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THE PROSPECTS FOR AN ELECTRICAL GENERATION AND TRANSMISSION COOPERATIVE FUELED BY STRAW PRODUCED IN EASTERN WASHINGTON*

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Abstract

The objective of this study was to determine the economic prospects of operating a cooperatively-owned electrical generating and transmission facility fueled by straw produced in eastern Washington. Beyond the generally understood parameters of a cooperatively-owned enterprise, this study attempts to address several related economic feasibility issues. For example, the total availability of straw first had to be determined. Second, the total cost of producing, harvesting, transporting and storing fuel (straw) was estimated. Next, we sought to determine the most cost-effective means (from among those available) for harvesting, transporting, and storing the straw. Fourth, we attempted to determine the costs to construct, operate, own, and manage a straw-fired electrical power generating facility. Next, an assessment was made as to the profitability and competitive performance of such a facility within electrical rate schedules currently in place throughout the region. Finally, we sought to entertain additional secondary benefits which might contribute to, or accrue from, such a prospective project.

Our research findings suggested that not all wheat, barley, and grass seed straw is economically available for harvesting. Where yields are low and distances are great, the cost of harvesting, storing and transporting eastern Washington straw may be excessive. From among our annual production of "eligible" straw, however, supplies are more than sufficient to fuel not just one, but a multiple of 30 MW electric co-generating facilities. The most cost-effective location of such a facility (or facilities) would be Whitman County, due mostly to its central location and its inherent density of straw production.

Electricity could be produced from straw burning at an estimated total cost of $0.08 kwh, compared with current retail rates of around $0.04 kwh. As such, straw does not currently appear to be an attractive alternative fuel compared with those on which we traditionally rely. This alone, however, does not render the straw burning option to be uninteresting. Should the regional demand for electricity continue to grow, and should traditional sources of fuel prove fixed in magnitude, other alternative (and more expensive) sources of fuel will need to be explored. In addition, straw burned in the process of producing electricity incorporates several externally-generated benefits not normally accruing to non-renewable fuels.

Introduction

Eastern Washington contains one of the most fertile and productive cereal crop regions in the world. Though consisting of some irrigated land, it is the yields of the region's dryland cereal crops, particularly winter wheat, that demonstrates the true potential of its native soils and natural climate. Because of the region's exceptional crop production capabilities, agriculture plays a crucial and significant role in the economy of eastern Washington.

Due mostly to the region's unusually high crop yields, the residue (stubble/straw) leftover after the grain harvest can constitute a major production problem. This excess amount of residue can become a nuisance for the following crop, serving to propagate vertebrate pests, insects, weeds and diseases. This large amount of stubble also makes it more difficult to cultivate, prepare, and plant the subsequent crop. To manage and/or dispose of this excess stubble in grain fields, eastern Washington farmers have only a few options: leave the residue untouched via minimal tillage (no-till farming); multiple tillage passes to better integrate the stubble into the soil; mow/chop the stubble to encourage its decay; bale the stubble and remove it from the field; or burn the stubble. By far the most efficient and cost-effective option is stubble burning. One of the primary benefits of stubble burning after grain harvest is the ability to control insects, weeds, and disease. The practice may even allow a farmer to grow one ideal crop each year with minimal crop rotation. Also, burning helps to control heavy residue areas where subsequent plantings may otherwise be very difficult. Burning is also a major aid to no-till farmers who direct-seed their crop without any type of tillage. Contrary to common understanding, stubble burning is not a new production practice and has been in use in eastern Washington since Europeans migrated to this region prior to the twentieth century. Prior to thirty years ago, it is estimated that up to four-fifths of the state's total wheat stubble was burned as part of the region's normal cultivation practice (Sorensen).

Due mostly to its unique soils and topography, eastern Washington is very sensitive to soil erosion. It is no secret that stubble burning contributes to serious soil erosion in the region. Certain government subsidy programs in the past twenty to thirty years favored conservation and, when implemented, helped to curtail this practice of burning. When given the choice, most farmers chose a government subsidy over the effective practice of stubble burning.

Then along came the 1996 Farm Bill, also known as the "Freedom to Farm" bill. This bill gave more production freedom to farmers, but at the same time initiated the withdrawal of government subsidies. With no incentive to restrain the effective, low-cost practice of stubble burning, farmers returned to burning and in 1998 and 1999, burn permits reached a high of more than 229,000 acres in eastern Washington (Washington State Department of Ecology). In 1997, the Natural Resource Conservation Service approved a program that recommended burning wheat stubble in certain cases after grain was harvested, and as some opponents of burning claim, they "approved burning as an acceptable practice" (Sudermann, Steele).

Not long before burning was reintroduced as a more prevalent farming practice, the method of "no-till" was also becoming more prevalent. No-till came about in response to the two major issues facing many American farmers, i.e., soil erosion and economics. No-till is a farming practice that requires the absence of, or minimal amount of tilling or plowing the land. This retains the natural soil structure, which allows soils to hold moisture better and withstand the natural occurring erosion due to rain and wind. No-till has been an efficient and effective method to slow or even stop soil erosion in eastern Washington. But, no-till farming is not consistent with thick stubble, and in some cases seeding becomes impossible. The method of no-till adapts perfectly with the practice of stubble burning; i.e., the burning controls pests and minimizes costs, while the absence of tillage maintains the ideal soil structure with little soil erosion.

With the recent increasing trend of stubble going up in flames, the non-farming population, particularly the urban population, has begun to resist. With a significant portion of the state's agricultural burning near the metropolitan area of Spokane, field burning affects a significant amount of our urban population. This situation has brought about the creation of a Spokane-based air quality conservation group, Save Our Summers, determined to stop agricultural burning. As a result of constant litigation brought about by this conservation group through many court cases, the farming practice of stubble burning is slowly, but surely, being phased out (Steele, Jewell, Wiley, Washington State Department of Ecology).

With the eventual phase-out (be it voluntary or mandated) of this effective agricultural practice of stubble burning in coming years, practical alternatives must be found. Of the production management alternatives mentioned previously, leaving the residue untouched for the no-till farmer and multiple tillage passes for the conventional farmer are used most frequently. However, there are many flaws with these alternatives. When the no-till farmer leaves the residue untouched on the field, the no-till seeder machines can only be moderately effective in the thick stubble. With such a considerable amount of residue, a significant amount of the seeds may never reach an adequate soil depth to establish a decent root structure. Also, many of the no-till seeders get clogged with straw, such that seeding becomes very time-consuming and, therefore, very expensive. With such a thick residue from the previous crop, even some "no-till farmers" are forced to perform some sort of tillage in order to render the planting of the following crop cost-effective.

As for the conventional tillage farmers, heavy straw residue can also be a major problem. When prevented from burning thick stubble, the field requires many tillage passes just to incorporate the residue deeply enough into the soil to make a feasible planting surface for the next crop. Every tillage pass on a field is considerably costly, and therefore, each additional pass increases total production costs significantly. Other pieces of equipment, such as stubble choppers, shredders or mowers are also used, but at an extremely high purchase and operating cost.

This leaves us with just one remaining feasible alternative, i.e., the physical removal of the straw residue. Baling is an effective method to remove a significant amount of stubble and curtail the production problems earlier noted. However, most farmers currently find baling to be an uneconomical alternative. Baling is presently not used frequently because of the time/labor required, the high cost of the equipment, and the operating cost of the equipment once purchased. Hiring custom baling operators has also proven to be an uneconomical solution due to its high cost.

Another burden of baling is the disposal of the after-products, i.e., there can be thousands of tons of bales when finished, with a very low market value and a very high storage cost area. If there was a more sufficient market value for straw, whether it be wheat, barley, or grass seed straw, perhaps baling would be a more appealing and cost-effective alternative.

<u>Organizational Form – Agribusiness Cooperative</u>

The construction/operation of a straw-fired electrical generating and transmitting facility could be financed and managed by several alternative organizational forms of business. Should the venture appear profitable enough, corporations and/or private investors would likely find such an opportunity attractive. However, the nature and composition of this venture appears most suitable to the formation of a cooperative organization owned and operated by the farmers producing the straw used as the primary fuel. The reasons for this observation are several.

First of all, straw is a commodity, much like the wheat/barley/grass seed from whence it comes. Eastern Washington straw does not possess qualitative variations or other parameters which serve to separately identify it from that produced elsewhere in the Pacific Northwest. As such, the marketing of this product offers few options for exploitation or market differentiation. Were each individual farmer/straw producer to attempt to market their straw, their price-determining impact on the total market would be minimal. In addition, individual producers fail to control a volume of straw large enough to exert a market influence. The marketing of straw under a grower cooperative format would better address the commodity status of the product and represent a quantity of straw large enough to serve the interests of a generating facility.

Second, eastern Washington farmers continue in their dedicated search for a "value-added" increment to their annual earned incomes. In large part, straw may not represent so much a value-added as it does a "value not previously realized." Where postharvest residue is viewed as a detriment to subsequent cultivation or seed bed preparation, and where burning is viewed as an environmental hazard, straw becomes a product with a potential negative value, approximated by the cost of its removal. Any attempt, therefore, to harvest and remove this postharvest residue and create a value never before realized by farmers must be viewed with promise. Working in concert through a cooperatively-owned organization, farmers could better accomplish this prospective outcome.

Third, the costs of harvesting, storing and transporting straw are substantial. Individual producers would be faced with the need to purchase or custom-hire balers, stackers, and possibly even trucks to better realize this prospect of straw removal. Not all straw producers would be of sufficient size and financial strength to individually absorb these added capital costs. A cooperative organization, on the other hand, could assemble and make available this needed equipment to its farmer/members at a reduced cost (per ton, per acre or per producer).

Historically, farmers have retained little control over their products beyond the farm gate. How and where their products are subsequently utilized often falls beyond the realm of producer prerogative as private and corporate agribusiness organizations have assumed these functions. Cooperative ownership of the electrical generating and transmitting facility would address this issue insofar as the producers would remain in control of the actual conversion of their product into something of value for final consumers (electrical power).

Lastly, cooperative organizations are familiar to farmers in the region. A large portion of their grain/grass seed currently produced is marketed through locally-owned cooperative firms. Growers understand the role these organizations fulfill and better appreciate their competitive importance in the market place. An electrical generating and transmission cooperative, owned and operated by a consortium of grain marketing cooperatives is not beyond the realm of possibilities. By levering their financial positions and capitalizing on their already-existing relationships with growers, such pre-existing cooperatives could potentially accomplish this objective.

Straw as Biomass

Straw is used all over the world as a biofuel, also known as biomass. That is, straw can be incinerated in order to create energy. This option is very appealing not only because of the excess supply of straw in eastern Washington, but also because of the fact that biomass is a renewable resource. Unlike carbon-based fuels more commonly used for energy production that can eventually become depleted, straw is a renewable resource readily produced every year in massive amounts. Biomass is also considered "CO_2 neutral energy production"; i.e., the CO_2 released into the atmosphere when burned for energy is offset by the amount of CO_2 absorbed from the atmosphere during the growing process.

Energy Deficit

Another reason that straw as a biomass source of energy is appealing is because of the recent energy crisis that has affected many western states, including the state of Washington. Basically, the shortage of energy had come about due to the booming West Coast economy – therefore an increase in power demand – and the lack of construction of new power-generating facilities. Over the past decade, the Northwest (Oregon, Washington, Idaho) power demand has risen 24%, while the region has increased its power generating capacity by only 4% over the same period of time (Northwest Power Planning Council, Gavin).

Another one of the major reasons for the crisis was California's major power shortage. California and Oregon/Washington import and export power to and from each other at different seasons of the year, according to each state's "peak demand" time of the year. In the last two years, California has demanded an enormous amount of power, leaving the Northwest, particularly Washington, with little power. During Washington's peak demand, California had little power to export to Washington as they would in any normal year.

At the same time, the Northwest had experienced a mild drought in the winter of 2000-2001, leaving snowpack levels well below normal. This resulted in leaving reservoirs and rivers at lower than normal levels. Adequate water levels and snowpack are crucial to Northwest power generation because of the fact that hydroelectric generation (electrical power generation from dams) accounts for 70-75% of the Northwest's power (Gavin, Booth). All these factors led to the power crisis, resulting in wholesale electricity prices 100 times higher than normal at one point.

In the Northwest, electricity prices are comparatively low – one-third to one-half the price elsewhere in the nation. This is mainly due to the region's abundance of cheap power generated from hydroelectric dams (Gibbs). But, with growing conflicts between the survival of fish and hydroelectric dams, it is very unlikely that any more of these dams will be constructed in the future. In fact, there has even been some thought given to breaching those dams already in existence.

Although this energy crisis described above is currently behind us, the risk of similar crises will persist into the future. With a growing economy and increasing population in the West, energy demand will continue to increase, while power generating facilities, particularly hydroelectric dams, are no longer being constructed to serve this growing energy demand.

The Alternative

An alternative to stubble burning in eastern Washington is to harvest and market the after-product (baled straw). With the search for straw utilization alternatives in eastern Washington occurring at the same time of a short-lived, but very significant energy shortage, straw as a biofuel appears to propose a very attractive resolution. Constructing a straw-fired electrical co-generating power plant may have a huge benefit on the economy of the state of Washington, positively affecting both the imperative agricultural economy of eastern Washington and helping to fulfill the ever-present energy demand in western states.

Harvesting

The only effective way of harvesting stubble is to bale it as straw. The stubble may be harvested any time after the grain harvest, so long as the product has not been impacted by significant moisture from rain. Therefore, with grain harvest ranging from early July to as late as October, rain is always a realistic threat. The best way to avoid this is to harvest the stubble as soon as possible after grain harvest. There are three operational procedures that comprise the straw harvest: swath (cut), bale, and stack.

Swathing

The first procedure requires the most widely used straw-harvesting machine, i.e., a swather or windrower. The swather comes into the field and cuts the remaining stubble as close to the ground as possible and lays the cut stubble in windrows. The header of the swather can vary in width, anywhere from 14 feet to 30 feet. The cost of swathing ranges from $4 to $10 per ton, with the average at about $6 per ton (Fife/Miller, Levy). Costs range according to density of stubble (crop yield) and header width. The denser the crop, the lower the cost per ton, e.g., the cost per ton of harvesting 3 tons of straw on one acre is much lower than harvesting a half ton straw yield on that same acre. This product density efficiency impacts the rest of the harvesting methods as well.

Baling

After the stubble is cut and windrowed, it must be baled. Often the straw is dry enough to bale immediately, unless of course the windrows or the stubble were recently rained on, in which case it may require additional days for drying. Balers are mechanically complicated and expensive pieces of equipment and may vary in both size and capacity. The most obvious variation between balers is the size of the bale it produces. Bales can range from small, three-tie bales (16”x18”x52”) weighing about 60 pounds, to large round and square bales (48”x48”x98” or 4’x4’x8’) weighing well over 1,000 pounds. Of all the different bale sizes and weights, the large square bales are the most cost efficient. All of the large balers are the most cost-effective on a per ton harvesting basis, while the large square bales are the most cost-effective to transport and store due to their convenient shape and high density (Miles, Fife/Miller, CA Rice, Case IH, JA Freeman). When baling straw with large square balers, costs range from $5 to $18 per ton, with the average at about $14 per ton (Fife/Miller, Levy). These costs range mainly due to density of straw (crop yield), condition of field (ruts, mud, etc.), and terrain (steep hillsides, flat ground, etc.).

Of the large square bales, there are two common size bales: 3’x4’x8’ and 4’x4’x8’. There are slight variations within a few inches for all the dimensions, particularly in the length, i.e., producing bales up to 9’ on some balers, but 8’ in length is the most common. The weights of these bales range from 900 pounds to 1,350 pounds. Though the larger of the two common bale sizes is slightly denser, making it more cost-effective for storage, the smaller 3’x4’x8’, 950-pound bale, is the most efficient for two reasons: (1) it holds together better and is therefore more stable, and

(2) for transportation reasons (Miles, Levy, Moris). Because of trucking laws and regulations related to truck loads, using the 3’x4’x8’ bale instead of the 4’x4’x8’ bale allows more bales per truck load. The lack of 1’ on the one dimension of the smaller bale allows for more bales that can be stacked higher (3 bales high instead of 2), therefore allowing more bales and weight per truck.

Stacking

After the straw is baled in the field, it must be collected and stacked in a timely, efficient manner. Large bales can be stacked with a number of different pieces of equipment, but the most efficient are harrowbeds or stackwagons specifically designed for the task. This machine collects the bales into a block of several bales and stacks it neatly in the field, i.e., the point at which the straw is considered “roadsided.” Harrowbed costs range from $4 to $8 per ton, usually depending on density of crop, condition of field, and terrain (Fife/Miller, Levy).

With these three stubble harvesting procedures in mind, the total cost of roadsiding the straw ranges from $25 per ton to $30 per ton, using large square bales (Miles, Fife/Miller, Whitmore, Levy, Moris, Baden, Van Mouerick). The total costs are extremely variable and can depend on many different factors such as the density of the stubble, size of the operation (farm), the specific equipment used, the conditions of the fields, and the terrain.

When looking at the total cost of harvesting, the term “cost” largely depends on one’s point of view. For example, much depends on whether it is the machine owner’s cost or the cost to the farmer who hires a custom operator. The cost to hire a custom operator will obviously be more expensive on a per ton basis, but it avoids the initial investment and maintenance cost of purchasing and operating the harvesting equipment. As for the owner of the harvesting equipment, the cost per ton may be as low as $20 per ton, varying according to the reasons stated earlier. However, this person bares the burden of purchasing and the upkeep of the equipment. When the farmer hires a custom operator to do the job, which is the assumed scenario for this study, the total cost is about $25 to $30 per ton.

Timing

As noted earlier, timing is also a concern when considering the harvesting of straw for a straw-fired power facility, i.e., there is a time/moisture constraint for baling. Grain harvest can take place as early as July and can go as late as October. As the season wears on towards the winter months, the threat of rain becomes greater. The highest yielding crops, such as grass seed and winter wheat in dryland and irrigated regions, are the first of the straw-yielding crops to be harvested – around mid to late summer. The later harvested crops are the spring planted crops, most of which are not considered to be an "eligible" crop with regards to straw yields (as defined in a later section). Therefore, there is more time available to harvest the higher yielding crops.

Another factor which impacts the time constraint of stubble harvesting is the particular rotation schedule by the farmer. Some crops, once harvested, are immediately followed by the planting of another crop, thereby making for a very short stubble-harvesting window. This is usually not a problem with dryland winter wheat since the following planting in the rotation is often summer fallow or a spring-planted crop. Winter wheat is rarely followed by a planting of another winter wheat crop due to pest and/or soil moisture reasons.

Though it is critical to get stubble harvested before the chance of rain, there usually is sufficient time. Rainfall levels can differ greatly between counties and regions of the eastern portion of the state and this harvest window can also vary greatly. It can be as long as a few months to only a couple of weeks.

In the absence of a cooperative effort or a cooperative marketing entity, harvesting would probably be done on an individual basis. Each farmer who wishes to sell his or her straw will go about it in his or her own way, i.e., either with his or her own equipment or with a custom baling operator. Supply, demand, and price will determine how much straw gets baled and sold. But, to see just how much capital and labor it would take to fulfill a certain amount of demanded straw before the threat of rain, different scenarios will be assessed in *Table 1.* For example, a proposed electrical co-generating facility would consume approximately 200,000 tons of straw annually. If 200,000 tons of straw were to be harvested in one season, and if there was a two-month (60 days) harvesting window before significant rain started, a minimum of 28 balers would be required to complete the harvest (assuming a ten-hour work day, seven days a week) and supply the needs of this single co-generating plant. The required number of balers is calculated because they are the slowest of the three essential pieces of harvesting equipment; therefore, the number of swathers and harrowbeds will be fewer.

Table 1.

Collection Time

TONS per bale	**RATE**		
3'x4'x8' bales at 950 lbs.	bales/hour	tons/hour	hours/day
0.48	25	12	10

TOTAL TONNAGE Scenarios

200,000		**600,000**		**3,000,000**	
total hours	total days	total hours	total days	total hours	total days
16,667 **(1)**	1667	50,000	5,000	25,0000	25,000

Number of balers required

	Days in harvesting window scenario			
Total Tonnage	20	30	60	90
200,000	**83**	**56**	**28 (2)**	**19**
600,000	**250**	**167**	**83**	**56**
3,000,000	**1250**	**833**	**417**	**278**

(1) calculation: (200,000 tons divided by 12 tons per day)
(2) calculation: (1,667 total days divided by 60 days)

"RATE" derived from Rice Straw Feedstock Study and Field Practices Report.

Transportation

Transporting the straw to a selected location within eastern Washington requires an analysis of the most cost-effective method. Transportation costs can often be the main setback to selling straw at a marketable price because of its bulk and low value-to-weight ratio. The most widely used mode of transporting bales within the industry are eighteen-wheel, 80,000-lb. GVW trucks with double flatbed trailers. These trucks, as opposed to other potential "trucks" such as smaller flatbed trucks and even pickup trucks, are the most cost-effective way to haul bulk material across land as evidenced by their dominant use within the industry.

One eighteen-wheeler truck with double flatbed trailers can haul 22-23 tons of straw in large 3'x4'x8' bales. Transportation costs can vary over a wide range. It is extremely difficult to estimate the transportation costs for a given distance by pinpointing one specific number. This can be proven from experience based on our attempt to obtain different costs or rates from various haulers for this study. One example of this variability was demonstrated when a relatively large local hay hauler was asked about his hauling rates. For a specific distance he could not even reveal an estimated number without very specific details of the situation, such as exact location points, field condition, time of year, etc. The costs in this study are estimated by averaging various haulers' rates in the area and what they would consider average numbers within the industry (*Appendix A*). Gary Moris (custom baler, Princeton, ID) is confident that the best average rate changes by approximately $1.50 per mile per loaded truck.

The costs can also differ significantly depending on who pays the freight, i.e., does the farmer who produces the straw own the truck, or does he or she have to pay someone to haul it for him or her. For this study, we will assume that the majority of the straw producers do not have their own trucks with which to haul hundreds or thousands of tons of straw. Therefore, the transportation costs assume that someone – whether it's the farmer or the person buying the straw – has to hire the job done.

Another cost comes into play and is separate from the transportation costs that were estimated in *Appendix A*. This is the cost of loading and unloading the straw on and off the truck on which it is transported. This task is primarily done by a machine called a "squeeze," but can also be done with other equipment such as a front-end loader. One of these pieces of equipment loads a block of several bales onto the truck, keeping the bales neatly stacked. These loading costs are also extremely variable and range from $1.50 to $3.50 per ton (Moris, Fife/Miller, Levy).

Storage – Cover and Space Required

Storage is an essential part of assessing costs for straw-burning purposes. The reason is that burning straw efficiently must be done with a relatively dry product (less than 25% moisture). Also, we must recognize that straw for fuel must be readily available throughout the year. There are a couple options with regard to storing straw: stacks left roadsided and covered with tarps, or relocated from the field to be tarped or roofed at the location where they're to be used. The option to leave the straw stacks uncovered at the place of harvest until needed for consumption is also a possible alternative in order to minimize costs, but it would most likely result in too much moisture from rainfall by bringing the bales' moisture content too high for efficient combustion.

Straw storage costs associated with covered barns are by far the most expensive, costing at least $7 to $8 per ton per year (Miles). Most large-scale projects involving the consumption of straw use as little covered storage as possible because of its high cost. Perhaps the only cost-effective covered storage that could possibly be provided would be at the place of straw utilization, i.e., the electric co-generating plant. This would require that only a fraction of the total straw required annually (e.g., only several hundred tons) be covered, and which would be used for immediate consumption at the plant.

Covering stacks with tarps is much less expensive at about $2.00 to $2.50 per ton per year (Inland Tarp and Cover, Fife/Miller). Inland Tarp and Cover in Moses Lake, WA would charge about $400 for a 25'x54' tarp to cover a large bale (3'x4'x8' bale) stack of 7 bales x 7 bales x 7 bales. Within this stack, there are a total of 163 tons of straw, and when divided by $400, would cost about $2.45 per ton. This is consistent with Fife/Miller's figures of $2 to $2.50 per ton for tarping.

These storage costs only take the material for coverage (tarp or building) into consideration. One must also consider the cost of the area the stored straw will utilize. Different scenarios are assessed in order to approximate the total land area required to store a particular quantity of straw, as seen in *Table 2*. The first scenario assumes storage for 200,000 tons of straw, which is the total amount of straw that would be consumed by a straw-fired power plant proposed in this area, and which will be further

Table 2.

- large bale stack: 7 bales x 7 bales x 7 bales
- large 3'x4'x8' bale
- individual bale weight: .48 ton

Stack:

	dimension(feet)	number of bales
height	21	7
width	28	7
length	56	7

TOTAL # bales per stack	TOTAL weight(tons)	TOTAL area (sq.ft.)	tons/sq.ft.
343	165	1,568	0.105

Total Tonnage	**Minimum Acres Required for Storage Area**
100,000	**22**
200,000	**44 (1)**
600,000	**131**

(1) calculation: 200,000/((43560/1568)*165)

described in a later section. As shown, it is estimated that the storage of 200,000 tons of straw would require a minimum of 44 acres. Keep in mind that these acreage requirements are the absolute minimum amount of land area occupied. They do not take into account necessary space between stacks for tarps and equipment and/or vehicle access.

Obviously a very large area of land is required to store a significant amount of straw. But, one of the mentioned storage options is to leave the straw stacked and covered with tarps in the field after harvest until it is ready to be utilized by the plant. Not only would this lower total costs by minimizing the number of times the straw is handled, but it would also eliminate the costly alternative to purchase or lease an additional piece of land (e.g., greater than 44 acres for 200,000 tons).

Acreage/Yields/Eligible Straw

To say that there is an enormous amount of wheat, barley and grass seed straw produced in eastern Washington would be an understatement. Between the large acreage and the generous yields that this region produces, straw is more than abundant. When estimating the amount of straw in the region, volumes are calculated on a per county basis because this is the most detailed amount of data provided every year. Each of the three crops (wheat, barley, and grass seed) is assessed in each county. Winter wheat and grass seed crops make up the majority of the residue problem in eastern Washington. Though spring wheat and barley residue can be somewhat of a nuisance, they do not necessarily create the major production problems that arise with high yielding winter wheat and grass seed residue. When determining the total amount of “eligible” straw in eastern Washington, all the higher yielding crops (translating to a heavy residue) were taken into consideration, whether they be winter wheat, spring wheat, barley or grass seed. *As it turns out, no dryland spring wheat has yields high enough to produce "eligible" straw in this study*.

To find the amount of eligible straw for each crop in a given county, the grain yields of that crop must first be assessed. Grain yield (in bushels or pounds) is estimated annually on a per county, per crop basis by the Washington Agricultural Statistics Service (WASS). With these data, the total amount of straw per county can be estimated, as well as the portion of this straw that is most economical to harvest.

Since the yield of each crop is what is being assessed here, crops must be broken down into categories. Then, for wheat only, the annual crop must be segmented because yields in a given area can vary greatly between the spring and winter crop. Next, for each of the three straw-producing crops, the irrigated acreage and yields must be separated from the dryland acreage and yields. Crop yields differ significantly between irrigated land and dryland in any particular county. These segregated data were averaged over the past seven years on a per county basis (a five-year average was assumed to be adequate, but some counties are missing one or two years of data). Therefore, the counties have either five- or seven-year averages and the data can be seen in *Appendix B*.

To transit from grain yields (bushels) to straw yields (tons) requires several conversions. For example, the amount of straw that is harvestable after grain harvest can be affected by the combine harvest technique, i.e., how high or low the combine (grain harvester) cuts on each plant. Most farmers harvest grain at a very similar height on the plant. According to articles appearing in *Harvesting Cereal Grain*, *Best Management Practices when Harvesting Surplus Cereal Straw*, and *Straw for Energy*

Production, baling removes 0.6-0.8 ton of residue per ton of grain produced. With this information, along with additional input provided by custom balers, stubble harvesting is estimated to take 0.7 ton of residue per ton of grain. With a wheat bushel weight of 60 pounds, and barley bushel weight of 48 pounds, the amount of resultant straw can be calculated. For example, with an average winter wheat yield of 90 bushels per acre, there are (90 bu x 60 lbs) 5,400 lbs of grain per acre. With our conversion above of *0.7 ton of residue per ton grain*, this comes to (5,400 lbs x 0.7) 3,780 lbs of residue (straw) per acre and converts to (3,780 lbs/1 ton) 1.89 tons of straw per acre. If the county produces an average of 50,000 acres of winter wheat, that county would generate a total of (50,000 acres x 1.89 ton/acre) 94,500 tons of winter wheat straw annually. This is how the last column labeled "TOTAL STRAW" is calculated in *Appendix B*.

With the calculations mentioned, 50 bushels of wheat per acre and 60 bushels of barley per acre yield approximately 1 ton of straw per acre. According to *FiberFutures* and other farmers and balers, wheat which yields less than 50 bushels should not be considered adequate to produce a harvestable straw crop. There are two reasons for this. First, with wheat yields less than 50 bushels per acre, the remaining residue (stubble) after grain harvest is not considered a major nuisance. That is, with wheat yields at less than 50 bushels per acre (and barley yields less than 60 bushels per acre), the farmer would not find it necessary to burn the stubble because the residue does not cause a significant production problem. In fact, with wheat yields below 50 bushels per acre, most farmers would rather leave all the stubble in the field for water holding and erosion purposes. The second reason is due to the high baling cost, i.e., the fact that the straw yield is less than 1 ton/acre produces high costs per ton of straw harvested. The lower the yield of any balable crop (the less dense the stubble), the higher the harvesting cost per ton of straw becomes. Many balers assume that a straw crop with yields less than 1 ton/acre is, for the most part, not cost-effective and not worth baling (Moris, Von Mouerik, Levy). For the reasons mentioned, wheat and barley yields of less than 50 bu/ac and 60 bu/acre, respectively, will not be considered "eligible" product in this study and, therefore, are not included in the estimated total amount of straw available for harvest as calculated in *Appendix B*.

Three counties – Klickitat, Okanogan, and Stevens – were also removed from the data before the yields were even evaluated. This was due to the combination of an insignificant amount of eligible crop acreage – only about 2.5% of total average annual grain crop – as well as the non-central location of these counties relative to the remaining producing counties in eastern Washington.

Grass seed yields are measured on a pound-per-acre basis instead of a bushel-per-acre basis, and no credible data or ratios for grass seed yields exist. Since the majority of the grass seed is grown in the higher yielding counties and under conditions of irrigation or higher rainfall, the average grass seed straw yield is estimated to be about 2 tons per acre.

As shown in *Appendix B,* the significant counties' total amount of eligible straw summed to a total of almost 3 million tons in eastern Washington.

Plant Location

Total transportation costs are one of the main criterion considered when the plant location is evaluated. Harvesting and hauling costs on a per-ton or ton-per-mile basis have already been added. The most cost-effective and economically efficient methods for harvesting and hauling have already been calculated and expressed. Producers have little control over per ton transportation costs and generally cannot change them. The only cost that can be manipulated and minimized in this situation is the TOTAL cost of hauling. Hence, although the hauling cost on a ton-per-mile basis is set by the hauler, the total cost of transporting all the demanded straw can be minimized by hauling the product the shortest possible distance. The objective, therefore, is to identity an electric co-generating plant location where the total cost of transporting straw to that potential site is minimized.

It is probably unrealistic to believe that all 3 million tons of the eligible straw in the eastern half of the state will be harvested and transported to one specific location. But, an analysis will be performed to determine where, if possible, the least cost single location would be should it become the destination of all possible straw supply. This exercise will reveal where the heaviest producing areas are located and where the least cost point of usage would be.

Since the most detailed data available is on a per county basis, only the least cost county can be found, i.e., no more site specific location can be found with the available data. First, the total amount of straw produced per county has to be determined, as explained and already accomplished in the previous section. The approximate center-point distance between all producing counties must then be estimated. This distance estimate does not take actual roads, highways or topography into consideration, but is just a general estimate of the proximity between center points of each county. Every county is then singularly considered a candidate as a supply location and a demand location. The total amount of transportation costs is then determined for each recipient county by simply multiplying the trucking cost between two producing and consuming counties – depending on the distance between them – by the total amount of straw that has to be transported. In essence, this was done making every county a possible demand location while simultaneously making all other counties supply locations. When calculating the total cost of the demand county, it is assumed that the product produced within that county will not have any transportation cost, i.e., only the cost of transporting the product from all the other counties to this demand county will be considered. Finding the demand county with the minimal amount of total transportation costs is the obvious objective in this procedure. This analysis is shown in *Appendix C*.

The demand county with the minimal amount of transportation costs was determined to be Whitman County (*Appendix C*). This came as no surprise considering the fact that Whitman generates by far the largest amount of product (eligible straw) due to its high acreage and yields, and is one of the most centrally located counties amongst the other major producing counties in eastern Washington. This conclusion can be considered significant, if not surprising, since a Whitman County location generates 10% less in total cost. When considering Whitman County as the demand county, a total cost of about $25.8 million is incurred. This is 10% lower than the second least-cost demand county, Adams County, for which a total cost of about $28.7 million is determined (figures shown in *Appendix C*).

Where the cost-minimizing demand location is within Whitman County cannot be determined given the methodology employed. This would require an entire separate study which would include a multiple of other factors such as rural road and highway conditions, traffic, location of every ton of straw produced in every county including Whitman County, land cost, zoning restrictions, taxes, labor supply, etc.

Plant Structure

Today's existing straw-fired electric power generating facilities produce a range of output from 3 to 36 megawatts. The total costs of constructing a straw-fired power plant with output capacities of 5 to 30 megawatts (MW) are estimated from $14 to $80 million, depending on the facility's output capacity, or $2.5 to $3.5 million per megawatt (Miles, Ecotherm). Operating costs of such facilities can vary depending on the particular burning system used, and the conveyer system of moving the product to its area of combustion. However, the most technologically advanced facilities consuming purely straw have capital costs – cost to own and operate once built – of about $30 to $50 per MW or $.03 to $.05 per kilowatt (kW) (Miles, Sterzinger, Ecotherm).

Currently, the United States has no such power generating plants in use. The most similar facility in the Northwest region is a refuse burning power plant located in Spokane, WA. According to Tom Miles, the proposed straw-fired power plant considered for this study would be very similar to the current facility in Spokane – similar with regards to engineering technicalities such as boiler and turbine design.

Some European countries, however, do have straw-fired power plants already in operation. The countries with the biggest and most efficient straw burning facilities are Denmark, the United Kingdom, and Spain, with Denmark far ahead of anyone else and burning two million tons of straw per year for electrical power generation (Miles). These facilities and their operating costs, however, are subsidized by the federal governments.

According to Tom Miles and the Center for Biomass Technology in Denmark, a majority of the straw-fired power plants in Denmark have an output capacity of 5 to 6 MW. The construction costs of such plants approximate $14 million. Many of these plants are combined heat and power plants (CHP) capable of producing both heat and electricity for area homes. The plants with a 5 to 6 MW capacity can consume straw ranging from 15,000 tons per year up to as much as 30,000 tons per year (Center for Biomass Technology).

One example of the world's largest and most recently constructed straw-fired power station is located near Ely in Cambridgeshire, United Kingdom. The plant has a total capacity of 36 MW, and cost a total of $85 million to build. The plant will generate enough electricity to fulfill the demand of 80,000 homes, requiring a total of 200,000 tons of straw annually, gathered within a 50-mile radius of the plant. The plant is supplied with large bales having a moisture content of less than 25%. The plant site contains enclosed barns with a capacity to store 2,200 tons of straw, which is a four days' supply of fuel. It is estimated that about 45 long-term jobs are directly created by the facility (Department of Trade & Industry, United Kingdom).

A similar plant proposed in eastern Washington by Ecotherm would have a capacity of about 25 MW with a total construction cost of approximately $70 to $80 million and capital costs of approximately $.03 per kW. Such a facility would consume 180,000 to 200,000 tons of straw annually. Ecotherm elected this size of plant as the best option for the area because a smaller facility will be less economical, due to economies of size, and a larger plant would become too expensive to build and would require too great a distance radius from which to draw and transport straw.

Another facility has been proposed by Chariton Valley Resource Conservation & Development (RC&D) Inc., a rural development organization in Iowa. This facility will be designed to consume switchgrass and coal. The plant has not yet been built, but the RC&D and the state of Iowa are very optimistic that it will be constructed, hoping to produce 35 MW from 200,000 tons of switchgrass (Iowa Department of Natural Resources).

A plant within this range – 20 to 30 MW – would likely be the best proposition for the eastern Washington region for at least two reasons. Though there exists a large assembly cost for such a facility capable of producing 25 MW, it is already known from the plant in the UK and similar ones in Denmark and Spain that a plant of this size can be run very efficiently. A plant of this size, as opposed to a smaller plant capable of producing only 3 or 4 MW output, would also demand a significant amount of straw in the region (approximately 200,000 ton annually) resulting in a more significant demand, and therefore greater benefit for the local agricultural economy. There are no purely straw burning facilities in the world that currently produce more than 36 MW. Therefore, it would not be rational to propose, in the abstract, a plant with greater output for this study.

Impact

Generating costs notwithstanding, the total possible amount of electricity that can be generated from straw produced in eastern Washington can be assessed. As already calculated and explained in the **Acreage/Yields** section of the paper, the total eligible amount of straw produced each year in eastern Washington is approximately 3 million tons. The previous section shows that the most efficient straw-fired power facilities can produce 30 to 35 megawatts consuming about 200,000 tons of straw per year. Therefore, eastern Washington has the total potential to produce approximately 450 to 525 megawatts annually from burning purely straw in plants of the size noted. For comparison purposes only, the volume of power exceeds the output (annually) of any of the current Snake River dams.

Conversions

According to Tom Miles, who has already done extensive work on biomass energy and is internationally known for his knowledge and consulting on the subject, one dry ton of straw generates about one megawatt hour of electrical energy. This pertains to the most efficient systems for burning straw for power generation. Hypothetically, if it costs $30 to get one ton of straw to the point of consumption (including harvesting costs, transportation costs, etc.), it would cost $30 in fuel to generate one megawatt or $.03 per kW. The capital cost to own and operate a facility with this output would cost (as already determined) about $30 to $50 per MW or $.03 to $.05 per kW (Miles, Sterzinger, Ecotherm). Therefore, the total cost of producing one megawatt of electricity from straw in this example would be $70 per MW or $.070 per kW.

Results

So far, this study has calculated the total supply of product that eastern Washington agriculture has to offer, on an aggregate basis. The study has also assessed all of the possible costs to harvest, move, and store the straw on a per ton basis. These are the critical data needed to determine the economical feasibility of such a project. These per ton costs will comprise the total fuel (straw) cost ready for consumption. With these fuel costs, plus the capital costs to own and operate the plant, it can be determined whether or not straw is an economical and competitive fuel source for producing electricity:

Assume a scenario with an average straw yield of 2 tons per acre, transported in from a 20-mile radius from the site of consumption and stored for most of the year.
Costs will be the average of, on a per ton basis, storage cost on a per ton per year basis:

	Per ton/Per MW	Per kW
• Total harvesting cost (includes cut, baled and stacked in field)	$27	$0.27
• Storage cost (assume tarped in field)	$2.5	$.0025
• Loading and unloading	$3	$.003
• Transportation (20 miles)	$8.5	$.0085
TOTAL FUEL COST	**$41**	**$0.41**
• Plus: Capital Cost of Plant	$40	$.040
TOTAL CONVERSION COST	$81	$.081

To produce one megawatt of electricity with straw as a fuel source transported from within a 20-mile radius and stored for the majority of the year, the total cost would be approximately $81 per MW or $.081 per kW. According to Tom Von Muller of

Bonneville Power Association, the present (2002) market price per kilowatt in the Pacific Northwest is approximately $.035 to $.040 per kW.

Conclusion

Though straw as a fuel for electricity generation appears to be comparatively uneconomical at this time, it should not be assumed to be forever unfeasible for three reasons: blend pricing, environmental benefits and the volatile electricity market.

Blend pricing refers to the manner in which the electricity suppliers price their product. Though the current market price for a kilowatt is about $.035, this does not imply that every alternative means of producing power costs $.035 or less to produce. Bonneville Power Association (BPA) may sell their power at the market price of $.035 per kilowatt, but they may have a portfolio of numerous suppliers in order to satisfy their total demand. The various power producers within BPA's portfolio may include relatively expensive to very cheap power producing sources. For example, a kilowatt generated from hydroelectric dams may cost less than $.001 to produce, while the cost to produce a kilowatt from the refuse burning plant in Spokane may cost well above the market price of $.035. This consideration is often characterized as pricing on the margin – basing the price of the power on the producing cost of the final supplier or method. Though the power produced from the refuse burning plant may prove uneconomical when priced on the margin, its additional supply of electricity may render the higher cost acceptable when their supplies are blended in with the various other much less expensive methods of power production. This is the practice of blend pricing – a specific method's high production cost is judged acceptable because of the benefit of the additional supply when its high cost is blended with other methods' lower production costs into one supply portfolio. Therefore, in a time of a power supply shortage or excess demand, the relatively expensive cost of producing power from straw may prove acceptable when its cost is blended with the comparatively lower costs of power production from the other alternative suppliers.

The fact that straw as a fuel is considered "green power" and represents a renewable fuel resource can make the alternative of straw-fired power even more attractive. Many organizations and state and federal governments are looking for more sustainable energy production through the use of green power. Unlike carbon-based fuels, such as coal, straw is a "CO_2 neutral" form of fuel. That is, although the consumption of straw to produce electricity releases CO_2 into the atmosphere, the effect is balanced by the fact that the very same straw absorbs CO_2 from the atmosphere through photosynthesis during its growing process (Skott). Therefore, straw used as a fuel would not contribute to the ever increasing CO_2 content in the atmosphere, which may be an additional incentive or added value to straw when considered as a fuel source (Center for Biomass Technology).

The proposed project involving switchgrass in the state of Iowa mentioned previously also valued these environmental benefits. They referred to these benefits as "value externalities," which consisted of three specific benefits: carbon credits, environmental benefits, and renewable portfolio incentives. They claim they can put a monetary value on these value externalities in order to offset the high costs of straw as a fuel source.

The last reason not to be too skeptical about the prospects of such a straw-fueled power generation project is due to the volatility of the energy market/industry in the past couple years. One of the incentives for this study was the fact there had been a major power shortage in the Northwest and electricity prices soared to unimaginable levels during the year 2001. To illustrate this, review these price fluctuations in 2000 and 2001 as reported by Avista Utilities:

- Before April 2000, wholesale electric prices ranged from $20 to $30/MW.
- During the summer of 2000, those prices increased to over $200/MW, peaking as high as $1,000/MW.
- Then, during this last winter prices remained high averaging over $300/MW, peaking as high as $3,000/MW.
- The average wholesale electric price in the Pacific Northwest for the year 2000 was $118/MW, and for the first six months of 2001 the average has been $227/MW.
- During June 2001, prices have moderated due in part to federal price caps. The average wholesale electric price for June was down to $61/MW.

With an obviously volatile electricity market, and the lack of construction of new power generating facilities in the Northwest, there is the distinct possibility of more electricity shortages and price fluctuations in the near term future.

To see when the market would possibly accept straw as an economical biofuel, we provide the following sensitivity analysis in *Table 3*. The analysis shows how sensitive the total cost of electrical power generation from straw is at different collecting distances and changes in electricity market price.

Table 3.

costs for fuel source (straw)	cost/ton	
Total Cost for Fuel excluding transportation	$33.00	$33/MW or $.033/kW
Capital Cost for Plant Operation	$40.00	$40/MW or $.040/kW
Total Costs to Produce one MW not including transportation costs	**$73.00**	$70/MW or $.073/kW

Sensitivity Analysis Objective: *how sensitive the total cost of electrical power generation from straw is to changes in straw collecting distances and changes in market price (shaded cells indicate total cost to generate electricity from straw is less than market price)*

		Market Price per kilowatt hour (kWh)							
Transportation cost per ton		**$0.05**	**$0.06**	**$0.07**	**$0.08**	**$0.085**	**$0.09**	**$0.095**	**$0.10**
10 miles	$7.75	$0.081**(1)**	$0.081	$0.081	$0.081	$0.081	$0.081	$0.081	$0.081
20 miles	$8.50	$0.082	$0.082	$0.082	$0.082	$0.082	$0.082	$0.082	$0.082
30 miles	$9.25	$0.082	$0.082	$0.082	$0.082	$0.082	$0.082	$0.082	$0.082
40 miles	$10.00	$0.083	$0.083	$0.083	$0.083	$0.083	$0.083	$0.083	$0.083
50 miles	$10.75	$0.084	$0.084	$0.084	$0.084	$0.084	$0.084	$0.084	$0.084
60 miles	$11.50	$0.085	$0.085	$0.085	$0.085	$0.085	$0.085	$0.085	$0.085
70 miles	$12.25	$0.085	$0.085	$0.085	$0.085	$0.085	$0.085	$0.085	$0.085
80 miles	$13.00	$0.086	$0.086	$0.086	$0.086	$0.086	$0.086	$0.086	$0.086
90 miles	$13.75	$0.087	$0.087	$0.087	$0.087	$0.087	$0.087	$0.087	$0.087
100 miles	$14.50	$0.088	$0.088	$0.088	$0.088	$0.088	$0.088	$0.088	$0.088
110 miles	$15.25	$0.088	$0.088	$0.088	$0.088	$0.088	$0.088	$0.088	$0.088
120 miles	$16.00	$0.089	$0.089	$0.089	$0.089	$0.089	$0.089	$0.089	$0.089
130 miles	$16.75	$0.090	$0.090	$0.090	$0.090	$0.090	$0.090	$0.090	$0.090
140 miles	$17.50	$0.091	$0.091	$0.091	$0.091	$0.091	$0.091	$0.091	$0.091
150 miles	$18.25	$0.091	$0.091	$0.091	$0.091	$0.091	$0.091	$0.091	$0.091
160 miles	$19.00	$0.092	$0.092	$0.092	$0.092	$0.092	$0.092	$0.092	$0.092
170 miles	$19.75	$0.093	$0.093	$0.093	$0.093	$0.093	$0.093	$0.093	$0.093
180 miles	$20.50	$0.094	$0.094	$0.094	$0.094	$0.094	$0.094	$0.094	$0.094
190 miles	$21.25	$0.094	$0.094	$0.094	$0.094	$0.094	$0.094	$0.094	$0.094
200 miles	$22.00	$0.095	$0.095	$0.095	$0.095	$0.095	$0.095	$0.095	$0.095

(1) calculation: ($73 + $7.75)/1,000

From this sensitivity analysis, straw as a fuel is very dependent on, or sensitive to, market electricity prices. With a change in market price of only $.02 per kW ($.08 to

$.10), straw is an uneconomical fuel source at a market price of $.08 no matter how close the collecting distance, while becoming an economical fuel source at a market price of $.10 at distances collected from 200 miles.

The table also shows that a change in distance from which the straw is collected is a much less significant factor in determining whether straw as a fuel is economical or not. It is a significant determinant when considering straw as a fuel only within a small market price window. For example, if the market price for a kilowatt is fairly steady at about $.085, then the distance from which the straw is gathered becomes a significant factor. At this market price, hauling straw a distance of no more than 70 miles is economically feasible, but any further increase in distance and the fuel becomes uneconomical. However, if the market price is at $.04 or $.05 per kW, the distance from which the straw is gathered is not a significant factor, for it becomes an uneconomical source of fuel no matter how close the radius distance of collection.

Many would claim that a major setback for selling baled straw at a marketable price is linked to the cost of transportation. From this analysis, however, transportation costs only significantly raise the total cost of straw at a relatively long radius distance. For example, the increase in transportation cost from a distance of 10 miles to a distance of 100 miles is about $7/ton ($7.75 to $14.50, *Appendix A*). Considering that the total cost of producing electricity with one ton of straw (excluding transportation cost) is about $73/ton, the price difference in straw collected from 10 miles to 100 miles is only about 10% ($7/$73) of the total cost.

One must conclude that the most significant factor to take into consideration for a straw-fired power plant is the current and expected future market price for electricity. If the market price is expected to stay at its current level of about $.04 per kW, this proposed plant does not appear economical. If, however, prices are expected to rise significantly, as they did in 2000 and 2001, and perhaps stabilize at a higher market rate, then the proposed plant proves more attractive and economical.

The term "economical" takes into consideration only whether or not the power facility can possibly be profitable. It does not take into consideration the practice of blend pricing or external benefits such as the positive impact on the agriculture industry, the local economies, or the beneficial environmental impacts that would result.

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Equipment Information

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Appendix A

Loaded truck with 3'x4'x8' bales totaling 20-25 tons

Miles	Price/Ton	Price/Truck	Change by $1.50 per Loaded Mile
10	**$7.75**	$155.00	$7.50
15	**$8.13**	$162.50	$7.50
20	**$8.50**	$170.00	$7.50
25	**$8.88**	$177.50	$7.50
30	**$9.25**	$185.00	$7.50
35	**$9.63**	$192.50	$7.50
40	**$10.00**	$200.00	$7.50
45	**$10.38**	$207.50	$7.50
50	**$10.75**	$215.00	$7.50
55	**$11.13**	$222.50	$7.50
60	**$11.50**	$230.00	$7.50
65	**$11.88**	$237.50	$7.50
70	**$12.25**	$245.00	$7.50
75	**$12.63**	$252.50	$7.50
80	**$13.00**	$260.00	$7.50
85	**$13.38**	$267.50	$7.50
90	**$13.75**	$275.00	$7.50
95	**$14.13**	$282.50	$7.50
100	**$14.50**	$290.00	$7.50
105	**$14.88**	$297.50	$7.50
110	**$15.25**	$305.00	$7.50
115	**$15.63**	$312.50	$7.50
120	**$16.00**	$320.00	$7.50
125	**$16.38**	$327.50	$7.50
130	**$16.75**	$335.00	$7.50
135	**$17.13**	$342.50	$7.50
140	**$17.50**	$350.00	$7.50

Miles	Price/Ton	Price/Truck	Change by $1.50 per Loaded Mile
145	**$17.88**	$357.50	$7.50
150	**$18.25**	$365.00	$7.50
155	**$18.63**	$372.50	$7.50
160	**$19.00**	$380.00	$7.50
165	**$19.38**	$387.50	$7.50
170	**$19.75**	$395.00	$7.50
175	**$20.13**	$402.50	$7.50
180	**$20.50**	$410.00	$7.50
185	**$20.88**	$417.50	$7.50
190	**$21.25**	$425.00	$7.50
195	**$21.63**	$432.50	$7.50
200	**$22.00**	$440.00	$7.50
205	**$22.38**	$447.50	$7.50
210	**$22.75**	$455.00	$7.50
215	**$23.13**	$462.50	$7.50
220	**$23.50**	$470.00	$7.50
225	**$23.88**	$477.50	$7.50
230	**$24.25**	$485.00	$7.50
235	**$24.63**	$492.50	$7.50
240	**$25.00**	$500.00	$7.50
245	**$25.38**	$507.50	$7.50
250	**$25.75**	$515.00	$7.50

Sources: Gary Moris, Fif/Miller Study, California Rice Commission, K&L Farms, Rob Moris Trucking, Troy Fine Trucking

Appendix B

TOTAL STRAW

Shaded cells indicate "ineligible" straw due to low yields or insignificant county which is NOT included in "TOTAL STRAW" column.

Empty cells indicate either crop not grown in that county or no available statistics due to insignificant acreage.

		IRRIGATED						DRYLAND						
		Spring			Winter			Spring			Winter			
	Total Acreage	acreage	bushels	tons	acreage	bushels	tons	acreage	bushels	tons	acreage	bushels	tons	TOTAL STRAW (TONS)
Adams														
wheat	313,771	8,817	83.6	1.7556	38,267	100.917	2.12	35,050	30	0.63	230,900	49	1.0269	333,686
barley	8,386	1,800	100.0	1.7				7,357	54.3143	0.91				3,024
grass seed	3,471			2										6,943
Asotin														
wheat	24,817			0			0	5,800	35	0.73	19,000	55	1.1501	21,852
barley	9,567							9,567	47.1167	0.79				0
grass seed	0													
Benton														
wheat	129,629	2,050	83	1.7430	8,133	109.350	2.3	17,350	21	0.43	104,050	36	0.7609	22,250
barley	0													0
grass seed	0													
Columbia														
wheat	94,133			0			0	8,767	41	0.86	85,375	67	1.4102	120,392
barley	16,114							16,114	67.7143	1.14				18,332
grass seed	0													
Douglas														
wheat	217,600			0			0	28,333	24	0.50	184,367	44	0.9279	0
barley	3,650													0
grass seed	0													
Franklin														
wheat	122,543	8,360	93.84	1.9706	21,950	104.783	2.2	13,540	33	0.68	81,883	41	0.8533	64,774
barley	2,250													
grass seed	3,571			2										7,143
Garfield														
wheat	82,500			0			0	16,050	34	0.72	64,980	62	1.3087	85,041
barley	37,429							37,429	58.1571	0.98				0
grass seed	3,443			2										6,886

Appendix B, Cont.

		IRRIGATED						DRYLAND						
		Spring			Winter			Spring			Winter			
	Total Acreage	acreage	bushels	tons	acreage	bushels	tons	acreage	bushels	tons	acreage	bushels	tons	TOTAL STRAW (TONS)
Grant														
wheat	217,629	23,633	90.1	1.892	60,550	110.833	2.33	9,467	30	0.63	127,767	51	1.0686	322,172
barley	7,500	2,071	107.6	1.8				5,429	52.257	0.88				3,743
grass seed	4,829			2										9,657
Klickitat														
wheat	48,786			0			0	5,800	21	0.44	34,500	40	0.8308	0
barley	10,743							15,029	35.186	0.59				0
grass seed	0													
Lincoln														
wheat	368,886	4,200	69.575	1.461	27,683	94.317	1.98	44,275	42	0.88	283,250	62	1.3059	430,850
barley	102,114	3,140	89.8	1.5				99,871	63.571	1.07				111,399
grass seed	1,700			2										3,400
Okanogan														
wheat	9,633			0			0	0	0	0.00	5,700	54	1.1261	0
barley	1,100													
grass seed	0													
Spokane														
wheat	119,457			0			0	24,567	47	0.98	93,650	64	1.3447	125,931
barley	39,386	700	87.0	1.5				39,086	60.529	1.02				40,769
grass seed	25,329			2										50,657
Stevens														
wheat	10,014			0			0	2,500	42	0.88	7,750	61	1.2793	0
barley	4,957	580	82.3	1.4				4,543	57.286	0.96				0
grass seed	0													
WallaWalla														
wheat	228,543	8,060	85.48	1.795	15,525	92.400	1.94	31,640	43	0.90	169,375	69	1.4427	288,950
barley	23,000	1,160	63.5	1.1				22,171	66.743	1.12				26,097
grass seed	8,700			2										17,400

Appendix B, Cont.

		IRRIGATED						DRYLAND						
		Spring			Winter			Spring			Winter			
	Total Acreage	acreage	bushels	tons	acreage	bushels	tons	acreage	bushels	tons	acreage	bushels	tons	TOTAL STRAW (TONS)
Whitman														
wheat	494,086			0			0	84,250	47	0.99	411,500	73	1.5288	629,101
barley	159,143							159,143	69.9	1.17				186,885
grass seed	4,214			2										8,429
Yakima														
wheat	41,500	6,850	93.425	1.9619	10,033	106.633	2.24	8,800	28	0.58	17,217	27	0.5691	35,907
barley	1,743							1,686	66.7857	1.12				1,891
grass seed	0													
											TOTAL STRAW			**2,983,560**

Appendix C

TOTAL COST per county							
	Demand →						
Supply ↓	Whitman	Asotin	Garfield	Columbia	Walla Walla	Spokane	Franklin
Whitman		$8,862,454.92	$7,320,799.97	$8,557,421.59	$9,794,043.21	$8,862,454.92	$10,412,354.02
Asotin	$234,909.00[1]		$194,045.76	$210,434.76	$251,298.00	$316,854.00	$292,379.76
Garfield	$816,311.76	$816,311.76		$781,379.50	$988,215.25	$1,195,051.00	$1,126,105.75
Columbia	$1,439,955.12	$1,335,912.12	$1,179,154.00		$1,283,197.00	$1,907,455.00	$1,491,283.00
Walla Walla	$3,949,470.36	$3,823,140.50	$3,573,805.25	$3,075,134.75		$4,946,811.36	$3,075,134.75
Spokane	$2,336,587.75	$3,151,676.50	$2,825,641.00	$2,988,658.75	$3,234,272.16		$3,234,272.16
Franklin	$908,311.71	$962,249.46	$880,983.25	$773,107.75	$665,232.25	$1,070,124.96	
Adams	$3,694,269.75	$4,598,077.14	$3,952,009.50	$3,824,857.89	$3,824,857.89	$4,082,597.64	$3,436,530.00
Lincoln	$6,481,953.72	$8,320,689.75	$7,300,382.22	$7,502,261.25	$7,502,261.25	$5,865,404.25	$6,891,167.97
Grant	$4,865,794.00	$5,620,831.00	$5,117,473.00	$4,865,794.00	$4,489,953.36	$4,993,311.36	$3,734,916.36
Douglas	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Yakima	$718,162.00	$746,510.50	$704,176.74	$647,479.74	$576,419.50	$774,859.00	$519,722.50
Benton	$339,312.50	$339,312.50	$322,625.00	$289,250.00	$239,187.50	$389,375.00	$214,267.50
SUM	**$25,785,037.67**	**$38,577,166.15**	**$33,371,095.69**	**$33,515,779.98**	**$32,848,937.37**	**$34,404,298.49**	**$34,428,133.77**

[1] Whitman County as demand county and Asotin as supply county. Distance between the two counties is 50 miles which costs $10.75 per ton to haul (given in Appendix A). The total cost is the hauling cost per ton multiplied by the total amount of straw to be hauled: $10.75 X 21,852 tons = $234,909.

Appendix C, Cont.

						supply constraint
Adams	Lincoln	Grant	Douglas	Yakima	Benton	total tonnage
$8,862,454.92	$9,794,043.21	$11,954,008.97	$13,190,630.58	$15,663,873.82	$12,572,319.77	824,414
$292,379.76	$333,243.00	$366,021.00	$415,188.00	$431,577.00	$333,243.00	21,852
$1,057,160.50	$1,229,983.26	$1,401,886.75	$1,574,709.51	$1,712,600.01	$1,332,941.50	91,927
$1,543,998.12	$1,907,455.00	$2,011,498.00	$2,323,627.00	$2,376,342.12	$1,803,412.00	138,724
$3,700,135.11	$4,571,146.25	$4,448,140.86	$5,319,152.00	$5,069,816.75	$3,573,805.25	332,447
$2,582,201.16	$2,336,587.75	$3,234,272.16	$3,314,694.25	$4,455,818.50	$3,803,747.50	217,357
$719,170.00	$908,311.71	$800,436.21	$1,016,187.21	$988,858.75	$692,560.71	71,917
	$3,436,530.00	$3,694,269.75	$4,467,489.00	$5,371,296.39	$4,340,337.39	343,653
$5,456,190.00		$6,072,739.47	$6,274,618.50	$9,346,453.47	$8,118,810.72	545,619
$3,607,399.00	$3,734,916.36		$3,355,720.00	$4,362,436.00	$4,110,757.00	335,572
$0.00	$0.00	$0.00		$0.00	$0.00	0
$590,782.74	$647,479.74	$491,374.00	$562,434.24		$434,677.00	37,798
$281,017.50	$331,080.00	$272,562.50	$339,312.50	$255,875.00		22,250
$28,692,888.81	**$29,230,776.28**	**$34,747,209.67**	**$42,153,762.79**	**$50,034,947.81**	**$41,116,611.84**	

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