Economic and logistic	Responsible	IKJ
	Made	06-01-2014
Project: 2525 - Biochain	Page	1 af 13

1 Introduction

The management of a biomass can be done in various ways prior gasification in a biogas plant. The design of the supply chain will depend on factors such as harvest time, biomass composition, and biomass stability during storage and also time of use in the biogas plant. There are many supply chain opportunities but only few are optimal based on economic and environmental aspects. The aim of this project named Biochain is to develop a dynamic value chain model which will work as a decision support tool for consultants and biogas producers when assessing establishment of biogas plant. The overall result is an advanced mathematical model. The research activities are organized in six closely linked work packages which are shown in figure 1.

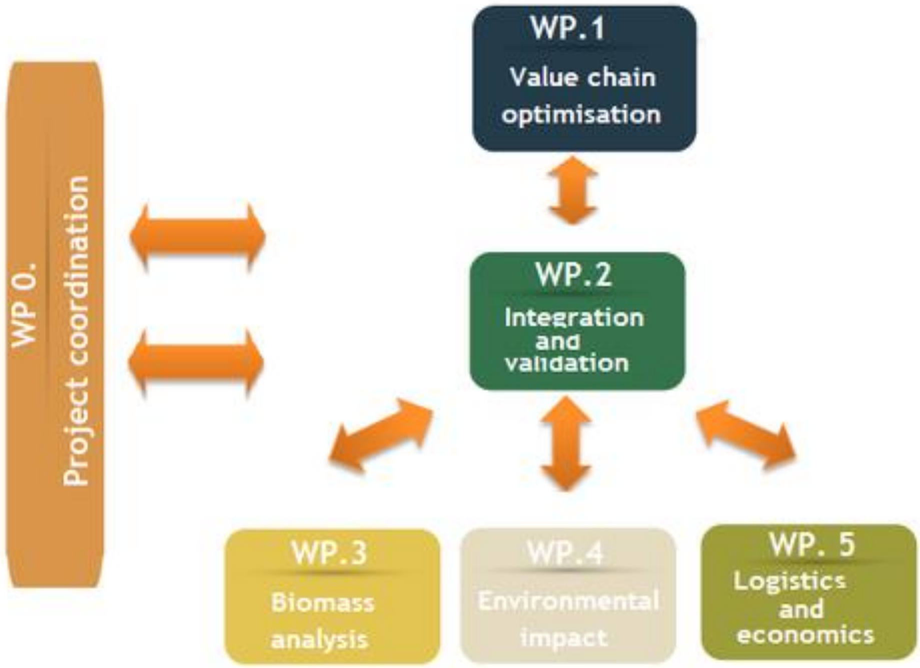

Figure 1: The interactions between the work packages in the Biochain project

In work package 0, all coordination and dissemination will be carried out whereas work package 3-5 focus on providing information and models needed to assess biogas production, environmental benefits and costs associated with each unit of the supply chain. The information from these work packages will be integrated and validated on existing biogas plants in work package 2. Work package 1 integrates the different information and sub-models gained from the other work packages into an advanced dynamic value chain model. The Knowledge Centre for Agriculture (KCA) is responsible for work package 5. The aim of this WP is to provide sub-models to optimize the logistics of harvest, storage and transportation of biomasses for biogas plants. This will be economically evaluated by estimating the costs associated to each unit operation and the income based on the expected biogas potential of the biomass by using some specific biomasses as substrate in biogas plants. Based on that, the supply chain can be optimized.

2 System boundary

An excel model is developed which can optimize the logistic of harvest, storage and transport of large amounts of biomasses and also evaluate the economy. The model which KCA are developing, focus on the economy in each unit operation from field to plant based on seven different biomasses as listed below:

- Manure
- Deep litter
- Wheat straw
- Rapeseed straw
- Meadow grass
- Beets
- Whole crop corn

The supply chain of the biomasses is very diverse. Among others can be mentioned the harvest method, the management of the biomass and the stability of the biomass during storage. The boundary of the supply chain for the biomasses is similar to each other. The supply chain of the biomass initiates with the production and harvest and ends with storage of the biomass at the biogas plant site. An exception is the supply chain of straw where production and harvest of the straw is not included as those operations are allocated to the grain. Hence, the supply chain is initiated with collection of the straw. In appendix 1, some scenarios of the value chain for straw is presented.

Manure and deep litter are residual products from the animal production. The supply chain of manure initiates from collection of the manure from the manure pre-tank at the animal house and finish off by delivering the manure to the biogas plant in the pre-tank. As concerns deep litter, the supply chain initiates by collection of the deep litter at a site near the animal house and ends by storing the deep litter in stack at the biogas plant.

3 Model structure

The contribution to the model work by KCA is made in Excel.

3.1 Transport and logistical model

The model is organized so that it consists of 7 sub-models – one for each biomass. Each sub model consists of an assumption sheet where all assumptions are listed. It includes dry matter %, hourly rate of different machines and vehicles, capacities, time consumption, transport distance, efficiency in gas engine and price for electricity and heat. All these values are variable and can be changed. If the user changes the values, the model sheet will automatically recalculate new results. The model sheet where the results are presented is categorised in the following categories:

- Biomass (e.g. yield in field, field size, dry matter %)
- Production and harvest (unit costs and machine- and work costs)
- Transport (time consumption - loading, on road and unloading)
- Storage (storage methods)
- Potential pre-treatment (briquetting and extrusion)
- Gas yield and gas engine efficiency

The costs are stated in kr. per ton of biomass, so that the costs are comparable to each other. The model is corrected so that limited capacities of vehicles and storages are taken into account. For instance, the costs (kr. /ton) for storage will vary depending on the utilisation of the capacity of the storage facility. The lowest cost level is gained when the capacity is fully utilised. It is not taken into account that other biomass may utilise free capacity which will reduce the storage costs if the capacity is not utilised.

The costs of using the machines and vehicles are given in an hourly rate based on price levels from a contractor. In these prices, the manpower, insurance and depreciation of the machinery are included. The time consumption of each operation is likewise based on experiences gained from contractors. The model also estimates the expected biogas potential for each biomass, treated and untreated prior gasification. Biomasses which will require some kind of pretreatment is straw, deep litter and meadow grass. The pretreatments are limited to extrusion and briquetting. It is possible to pre-treat the straw by briquetting or extrusion. Meadow grass and deep litter can only be extruded to this point. The intension is to try to pre-treat meadow grass by briquetting.

The biogas potential is based on experiments performed at Foulum Research Centre, Aarhus University. The biogas yield is converted into an income in form of sold electricity and heat by conversion in a CHP. Another option is to upgrade the biogas for the purpose of selling the gas to the gas grid. However, this is not modelled to this point. In appendix 2, an example of a sub model is shown. In figure 2, the conclusions of total costs or transport costs for the supply chain for straw (untreated and briquetted) is shown in relation to the driven kilometres. The model is still being in the process of modification.

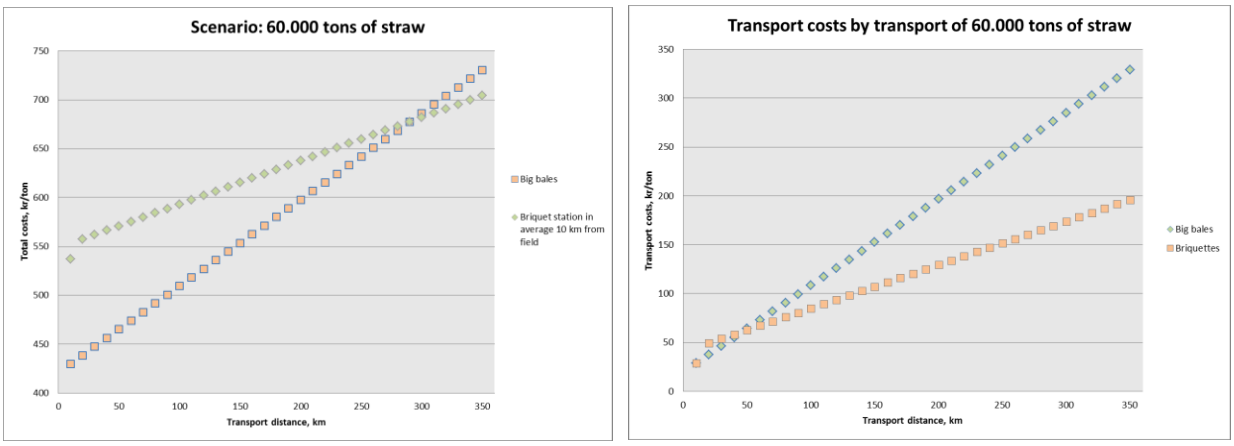

Figure 2: Total- and transport costs for the supply chain of straw, untreated or briquetted in relation to number of driven kilometres. It is presumed that 60.000 tons of straw can be collected in a radius of 25 km from origin. Within this circle, one briquette station is placed. In the calculation behind the curves it is assumed that there is a distance of 10 km in average from each supplier to the briquette station.

The model will be integrated in the larger dynamic model made by DTU which can calculate different parameters in a given case such as greenhouse gas emissions when using wheat straw as substrate in a biogas plant

3.2 Storage model

The input of biomass to a biogas plant requires optimization of which biomasses that is available and when the biomasses are going to be used in the biogas plant, so the plant can adapt the production of biogas and avoid different kind of inhibitions such as substrate inhibition and ammonia inhibition. The biomasses are only available few months every year and the quality of the biomasses may be impaired since harvest. For that reason, KCA are working on a model called an *annual wheel* for the chosen biomasses. The annual wheel will function as stock management model from where the biogas plant can adjust the input of biomass to the plant and hence optimize the gas production and the utilisation of each biomass. In a longer run, the model will be developed so it can correct for a quality change in the biomass during storage as a function of time. At present, the model is organized in weeks so each week has a sheet. In each sheet the storage stock is given for the stock left the week before, the input this week, the output this week and the stock left at the end of the this week. This amount corresponds to the initiated amount the week after. There are cells where the input and output can be entered each week. The stock is given in wet weight, dry weight, volatile solids, total nitrogen, phosphor, potassium and methane. This is showed in appendix 3.

Hence, the model provides an overview of which biomass and how much biomass in total, that is fed to and taken out of the storage on weekly and yearly basis and also a graphical presentation of the gas production and biomass composition, so that an undesirable substrate composition can be observed quickly by a predicted decreasing gas production. The decrease in gas production can then be traced back to the composition and substances in the biomass.

4 Storage and quality

There are many different ways to store biomass depending on the composition of the biomass. Some storage methods are ensiling in plan silo, wrapping of bales, storage in building or outside and also storage in tank. The choice of storage method depends among others of the dry matter content of the biomass.

4.1 Ensiling

Biomasses with a low DM content corresponding to 20-45 % is most efficiency stored by ensiling in order to avoid growth of fungus or another impairment of the biomass. Ensiling is normally done in plan silo where the biomass is compacted to a degree where anaerobic conditions are achieved. The process of ensiling takes at least 4 weeks. The time span of ensiling depends on the buffer capacity of the biomass. During ensiling pH drops during formation of acetic acid and lactic acid. A high level of lactic acid ensures a good preserving. The relation between lactic acid and acetic acid should be at least 3:1 and preferably 5:1 (Attermann *et al* 2003).

Figure 3: To the left: ensiling of corn silage in plan silo. To the right: Ensiling of grass.

Whole crop corn has a dry matter content of 30 %, and thus ensiling is required. During ensiling, pH drops to below 4.3 in order to achieve a good quality of the ensiled corn silage. Corn has to be stored quickly after harvest in order to avoid any loss and preferable within 2-3 hours. If aerobic conditions occur a lot of the energy in the biomass is lost as CO_2.

Beets have lower dry matter content than corn silage (20 %). For that reason, beets also need to be ensiled if stored in a longer period. Beets can be stored as whole beets in plan silo or as pulp in a tank or lagoon.

In some cases, it is also necessary to ensile meadow grass. However, it depends on the dry mater content of the grass which varies a lot. The critical pH value depends on the dry matter content. If the dry matter content of the grass is 20 %, pH has to drop to below 4.2 in order to achieve a good quality of the ensiled biomass whereas pH only has to drop to below 4,8 if the dry matter content is 45 % (Attermann *et al* 2003). Figure 3 shows a plan silo with corn silage and with grass silage.

4.2 Wrapping

It is necessary to wrap biomasses with a dry matter content of 45-85 %. A biomass is not storage stabile before the dry matter content reaches 85 %. It is not suited to ensile biomasses with a DM content of 45-85 % in plan silo because it is not possible to maintain the degree of compaction needed to maintain anaerobic conditions and oxygen will sink in between the biomass and initiate degradation to CO_2. The microbial processes happening after wrapping is similar to those when ensiling in plan silo. Anaerobic conditions are made and the biomass gets preserved after some time.

Figure 4: Grass wrapped in roundbales and stored on the flat surface

Wrapping will only be relevant in relation to meadow grass as the DM content of meadow grass can be within this range. Wrapped round bales have to be stored on the flat surface because a thicker layer of plastic is present there, see figure 4 (Attermann *et al* 2003).

4.3 Storage in hall or outside

Storage in hall or likewise is especially suited for dry biomasses such as wheat straw in order to keep the stability of the biomass during storage. Straw has a DM content of 85-95 %. There are nearly no loss of energy during storage of dry biomasses in a hall. Straw is often pressed into big bales. However, big bales are not suited to be stored outside in a longer period of time because the way big bales are pressed allows water to penetrate into the big bale.

Figure 5: To the left: straw in big bales stored under roof. To the right; Grass in round bales stored outside on the round side.

The DM content of meadow grass varies a lot and depends on the area where it is harvested. In some meadow areas, the grass has DM content close to 85 %. In such a case, the meadow grass will be left on the field after harvest to dry until the grass is storage stabile and pressed in bales afterwards. Meadow grass will be pressed in round bales due to the vulnerability of meadow areas against heavy traffic (Bertelsen *et al* 2012). Experiments made with meadow grass from Nørreådalen showed an average weight of round bales of 280 kg (Høy, 2010), whereas big bales have a weight of approximately 550 kg. It will not be necessary to store round bales inside as straw in big bales because water cannot penetrate into round bales to a degree seen in big bales if round bales are stored on the round side as seen in figure 5.

4.4 Storage in pre-tank

Liquid biomass such as manure is stored in the pre-tank on the biogas plant. In some cases, deep litter is mixed with manure in the pre-tank. However, it depends on how systematic the deep litter arrived to the biogas plant and also how the relation between manure and deep litter is. If deep litter arrives steady during time and in small amounts, the deep litter are stored mixed with manure. If the amount of deep litter is higher than what is pumpable, the deep litter will be stores on a site with drain outlets to the pre-tank with manure. A small number of biogas plants have a mixing- and shredding tank to deep litter with the purpose to get the deep litter more liquid so it can be pumped directly to the pre-tank or digestor. Den average retention time in a pre-tank is 4-7 days.

4.5 Quality change during storage

During storage qualitative and quantitative changes will happen in the biomass. There are small losses of energy in spite of the preservation of ensiled biomass. There is a loss of app. 7% DM during storage of whole crop corn silage (Farmtal Online 2013a). Laursen (2011) from KCA has made an experiment on 4 farms where the loss of DM from corn silage during ensiling was found to vary from 0.7-6.4 % with average 3.1 % loss of DM.

The storage loss is 7 % of DM from grass silage (Farmtal Online 2013b). Laursen (2011) made similar experiments with storage of grass as for corn silage and he found losses from 0.5-6.7 % DM on the 4 farms with an average loss of 3.7 % DM in the grass silage.

The loss from wrapped bales will be even higher than from biomass ensiled in plan silo due to higher surface area in proportion to the volume. For that reason, a larger amount of the bio-mass will be exposed to oxygen.

The loss during storage of beets is not investigated yet but experiments for this purpose are planned in 2014. There is a loss of 9 % of DM during storage of fresh beets in clamp (Farmtal Online 2013c).

During ensiling the biomass is depolymerized leading to formation of lactic acid and small amounts of CO_2. In the anaerobic digestor, lactic acid will be degraded in a fermentation process and create CO_2 and reduced compounds. The biogas potential after storage will decrease because a part of the biogas evaporates in the form of CO2 during storage. However, the methane potential of the biomass will change insignificant after storage and the biogas will have a higher methane %. However, the overall production of methane will not be higher due to the loss of DM.

During storage of deep litter, the biomass will compost and thus loose some of its energy when oxygen is present. According to Sommer (2001), there is a loss of 48.5 % carbon during storage of untreated deep litter from dairy cattle stored in 132 days. It corresponds to app. 55 % loss of the volatile solids after storage. However, deep litter used for biogas will only be stored up to 14 days on the biogas plant before used in the digestor which is why a smaller loss is expected. In general, the size of the loss depends on where the deep litter originates from (cattle, calves or pigs). The loss is lower in deep litter from cattle than from calves because the deep litter from cattle is much more compacted and oxygen will not penetrate into the deep litter. More straw is used to the calves and the deep litter is more loose which gives more access for oxygen. In order to minimize the loss from deep litter, the biomass should be moved as little as possible because every time deep litter is moved the biomass is oxidized (Møller & Jørgensen 2003).

Manure is stored in 4-7 days prior used in the digestor. The pre-tank, where the manure is stored, is not temperate. For that reason the temperature varies from app. 5-20 degrees depending on the season. Møller *et al* (2004) have investigated the loss of carbon from manure during storage and they found an accumulated loss of 1.8-3.8 % carbon after 5 days of storage at 15 degrees. The loss is calculated based on the degradable volatile solids which are present in cattle and pig manure. The highest loss was observed from storage of cattle manure and the lowest from pig manure. The losses are modest after short-term storage which also will be the case in the model. The content of volatile fatty acids increases within 5 days of storage but the actual distribution between the different volatile fatty acids is constant within the same period of time (Møller *et al* 2004). Hence, there is a modest substance and energy loss.

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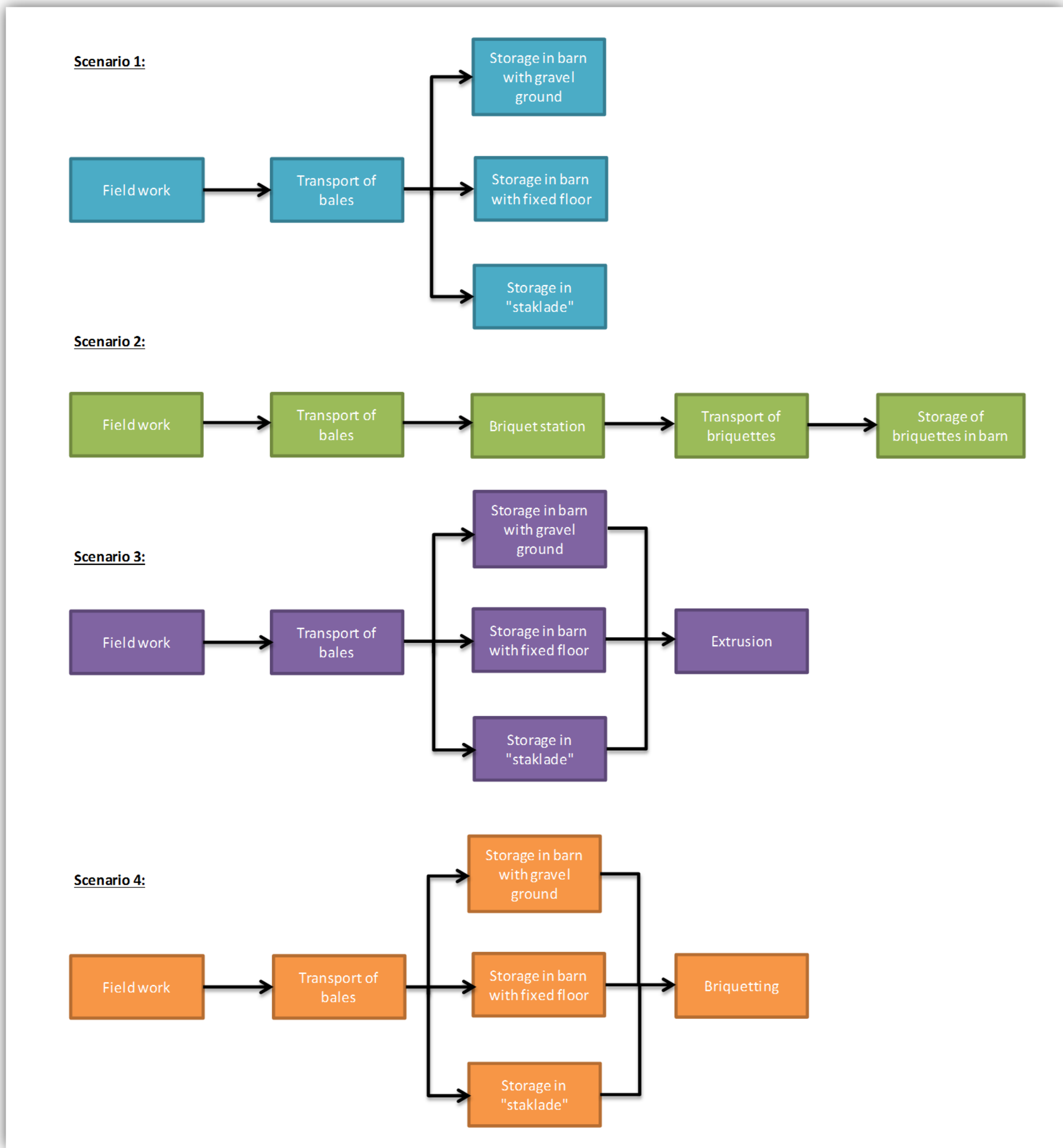
Appendix 1

The figure below presents possible supply chains for straw from field to storage at biogas plant.



Appendix 2

This appendix shows some print screens of the model from Excel.

Wheat straw

Biomass

Yield of wheat straw, tons/ha	3,5
Dry matter, %	85%
Yield in dry matter, tons DM/ha	3,0
Density of wheat straw, ton/m3	0,14
Weight, big bales, ton/bale	0,55
Density of briquettes (bulk), ton/m3	0,45
Field, ha	17142
Time of harvest:	Just after harvest of grain. August/September

Økonomidata	
Bjærgning, kr/ton	-308
Lager, kr/ton	-93
Forbehandling, kr/ton	-140
Lager til briketter, kr/ton	-60
Traktor med frontlæsser, kr/time	-625
Lastbil med lad, kr/time	-525
Lastbil med tipvogn, kr/time	-600

Collecting at field

Straw turning and collecting	
Turning/collecting, kr/kg	-0,07
Turning/collecting, kr/ha	-245
Capacity, ha/hour	4
Turning/collecting, kr/ton	-70
Straw baling in field	
Baler, big bales, kr/kg	-0,15
Capacity, bales/hour	24
Baler, big bales, kr/ton	-149
Loading with tractor with front loader	
Number of bales, bales/ha	6,4
Tractor cost, kr/hour	-625
Loading and unloading of bales, hours/ha	0,5
Loading and unloading of bales, kr/ha	-313
Loading, kr/ton	-89
Total costs for field work, kr/ton	*-308*

Storage

Barn with fixed floor		Barn with gravel ground		Barn "Staklade"		Barn for briquettes with fixed floor	
Price/loan, kr	1.816.500	Price/loan, kr	1.391.500	Price/loan, kr	1.001.500	Price/loan, kr	1.816.500
Capacity, m3	5.000	Capacity, m3	5.000	Capacity, m3	5.000	Capacity, m3	5.000
Utilisation of barn, %	90%	Utilisation of barn, %	90%	Utilisation of barn, %	90%	Utilisation of barn, %	80%
Storage capacity, m3	4.500	Storage capacity, m3	4.500	Storage capacity, m3	4.500	Storage capacity, m3	4.000
Number of big bales, stk	1.145	Number of big bales, stk	1.145	Number of big bales, stk	1.145	Service life, years	30
Service life, years	30	Service life, years	30	Service life, years	30	Interest, %	4%
Interest, %	4%	Interest, %	4%	Interest, %	4%	Fee, kr/year	kr. -105.048
Fee, kr/year	-105.048	Fee, kr/year	-80.471	Fee, kr/year	-57.917	*Fee, kr/ton*	*-60*
Fee, kr/ton/year	*-168*	*Fee, kr/ton/year*	*-129*	*Fee, kr/ton/year*	*-93*		

Wheat straw model | Assumptions, straw | Straw model in graphs | Beet model | Assumptions - beets | Background model data - beets | Meadow grass model | Assumptions - meadow grass | Background data - meadow grass | Deep

Pelletising in field, mobile

Cost price, kr	5.069.400
Service life, year	20
Interest, %	5,5%
Yearly fee, kr/year	-424.204
Yearly fee, kr/ton	-7
Operation costs, l/ton	-48
Curency, kr/l	7,5
Operation costs, kr/ton	-358
Capacity, ton/hour	2,5
Capacity, ton/year	4.650
Costs at max capacity, kr/ton	-449
Total costs, kr/ton	***-450***

Briquet plant

Cormall hammer mill, straw conveyer, straw bale breaker,	411.000
Currency	7,455
Cormall equipment, kr	3.064.005
Briquet plant, kr	1.250.000
Capacity of briquetter, ton/year	10.000
Number of plants, stk	6
Briquet plants, kr	7.500.000
Other things (installation etc.), l	50.000
Total price for plant, kr	10.936.755
Interest, %	5,5%
Service life, year	10
Yearly fee, kr/year	-1.450.955
Fee, kr/ton	-24
Maintenance costs, kr/ton	-40
Energy price, kr/kWh	-0,4
Energy use, kWh/ton	60
Operation costs, kr/ton	-24
A hire building, kr/year	-120.000
Insurance, kr/year	-50.000
Staff, kr/year	-1.860.000
Depreciation, %	10%
Depreciation, kr/year	-1.093.676
Costs, kr/ton	***-140***

Extruder

Extruder, mixer, conveyer, kr	5.500.000
Service life, year	10
Interest, %	5,5%
Fee, kr/year	kr. -729.673
Fee, kr/ton	-73
Operation costs, kWh/ton	-123
Capacity, ton/year	10.000
Maintenance costs, kr/ton	-25
Energy price, kr/kWh	0,4
Operation costs, kr/ton	-49
Depreciation, %	10%
Depreciation, kr/ton	-55
Costs at max capacity,kr/ton	-147
Costs, kr/ton	***-202***

Chain crusher

Price/loan, kr	2.319.314
Service life, years	10
Interest, %	5,5%
Fee, kr/year	kr. -307.698
Fee, kr/ton	-5
Equipment, intensive treatment, kr/ton	-1,19
Operation, kr/ton	-3,08
Capacity, ton/year	27.900
Costs at max capacity, kr/ton	-15
Costs, kr/ton	***-20***

Transport

Transport scenario 1

Transport of bales from field to biogas plant

Distance to biogas plant (and back), km	50
Truck vehicle, kr/hour	-525
Speed, km/hour	45
Capacity, big bales/load	24
Number of loads, ha-1	0,27
Time consumption, loading, hours/load	0,25
Time consumption on road, hours/load	1,11
Time consumption, unloading, hours/load	0,25
Time consumption, total, hours/load	1,61
Costs, kr/load	-845,8
Costs, kr/ha	-224
Costs, kr/ton	***-64***

Transport of bales from field to briquet station

Distance to biogas plant (and back), km	10
Truck vehicle, kr/hour	-525
Speed, km/hour	45
Capacity, big bales/load	24
Number of loads, ha-1	0,27
Time consumption, loading, hours/load	0,25
Time consumption on road, hours/load	0,22
Time consumption, unloading, hours/load	0,25
Time consumption, total, hours/load	0,72
Costs, kr/load	-379
Costs, kr/ha	-101
Costs, kr/ton	***-29***

Transport scenario 2

Loading of briquettes to tipper

Hourly rate for tractor with frontloader, kr/hour	-625
Time consumption for loading, hours/load	0,33
Capacity of tipper, m3/load	60
Capacity of tipper, ton/load	27
Costs, kr/load	-208
Costs, kr/ton	***-8***

Transport of briquettes from briquet station to biogas plant

Distance to biogas plant, km	40
Truck with tipper, kr/hour	-600
Speed, km/hour	50
Capacity, m3/load	60
Capacity, ton/load	27
Number of loads, ha-1	0,13
Time consumption, loading, hours/load	0,3
Time consumption on road, hours/load	0,8
Time consumption, unloading, hours/loac	0,08
Time consumption, total, hours/load	1,18
Costs, kr/load	-708
Costs, kr/ha	-92
Costs, kr/ton	***-26***

Biogas potential and income

	Untreated straw	Briquetted straw	Extruded straw
Potential, m3 CH4/ton VS	197	221	229
VS% af DM	95%	80%	87%
CH4, m3/ha	556	526	593
CH4, m3/ton	159	150	169
Energy in CH4, kWh/m3	10	10	10
Energy, kWh/ton	1589	1503	1693
Gasmotor:			
Electricity, %	40%	40%	40%
Heat, %	50%	50%	50%
Electricity, kWh/ton	636	601	677
Heat, kWh/ton	795	751	847
Price of electricity, kr/kWh	0,79	0,79	0,79
Price of heat, kr/kWh	0,25	0,25	0,25
Income from electricity, kr/ton	502	475	535
Income from heat, kr./ton	199	188	212
Income in total, kr/ton	***701***	***663***	***747***

Total costs

	Untreated straw	Briquetted straw	Extruded straw
Costs, Kr/ton:			
Scenario 1, barn with fixed floor	-541		
Scenario 1, barn with gravel floor	-501		
Scenario 1, Staklade	-465		
Scenario 2, barn with fixed floor		-431	
Scenario 3, barn with fixed floor			-743
Scenario 3, Barn with gravel floor			-703
Scenario 3, Staklade			-667
Scenario 4, barn with fixed floor		-541	
Scenario 4, barn with gravel floor		-501	
Scenario 4, staklade		-465	

Profit

	Untreated straw	Briquetted straw	Extruded straw
Profit, kr/ton:			
Scenario 1, barn with fixed floor	160		
Scenario 1, barn with gravel floor	200		
Scenario 1, Staklade	236		
Scenario 2, barn with fixed floor		232	
Scenario 3, barn with fixed floor			4
Scenario 3, Barn with gravel floor			43
Scenario 3, Staklade			79
Scenario 4, barn with fixed floor		122	
Scenario 4, barn with gravel floor		161	
Scenario 4, staklade		198	

Appendix 3

The structure of the storage model is shown below for two weeks – week number 2 and week number 3. The end-stock from week 2 is equivalent to the initial stock in week number 3. The pattern continues until week 52.