwork and rhythm. *Acta Med Scand* 1953;**278:**102–107.
3. Wojtczak-Jaroszowa J, Pawlowska-Skyba K. Night and shift work. I. Circadian variations in work. *Med Pr* 1967;**18:**1.
4. Wever RA. Man in temporal isolation: basic principles of the circadian system. In: Folkard S, Monk T, eds. *Hours of Work. Temporal Factors in Work-scheduling*. Chichester: Wiley, 1985; 15–28.
5. Vidacek S, Kaliterna L, Radosevic-Vidacek B, Folkard S. Productivity on a weekly rotating shift system: circadian adjustment and sleep deprivation effects? *Ergonomics* 1986; **29:**1583–1590.
6. Wanat J. Nasilenie wypadkow w roznych okresach czasu pracy e kopalniach wegla kamiennego. *Prc Glow Inst Gorn* 1962;**Seria A:**Kom 285.
7. Quaas M, Tunsch R. Problems of disablement and accident frequency in shift- and night work. *Studia Lab Salut* 1972; **11:**52–57.
8. Levin L, Oler J, Whiteside J R. Injury incidence rates in a paint company on rotating production shifts. *Accid Anal Prev* 1985;**17:**67–73.
9. Smith L, Folkard S, Poole CJM. Increased injuries on night shift. *Lancet* 1994;**344:**1137–1139.
10. Wharf HL. *Shift Length and Safety*. Report to British Coal, 1995.
11. Vernon HM. The causation of industrial accidents. *J Ind Hyg* 1923;**5:**14–18.
12. Adams NL, Barlow A, Hiddlestone J. Obtaining ergonomics information about industrial injuries: a five-year analysis. *Appl Ergon* 1981;**12:**71–81.
13. Ong CN, Phoon WO, Iskandar N, Chia KS. Shiftwork and work injuries in an iron and steel mill. *Appl Ergon* 1987;**18:**51–56.
14. Wagner JA. Shiftwork and safety: a review of the literature and recent research findings. In: Aghazadeh F, ed. *Trends in Ergonomics/Human Factors V: Proceedings of the Third Industrial Ergonomics and Safety Conference*. New Orleans: Loisiana State University, 8–10 June 1988.
15. Åkerstedt T. Work injuries and time of day—national data. *Shift Int News* 1995;**12:**2.
16. Macdonald I, Smith L, Lowe SL, Folkard S. Effects on accidents of time into shift and of short breaks between shifts. *Int J Occup Environ Health* 1997;**3:**S40–S45.
17. Smith L, Folkard S, Poole CJM. Injuries and worktime: evidence for reduced safety on-shift. *J Health Safety* 1997;**12:**5–16.
18. Tucker P, Folkard S, Macdonald I, Charyszyn S. Temporal determinants in accident risk in a large engineering assembly plant. *Shift Int News* 2001;**18:**16.
19. Vinogradova OV, Sorokin GA, Kharkin NN. A complex study into the strenuousness of night work done by dockers. *Gig Truda Prof Zabol* 1975;**19:**5–8 [in Russian].
20. Oginski A, Oginska H, Pokorski J, Kmita W, Gozdziela R. Internal and external factors influencing time-related injury risk in continuous shift work. *Int J Occup Safety Ergon* 2000;**6:**405–421.
21. Monk TH, Wagner JA. Social factors can outweigh biological ones in determining night shift safety. *Hum Factors* 1989;**31:**721–724.
22. Folkard S. Black times: temporal determinants of transport safety. *Accid Anal Prev* 1997;**29:**417–430.
23. Haenecke K, Tiedemann S, Nachreiner F, Grzech-Sukalo H. Accident risk as a function of hours at work and time of day as determined from accident data and exposure models for the German working population. *Scand J Work Environ Health* 1998;**24(Suppl. 3):**43–48.
24. Nachreiner F, Akkermann S, Haenecke K. Fatal accident risk as a function of hours into work. In: Hornberger S, Knauth P, Costa G, Folkard S, eds. *Shiftwork in the 21st Century*. Frankfurt: Peter Lang, 2000; 19–24.
25. Nachreiner F. Extended work hours and accident risk. In: Marek T, Oginska H, Pokorski J, Costa G, Folkard S, eds. *Shiftwork 2000—Implications for Science, Practice and Business*. Kraków: Institute of Management, Jagiellonian University, 2000; 29–44.
26. Tucker P, Sytnik N, Macdonald I, Folkard S. Temporal determinants of accident risk: the '2–4 h shift phenomenon'. In: Hornberger S, Knauth P, Costa G, Folkard S, eds. *Shiftwork in the 21st Century*. Frankfurt: Peter Lang, 2000; 99–105.
27. Kopadekar P, Mital A. The effect of different work–rest schedules on fatigue and performance of a simulated directory assistance operator's task. *Ergonomics*, 1994; **37:**1697–1707.
28. Galinsky TL, Swanson NG, Sauter SL, Hurrell JJ, Schleifer LM. A field study of supplementary rest breaks for data-entry operators. *Ergonomics* 2000;**43:**622–638.
29. Dababneh AJ, Swanson N, Shell RL. Impact of added rest breaks on the productivity and well-being of workers. *Ergonomics* 2001;**44:**164–174.
30. Tucker P, Folkard S, Macdonald I. Rest breaks reduce accident risk. *Lancet* 2003; in press.
31. Costa G, Folkard S, Harrington JM. Shiftwork and extended hours of work. In: Baxter PJ, Adams PH, Aw TC, Cockcroft A, Harrington JM, eds. *Hunter's Diseases of Occupations*, 9th edn. London: Arnold, 2000; 581–589.
32. Knutsson A. Health disorders of shift workers. *Occup Med* 2003;**53:**103–108.
33. Åkertedt T. Shift work and disturbed sleep/wakefulness. *Occup Med* 2003;**53:**89–94.
34. Thorndike EL. *Mental Work and Fatigue and Individual Differences and their Causes*. New York: Columbia University, 1926.
35. Michelson M. Ueber die Tiefe des Schlafes. *Psychol Arbeit* 1987;**2:**84–117.
36. Carrier J, Monk TH. Circadian rhythms in performance: new trends. *Chronobiol Int* 2000;**17:**719–732.
37. Spencer MB. The influence of irregularity of rest and activity on performance: a model based on time since sleep and time of day. *Ergonomics* 1987;**30:**1275–1286.
38. Folkard S, Åkerstedt T. A 3-process model of the regulation of alertness–sleepiness. In: Broughton RJ, Ogilvie BD, eds. *Sleep, Arousal and Performance*. Boston, MA: Birkhauser, 1992; 11–26.
39. Folkard S, Åkerstedt T, Macdonald I, Tucker P, Spencer M.

Beyond the three-process model of alertness: estimating phase, time on shift and successive night effects. *J Biol Rhythms* 1999;**14:**577–587.

40. Åkerstedt T, Folkard S. Validation of the S and C components of the three-process model of alertness regulation. *Sleep* 1995;**18:**1–6.
41. Jewett M, Kronauer RE. Interactive mathematical models of subjective sleepiness and cognitive throughput in humans. *J Biol Rhythms* 1999;**14:**588–597.
42. Åkerstedt T, Folkard S. The three-process model of alertness and its extension to performance, sleep latency, and sleep length. *Chronobiol Int* 1997;**14:**115–123.
43. Folkard S, Monk TH. Shiftwork and performance. *Hum Factors* 1979;**21:**483–492.
44. Folkard S, Monk TH. Circadian performance rhythms. In: Folkard S, Monk TH, eds. *Hours of Work: Temporal Factors in Work Scheduling*. Chichester: John Wiley, 1985; 37–52.
45. Folkard S, Monk TH. Circadian rhythms in human memory. *Br J Psychol* 1980;**71:**295–307.
46. Monk TH, Embrey DE. A field study of circadian rhythms in actual and interpolated task performance. In: Reinberg A, Vieux N, Andlauer P, eds. *Night and Shift Work: Biological and Social Aspects*. Oxford: Pergamon Press, 1981; 473–480.

Appendix E

CHAPTER 29
COMBUSTIBLE FIBERS

SECTION 2901
GENERAL

2901.1 Scope. The equipment, processes and operations involving combustible fibers shall comply with this chapter.

2901.2 Applicability. Storage of combustible fibers in any quantity shall comply with this section.

2901.3 Permits. Permits shall be required as set forth in Section 105.6.

SECTION 2902
DEFINITIONS

2902.1 Definitions. The following words and terms shall, for the purposes of this chapter and as used elsewhere in this code, have the meanings shown herein.

BALED COTTON. A natural seed fiber wrapped in and secured with industry-accepted materials, usually consisting of burlap, woven polypropylene, polyethylene or cotton or sheet polyethylene, and secured with steel, synthetic or wire bands, or wire; also includes linters (lint removed from the cottonseed) and motes (residual materials from the ginning process).

BALED COTTON, DENSELY PACKED. Cotton, made into banded bales, with a packing density of at least 22 pounds per cubic foot (360 kg/m^3), and dimensions complying with the following: a length of 55 inches (1397 mm), a width of 21 inches (533.4 mm) and a height of 27.6 to 35.4 inches. (701 to 899 mm).

COMBUSTIBLE FIBERS. Readily ignitable and free-burning materials in a fibrous or shredded form, such as cocoa fiber, cloth, cotton, excelsior, hay, hemp, henequen, istle, jute, kapok, oakum, rags, sisal, Spanish moss, straw, tow, wastepaper, certain synthetic fibers or other like materials. This definition does not include densely packed baled cotton.

SEED COTTON. Perishable raw agricultural commodity consisting of cotton fiber (lint) attached to the seed of the cotton plant, which requires ginning to become a commercial product.

SECTION 2903
GENERAL PRECAUTIONS

2903.1 Use of combustible receptacles. Ashes, waste, rubbish or sweepings shall not be placed in wood or other combustible receptacles and shall be removed daily from the structure.

2903.2 Vegetation. Grass or weeds shall not be allowed to accumulate at any point on the premises.

2903.3 Clearances. A minimum clearance of 3 feet (914 mm) shall be maintained between automatic sprinklers and the top of piles.

2903.4 Agricultural products. Hay, straw, seed cotton or similar agricultural products shall not be stored adjacent to structures or combustible materials unless a clear horizontal distance equal to the height of a pile is maintained between such storage and structures or combustible materials. Storage shall be limited to stacks of 100 tons (91 metric tons) each. Stacks shall be separated by a minimum of 20 feet (6096 mm) of clear space. Quantities of hay, straw, seed cotton and other agricultural products shall not be limited where stored in or near farm structures located outside closely built areas. A permit shall not be required for agricultural storage.

2903.5 Dust collection. Where located within a building, equipment or machinery which generates or emits combustible fibers shall be provided with an approved dust-collecting and exhaust system. Such systems shall comply with Chapter 13 and Section 511 of the *International Mechanical Code.*

2903.6 Portable fire extinguishers. Portable fire extinguishers shall be provided in accordance with Section 906 as required for extra-hazard occupancy protection as indicated in Table 906.3(1).

SECTION 2904
LOOSE FIBER STORAGE

2904.1 General. Loose combustible fibers, not in suitable bales or packages and whether housed or in the open, shall not be stored within 100 feet (30 480 mm) of any structure, except as indicated in this chapter.

2904.2 Storage of 100 cubic feet or less. Loose combustible fibers in quantities of not more than 100 cubic feet (3 m^3) located in a structure shall be stored in a metal or metal-lined bin equipped with a self-closing cover.

2904.3 Storage of more than 100 cubic feet to 500 cubic feet. Loose combustible fibers in quantities exceeding 100 cubic feet (3 m^3) but not exceeding 500 cubic feet (14 m^3) shall be stored in rooms enclosed with 1-hour fire-resistance-rated fire barriers, with openings protected by an approved opening protective assembly having a fire protection rating of $^3/_4$ hour, constructed in accordance with the *International Building Code.*

2904.4 Storage of more than 500 cubic feet to 1,000 cubic feet. Loose combustible fibers in quantities exceeding 500 cubic feet (14 m^3) but not exceeding 1,000 cubic feet (28 m^3) shall be stored in rooms enclosed with 2-hour fire-resistance-rated fire barriers, with openings protected by an approved opening protective assembly having a fire protection rating of $1^1/_2$ hours, and constructed in accordance with the *International Building Code.*

2904.5 Storage of more than 1,000 cubic feet. Loose combustible fibers in quantities exceeding 1,000 cubic feet (28 m^3) shall be stored in rooms enclosed with 2-hour fire-resistance-rated fire barriers, with openings protected by an approved opening protective assembly having a fire protection

Color profile: Generic CMYK printer profile
Composite Default screen

rating of $1^1/_2$ hours, and constructed in accordance with the *International Building Code*. The storage room shall be protected by an automatic sprinkler system installed in accordance with Section 903.3.1.1.

2904.6 Detached storage structure. A maximum of 2,500 cubic feet (70 m^3) of loose combustible fibers shall be stored in a detached structure suitably located, with openings protected against entrance of sparks. The structure shall not be occupied for any other purpose.

SECTION 2905
BALED STORAGE

2905.1 Bale size and separation. Baled combustible fibers shall be limited to single blocks or piles not more than 25,000 cubic feet (700 m^3) in volume, not including aisles or clearances. Blocks or piles of baled fiber shall be separated from adjacent storage by aisles not less than 5 feet (1524 mm) wide, or by flash-fire barriers constructed of continuous sheets of noncombustible material extending from the floor to a minimum height of 1 foot (305 mm) above the highest point of the piles and projecting not less than 1 foot (305 mm) beyond the sides of the piles.

2905.2 Special baling conditions. Sisal and other fibers in bales bound with combustible tie ropes, jute and other fibers that swell when wet, shall be stored to allow for expansion in any direction without affecting building walls, ceilings or columns. A minimum clearance of 3 feet (914 mm) shall be required between walls and sides of piles, except that where the storage compartment is not more than 30 feet (9144 mm) wide, the minimum clearance at side walls shall be 1 foot (305 mm), provided that a center aisle not less than 5 feet (1524 mm) wide is maintained.

Copyright International Code Council
Provided by IHS under license with ICC
No reproduction or networking permitted without license from IHS
Thursday, December 01, 2005 1:57:00 PM
\Final VP_Chgo\29_ifc_2006.vp
Licensee=Atlanta, GA - location 9/5960458010, User=Shoaei, Mahnoosh
Not for Resale, 09/11/2006 11:40:14 MDT