PRACTICAL, ENVIRONMENTAL AND ECONOMIC EVALUATION OF DIFFERENT OPTIONS FOR HORSE MANURE MANAGEMENT

J.Lundgren[1,*], E.Pettersson[2]

[1]Division of Energy Engineering, Luleå University of Technology S-971 87, Luleå, Sweden
Telephone: +46 920 491 000, Telefax: +46 920 491 047
E-mail: Joakim.Lundgren@ltu.se

[2]Energy Technology Centre (ETC), Box 726, S-941 28, Piteå, Sweden
Telephone: +46 911 232386 Telefax: +46 911 232386
E-mail: epettersson@etcpitea.se

Abstract

In Sweden there are nearly 300 000 horses, generating around 6 million m^3 of waste annually. Today, this residue is usually spread on arable land or deposited at landfills. There are however other alternatives such as combustion for heat generation and biogas production for heat and electricity generation. These options are today applied to a limited extent. The main objectives of this study have been to identify practical, economic and environmental benefits of and problems with the above-mentioned alternatives, thereby aiming to find the most suitable horse manure management option for stables in Sweden. The study shows that using the residue for heat generation leads to the largest economic and practical benefits. The combustion alternative possesses a very unique feature in that the more energy in the form of heat that is used, the more money is saved. This alternative can also be considered the most suitable for many Swedish stables.

Introduction

The residue from horses contains both solid and liquid portions of waste, typically about 60% solids and 40% urine. (Wheeler et.al, 2002). Bedding materials are used on the floor of the horseboxes and are exchanged regularly in order to keep a hygienic environment for both people working in the stables and for the horses. The waste consists therefore of a mixture of manure, urine and bedding material. From a small inquiry made in northern Sweden it was found that the used amount of bedding material varied from 9 to 29 m^3 per horse and year. The large variations are due to the fact that the stables and riding schools often pay for the bedding material. Therefore the share of bedding material in the mixture depends strongly on how careful the keepers are when they clean the horseboxes. (Pettersson et.al, 2002). Wheeler et.al (2002) claim that approximately 20 m^3 of material is used per horse and year, which is close to the average value of the inquiry.

There are several different types of bedding materials used today, where the most common are wood shavings, sawdust, straw, peat, or paper pieces. The choice is strongly dependent on the geographical location of the stable. For example, in the northern part of Sweden, wood-shavings are commonly used due to rich assets of wood residues, while in the southern part straw is dominant for similar reasons. The use of newsprint is however decreasing, due to the suspicion that the printers' ink may be poisonous for the horses (Steineck et.al, 2000). Cardboard torn to pieces is however suitable and is often used in for example Norway (Jansson, 2004).

* Corresponding author

In Sweden, there are around 500 riding schools and approximately 300 000 horses (Swedish Statistics, 2000), meaning that around 6 million m^3 of waste is generated annually. Today, this residue is usually deposited at landfills or composted before it is spread on arable land.

Objectives

The main objective of this study has been to identify practical, economic and environmental advantages of and problems with the different horse manure management practices, for the purpose of finding the most suitable horse manure management option for most of the stables in Sweden.

Common handling procedures for horse manure in Sweden at present

Figure 1 shows the presently most common management practices for handling horse manure residues in Sweden according to Hammar (2001).

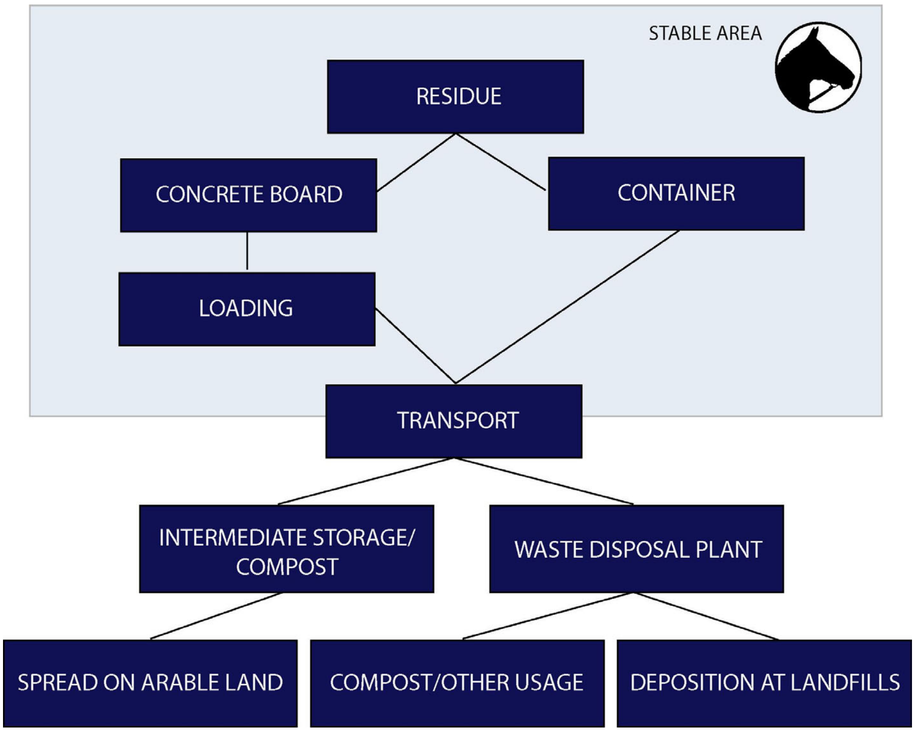

Figure 1. Most commonly used handling practices for horse manure (Hammar, 2001)

After cleaning the horseboxes, the waste is temporarily stored either on a concrete board or in a container on site, where the former method is the most common. The manure is stored up to about 10 months. Thereafter, it is transported to some kind of intermediate storage preferably close to arable land for a further digestion process for one year before the material may be spread.

The manure could also be loaded in containers directly after the cleaning of the horse boxes. A lorry collects the container when it is filled and transports it to a waste disposal plant or to an intermediate storage location, usually in the form of a pile on arable land for one year for composting before spreading.

Composting the horse manure may involve many benefits. The volume of the waste decreases while the concentration of nutrients increases. Raw manure contains high concentrations of nitrogen (N), phosphorus (P) and potassium (K). Auvermann et.al (1999) have made N-P-K analyses of finished composts, which showed average values of 0.74 % of elemental nitrogen, 0.24 % of elemental phosphorus and 1.65 % of elemental potassium. These values may be compared with a commercial fertiliser having an analysis of 0.75-0.6-2.0.

Different bedding materials are considered more or less suitable for spreading on arable land after composting. Table 1 shows briefly how the choice of bedding material influences the fertilisation characteristics.

Table 1. Fertilisation characteristics with different bedding materials (Steineck et al, 2000)

Material	Characteristics
Peat	Yields a compact fertiliser, which may easily be spread on arable lands.
Straw	Yields an uneven structure, which may complicate the spreading
Wood shavings	Yield similar characteristics as peat
Paper pieces	Yield similar characteristics as straw

Composts of horse manure mixed with straw are anyway considered to be suitable for spreading on arable land, even if many farmers may disagree. The reason is that longer straws may complicate the spreading (Hammar, 2001). Many do not recommend spreading composted manure mixed with wood-shavings recommended, because of a rumour saying that lignin and terpene contents tend to restrain the growth. According to Steineck et.al (2000) there are however no valid theories that confirm this rumour.

If the manure is transported to a waste disposal plant, it will either be deposited at landfills or the plant may make use of it, for example, use the waste for cleaning of oil polluted soil.

As from the year 2000, the Swedish government introduced a deposition tax per ton waste as an attempt to reduce the ever-increasing quantities of waste in landfills, as well as increase incentives for a more environment-friendly management of waste materials (Swedish Government Official Reports, 2002). Many riding schools and trotting courses around the country suffer economic problems and are often dependent on municipal subsidies. In addition, the stables often have to pay a fee to the waste disposal plants for leaving the waste. However, if the plant can make use of the waste in some way, the deposition fee may be reduced. In 2000, the tax amounted to SEK 250 per ton waste. From January 1 2003, it was increased to SEK 370 per ton. (Swedish National Energy Administration, 2003).

More importantly, as from the year 2005, there will be a prohibition of depositing organic material (Swedish Codes of Statutes, 2001), meaning that direct disposal at landfills may not be considered a viable solution.

Alternative options for manure handling

The waste could however be used for other purposes. It may for example be used as fuel for heat generation or biogas production for heat and electricity generation. These options are today applied to a lesser extent.

Direct combustion for heat generation

At present, electric- oil- or district heating is the most commonly used system for space heating and hot tap water preparation in Swedish stables. One of the larger costs for the stable- and trotting course owners is the cost for heating the facilities. Therefore, if the waste could be used for heat generation, the stable owners would on the one hand decrease the cost for heating and on the other reduce the volume of waste. The demand is of course that the combustion process should be performed in an optimally environment-friendly way.

Combustion of horse manure is nothing new. Schuster et al (1997) have written a report concerning combustion of animal manure, where the authors conclude that the firing techniques employed have in many cases been old and poor and that the fuel has been too wet. For this reason, problems such as high emissions and ash sintering have been frequently reported. The authors also claim that the primary driving force has been to get rid of the waste and not to develop a well-functioning combustion technique for this kind of fuel. The stable owners' current driving force is of course still to minimise their volume of waste, but in a way that is as environment-friendly, economical and practical as possible. Therefore, the interest in and demand for developing a furnace that could handle this kind of waste has increased dramatically in recent years, in particular due to the future regulations and the present heating costs.

Production of biogas for electricity and heat generation

The production of biogas with AD (anaerobic digestion) technique for electricity and heat generation is another interesting alternative.

When comparing biogas with other alternatives, many factors have to be considered. E.g. one factor is whether the plant should be running solely on horse manure or if other raw materials should be considered as well. The size and therefore the investment vary with different raw materials and kinetics. E.g. fat produces twice the amount of energy in the gas per kg of substrate compared to carbohydrates. Residual fat products, such as offal, have in many cases a negative value, which may give a suitably situated biogas plant substantial revenue from processing fat. The AD processes normally run at fairly low solid content (5 %), meaning that the residue may not be transported very far without processing to increase the solid content of the residue. This may become expensive, especially for smaller plants. The higher value waste quite often requires special plants due to certain requirements. E.g. offal from healthy animals requires hygienisation at 70° C for one hour.

Results of the economic calculations for different management options

Traditional management practices

From the economic point of view, composting of horse manure may be beneficial. The stable may have the opportunity to use the material as fertiliser on their arable land and thereby reduce purchases of artificial fertilisers. Moreover, the composted material may, in some cases, generate an extra income from selling the product to farmers. However, large quantities of horse manure may not find a farmer willing to receive the material even free of charge.

There are however costs for composting the manure. Hammar (2001) has made an economic analysis of different management options. In the analysis, investments of compost mixer, concrete board, wagons, costs for transports etc have been taken into account. Additionally, reduced purchases of artificial fertilisers are considered. The resulting costs are shown in table 2.

Table 2. Specific costs for different handling options valid for stables with 10 horses or more (Hammar, 2001).

Storage on site	Concrete board		Container	
Transported to	Waste disposal plant	Intermediate storage/ Composting	Waste disposal plant	Intermediate storage/ Composting
Spread on arable land (SEK/ton)	-	98	-	70
Deposition at landfills (SEK/ton)[1]	757	-	753	-
Other usage at waste disposal plant (SEK/ton)	253	-	223	-

[1] The cost for deposition at landfills presented in the table includes a deposition tax of SEK 250 per ton. As mentioned earlier, this tax is now increased to SEK 370 per ton waste.

Not unexpectedly, deposition at landfills is the most expensive alternative followed by the alternative when the disposal plant in some way makes use of the residue. However, it should be noted that the total specific cost for any of the alternatives strongly depends on the total transporting distance. In these calculations, the waste is transported 5 km to deposit or the final user.

According to Karlsson (2000), the cost for lorry transports amounts to 789 SEK h^{-1}. This means that a 10 km transport costs roughly 400 SEK, assuming that it takes 30 minutes for a roundtrip. It may further be assumed that one transport manages around 20 tonnes of waste, resulting in a specific cost of nearly 2 SEK km^{-1} ton^{-1}.

The combustion alternative

A riding school in Timrå, north of the town of Sundsvall in Sweden, has invested in a 240 kW_{th} heating plant for the purpose of using the waste as fuel. Previously, the waste was transported to a soil producer free of charge, but this was for some unknown reason **in** decline. The alternatives considered by the stable owner were to invest in a heating plant or deposit the waste in landfills. The plant was taken into operation in September 2003 and has since then been running more or less continuously. In order to calculate a specific cost per ton horse manure for the combustion alternative, this plant has been used as an example. Table 3 shows the present conditions at the riding school.

Table 3. Present conditions at the riding school in Timrå (Andersson, 2004).

Heated area	6 500 m^2
Number of horses	50
Yearly volume of waste	1000 m^3

Wood-shavings are used as bedding material in the horse boxes in Timrå. For the economic calculations, the average net heating value of the fuel mixture is assumed to be 800 kWh m^{-3}

and the density of the fuel around 450 kg m^{-3} (w.b). Table 4 shows the most important data needed for the economic calculations and the resulting annual heating cost.

Table 4. Economic calculations for the heating central in Timrå

Total energy available in waste (kWh)	800 000
Heat demand (kWh)[1]	400 000
Boiler efficiency (%)	80
Required fuel supply (kWh)	500 000
Surplus available energy (kWh)	300 000
Corresponding manure surplus (ton)	169
Investment buildings, culvert, installation etc (SEK)[2]	1 584 000
Concrete board 600 m^2 (SEK) [3]	180 000
Combustion equipment (SEK)[2]	1 234 000
Annual interest rate (%)	5
Depreciation time (years)	20
Capital cost (SEK)	240 727
Fuel cost (SEK)[4]	-
Maintenance and operation cost (SEK)	30 000
Ash transport (100 km, 2 SEK $ton^{-1}km^{-1}$)	6300
Total annual cost (SEK)	**277 027**

[1] Zätterqvist (2004). [2] Jansson (2004). [3] Hammar (2001), the cost for a concrete board is around SEK 300 per m^2. [4] The cost for the bedding material is excluded since it is needed nevertheless

This results in a specific cost of SEK 615 per ton waste for the stable in Timrå. Additionally, there is still, as shown in the table, a surplus of around 169 tonnes (375 m^3) of manure that has to be taken care of. Depending on whether this surplus is composted or transported to waste disposal stations for other usage, between SEK 98 and 253 per ton should be added according to table 2. This results in a total specific cost of between SEK 652 to 710 per ton waste for this alternative, which may be considered as a relatively high cost compared to the costs for composting presented in table 2. On the other hand, the heat demand is fully covered for free.

Biogas production

In Sweden a number of AD (anaerobic digestion) plants have been built. Most of them are at least partly using offal or municipal sewage sludge as feedstock. The investment has in many cases been large and only justified because the alternative costs have been substantial. In Germany, several small AD-plants have been built using building techniques with fairly low investments. Nilsson (2000) has made a pre-study of a small farm based plant for Plönninge agricultural upper secondary school.

The cost analysis is based on the economic calculations carried out by Nilsson (2000) and applied to the conditions of the Timrå plant. Table 5 shows the most important data.

Table 5. Economic calculations for the biogas plant in Timrå.

Investment of buildings, culvert, installation etc (SEK)[1]	1 584 000
Anaerobic digestion equipment (SEK)[2]	1 900 000
Annual interest rate (%)	5
Depreciation time (years)	20
Capital cost (SEK)	281 900
Maintenance and operation cost (SEK)	53 000
Transport of AD-rest (10 km)	90 000
Total annual cost (SEK)	**332 565**

[1] Jansson (2004). [2] Nilsson (2000).

The annual cost adds up to nearly SEK 332 600, corresponding to a specific cost of SEK 740 per ton waste. But by using Nilsson's measured methane production from straw mixed with horse manure, an anaerobic digestion of the total amount of manure in Timrå would only cover 60% of the total heat demand or in absolute figures, 233 300 kWh. However, this is an overestimation of the production potential from wood shavings based horse manure, since lignin-containing compounds will only be degraded to a limited degree. (Angelidaki, et.al 2000). Therefore, a supplementary heating source must generate at least 166 700 kWh annually to match the demand.

Economic comparison between the alternatives

In order to make a fair comparison between the different alternatives, the choice of management and the heat supplier must be included. As mentioned earlier, electric- oil- or district heating is the most commonly used system for space heating and hot tap water preparation in Swedish stables. Economic calculations for oil- and electric heating systems using the conditions of the riding school in Timrå have been performed. A comparison with district heating is not included in this study. Table 6 shows the assumed conditions and the resulting annual heating cost when the heat demand of the riding school has to be fully covered by using electricity or oil.

Table 6. Total annual heating cost by using oil and electricity.

Oil		Electricity	
Boiler thermal output (kW)	200	Boiler thermal output (kW)	200
Boiler efficiency (%)[1]	90	Investment of electric boiler[4]	60 000
Required fuel supply (kWh)	444 000	Investments in buildings, culvert, installations[2]	1 584 000
Investments in buildings, culvert etc[2]	1 584 000	Annual interest rate (%)	5
Combustion equipment[1]	120 000	Depreciation time (years)	20
Annual interest rate (%)	5	Capital cost (SEK)	132 000
Depreciation time (years)	20	Total specific electricity price (SEK/kWh)[5]	0.75
Capital cost (SEK)	136 730	Total electricity cost (SEK)	300 000
Specific fuel price (SEK/MWh)[3]	726		
Fuel cost (SEK)	323 000		
Maintenance and operation cost (SEK)[1]	12 000		
Total annual heating cost (SEK)	**471 400**	**Total annual heating cost (SEK)**	**432 000**

[1] Swedish Bioenergy Association (SVEBIO), [2] Jansson (2004), [3] Swedish Petroleum Institute (SPI) (2004), [4] Värmebaronen (2003), [5] Zätterqvist (2004)

For the biogas alternative, it has been chosen to use an electric boiler as a supplementary heat source. Calculating with an investment of SEK 30 000 and a depreciation time, annual interest and total specific electricity price according to table 6, the annual additional heating cost amounts to SEK 217 335.

The total annual management and heating cost for different alternatives are shown in figure 2.

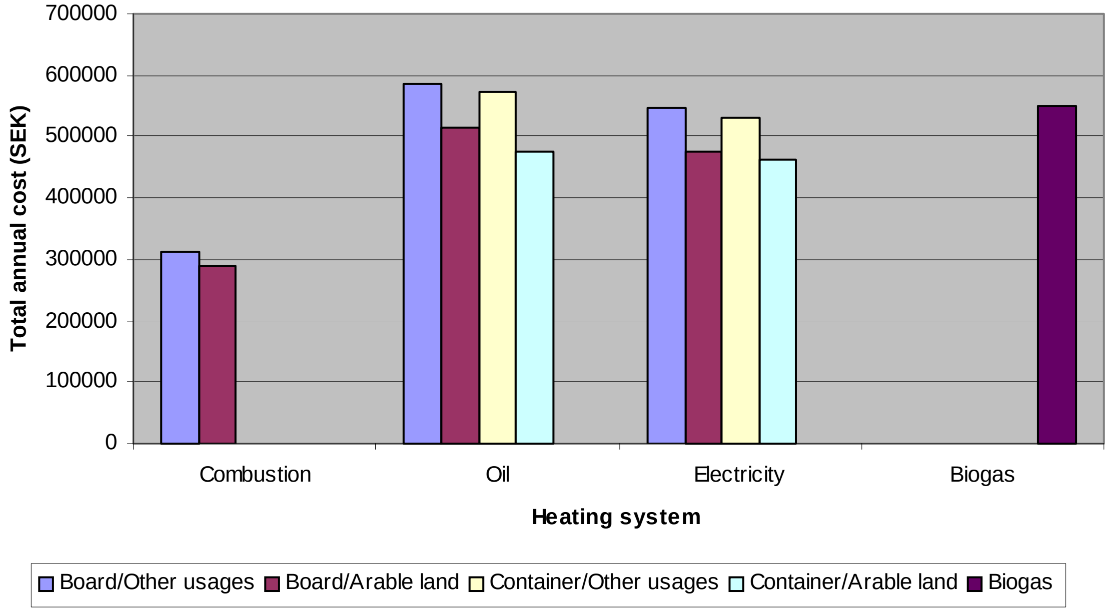

Figure 2. Total annual cost for heating of facilities and waste management with different alternatives for the riding school in Timrå.

As shown in the figure, the economically most attractive alternative is the use of waste as fuel for heat generation. The annual cost for heating and either composting the manure surplus or transporting it to a waste station for other uses amounts to about SEK 300 000 based on the assumptions made for the stable in Timrå. The most expensive alternative is to install an oil boiler and temporarily store the manure on a concrete board, before it is transported to a disposal waste station for other uses. The biogas alternative is more expensive than the combustion alternative, because it produces less net energy with an investment of the same order as the combustion alternative.

It is of no interest to calculate the annual cost for the combustion alternative and storage of the surplus in containers, due to the fact that a concrete board is already on site.

It should however be noted that the cost for handling of the manure surplus for the combustion alternative is exaggerated, since the cost for a concrete board is included in the heating- as well as the management cost calculations.

Additionally, the calculations should however be considered strictly as an example and are only valid for the conditions at the riding school in Timrå.

Environmental effects

Traditional management practices of the residue and oil based- or electric heating system

Mainly ammonia (NH_3) and carbon dioxide are released during storage as well as during the composting process. The ammonia is deposited in the soil forming ammonium (NH_4^+), before or after the deposit, and may in some circumstances contribute to acidification (Swedish Environmental Protection Agency, 2004). The deposition rate of NH_3 is considerably higher than for example NO_x, which means that NH_3 is to a higher extent deposited in the vicinity of the storage facility (Swedish Environmental Protection Agency, 2002). Emission of NH_3 is a relatively large problem in Sweden. The amount of emitted ammonia totalled 53 800 tonnes in 2001, of which 72 % originates from different kinds of manure. (Statistics Sweden, 2001)

According to the Swedish Board of Agriculture (1995), up to 10-50 % of the nitrogen in the manure may be emitted as ammonia during one year of storage. However, in a study carried out by Karlsson et.al (2003), the ammonia emissions from horse manure only amounted to 6-8 % of the total nitrogen content in the waste.

The choice of bedding material affects the escape of ammonia. Table 7 explains the differences briefly.

Table 7. Escapes of ammonia with different bedding materials (Steineck et al, 2000).

Material	Escapes of ammonia.
Peat	Results in relatively small escapes of ammonia
Straw	Larger emissions of ammonia
Wood shavings	Moderate emissions of ammonia
Paper pieces	Larger emissions of ammonia

As shown in the table, the peat compost results in small emissions of ammonia. The reason is that peat has a larger ability to absorb ammonium and thereby reduce the escapes (Hammar, 2001). It should be mentioned that compared to composting and storage of cattle manure, the ammonia losses from horse manure are small (Steineck et.al, 2001).

Other gases emitted during storage/composting of manure are carbon dioxide, methane and nitrous oxide. In a study carried out by Hao et.al (2004), it was found that the emissions of green house gases (CO_2-C equivalent) are about the same for straw and wood chip-bedded manure. For straw based manure the carbon loss was about 50 % giving larger emissions of green house gases (CO_2-C equivalent) than the initial amount of carbon. This shows that substantial reductions of green house gases will be achieved by manure combustion.

The environmental impact also depends on what kind of heating system a stable uses. For example, combustion of oil generates 0.27 ton of CO_2 MWh^{-1} (Möllersten et.al, 2003). The horse manure is a biofuel, which means that the combustion process does not contribute to any net emissions of CO_2.

It is however more difficult to estimate the environmental impact caused by using electric heating. An important aspect is however that since the Swedish parliament aims to phase out the country’s largest electricity producer, nuclear power, it is of great importance to put efforts into reducing the use of electric heating. Electricity is also a high quality energy product, which should be used for other purposes than heating up facilities.

Combustion of oil, coal and biofuels results in variously large emissions of NO_x. These are dependent not only on the fuel type, but also strongly on the combustion equipment and the combustion process. NO_x emissions from biomass combustion originate mainly from the fuel bound nitrogen (fuel- NO_x), while NO_x emissions from oil and coal occur when the nitrogen in the combustion air starts to react with O radicals (thermal NO_x). The latter is formed at temperatures above approximately 1300°C, a temperature level that is rarely reached during combustion of biomass. (Van Loo, 2002).

NH_3 as well as NO_x emissions contribute to acidification of soil. NO_x forms nitrate (NO_3^-) when it is deposited in the soil and if the soil is saturated by nitrogen, nitrate is always acidifying (Swedish Environmental Protection Agency, 2004).

Manure combustion alternative

A number of combustion experiments using wood-shavings as well as straw mixed with manure have been performed in a newly developed furnace primarily designed for combustion of wood-chips with high moisture content. The tests have been carried out mainly in order to study the resulting emissions of CO and NO_x. Table 8 shows the results obtained during the experiments. Typical emissions using wood-chips of high moisture content are also presented in the table. The thermal outputs during the experiments were around 150 kW.

Table 8. Typical ranges of emissions during combustion of different kinds of fuel (standardised to 10 vol% O_2).

	Manure and wood-shavings[1]	Manure and straw[2]	Wood-chips[1]
CO (mg/Nm^3)	50-120	40-135	5-50
NO_x (mg/Nm^3)	300-350	365-380	120-150

[1] Lundgren et.al (2004c), [2] Results not published

It should however be mentioned that only two experiments with straw have been carried out until now. To be able to draw any conclusions, it is necessary to carry out further tests. Other types of bedding material have not been tested yet.

As shown in the table, it is possible to obtain low emissions of unburnt carbon, like CO, using any of the fuels. It is known that low emissions of CO also mean low emissions of THC.

The emissions of NO_x are however significantly higher when using a manure mixture in comparison to combustion of wood-chips. According to Lundgren et al (2004c), the reason is that the waste has a higher content of fuel bound nitrogen originating from the urine of the horses.

At present, there are no official regulations concerning emissions of CO, NO_x or particles in Sweden for plants with heat power outputs below 500 kW. In Austria, the emissions of NO_x must be below 350 mg NO_2 Nm^{-3} (at 13 vol% O_2) for thermal outputs between 0.1-50 MW. In Germany the corresponding limit is 600 mg Nm^{-3} (at 13 vol% O_2) for thermal outputs below 500 kW. These limits are applied to combustion of wood waste (Van Loo et al, 2002).

The furnace used in the presented experiments and at the riding school in Timrå was primarily designed for wood-chips with a high moisture content as mentioned earlier. The combustion chamber is of grate fired type and has an integrated fuel drying zone and primary air supplied from above the fuel bed. The design and the obtained experimental results are presented by Lundgren et.al (2001, 2003, 2004a, 2004b). Further experiments are however necessary to evaluate the combustion process when using other bedding materials like peat and paper. Possible negative long-term effects, such as corrosion and fouling must also be investigated.

Ash related problems and ash disposal

Straw is, from the viewpoint of sintering, a more problematic fuel than wood fuels, due to a lower ash melting temperature. This problem was also experienced during the tests. A preliminary conclusion was that addition of chemicals or using small amounts of peat as bedding material to increase the ash melting temperature limit may be required. Combustion of manure mixed with wood-shavings did not result in any cumbersome ash sintering problems.

It has been shown that the ashes from horse manure combustion with wood-shavings contain less heavy metal than the level permitted by prevailing regulations (Lundgren et al, 2004c), which means that it should be possible to use the ash as fertiliser in forestlands. The calcium content of the ash was however slightly lower than the recommended limits, which may cause some problems in making an easily recycled product. No analysis has yet been performed of the ashes from straw combustion, but analysis of the fuel shows that from a heavy metal point of view the ash would fulfil the requirements. However, the ash does not origin from wood products and is therefore not covered by the recommendations.

Biogas

The emissions from a well-maintained digester can be neglected, but the emissions from the storage of the digestion residue can be substantial as regards ammonia. Up to 70 % of ammonium nitrogen can be emitted as ammonia to the atmosphere by careless handling during storage (Berg 2000). By precaution measures these emissions may be decreased to less than 2 % during storage of the digestion residue. The losses during spreading can be in the order of 10 % but also these can be decreased substantially by proper measures.

The emission from the combustion depends on the combustion equipment to a large extent. Reported values for small-scale gas burners are 20-40 mg NO_x MJ^{-1} and 50-120 mg CO MJ^{-1} (Swedish Gas Centre, 2000).

Transports

To get a complete picture of the environmental effects caused by horse manure management, the required transports of the waste should also be taken into account. The environmental influence depends strongly on the number of transports and the total distance, and it is therefore difficult to give a general estimation. It has to be calculated from case to case.

However, in order to handle residues, transports are required to a varying extent irrespective of which alternative is used. Additionally, if the stable has an oil heating system, transports of oil are required. Evidently, if the waste can be used on-site as fuel for heat generation, the number of waste and oil transports may be minimised and thereby also the environmental impact from heavy traffic.

Table 9 shows typical emissions of harmful substances from lorries.

Table 9. Emissions per litre of diesel from lorries (Stenberg, 2004).

	Emissions [g l^{-1}]
NO_x	19
CO_2	2700
HC	1.2
CO	2.2
Particulates	0.36

The average fuel consumption amounts to approximately 0.55 l km^{-1} of diesel for a lorry (Scania 124, motor classification Euro3) with three trailers. In the calculations it is assumed that one transport manages 50 m^3 of waste. The oil transports are not included.

Assuming that all the waste generated in Timrå (1000 m^3 annually according to table 3) is transported either to a storage for composting or to a waste disposal plant, 20 transports per year are required. If the manure is used as fuel, only the surplus of around 340 m^3 of waste has to be transported, corresponding to seven transports per year. Table 10 shows the resulting reduction of emissions due to fewer required transports.

Table 10. Reduced emissions due to less transports required.

	Emission reduction [kg a^{-1}]
NO_x	5
CO_2	712
HC	0.4
CO	0.6
Particulates	0.1

For this case, the emission reductions due to fewer transports may be considered minor. However, the “environmental profit” increases with larger quantities of waste as well as longer transporting distances.

Concluding discussion

Direct disposal is not a viable option due to the forthcoming prohibition regarding deposition of organic material. Additionally, the alternative is neither economically nor environmentally attractive.

Composting may be a good alternative for some stables. The most important advantage is that the volume of the waste decreases, while the concentration of nutrients increases which makes it suitable as fertiliser on arable land. The nearness to the land is however of crucial importance for the economy, since the transport costs represent a relatively large share of the total cost. One problem that makes for example cereal farmers hesitate to accept horse manure is that it may always contain oat weeds. This forces the farmer to weed the fields manually, because no other weed control is available. (Fredin, 2004).

Biogas generation for electricity and/or heat generation is an interesting alternative. The advantages and disadvantages are similar to those of composting, but involve the opportunity to generate electricity and heat at reasonable costs at the proper location as well. The lower dry content of the AD-waste compared with composting requires still smaller distances to spreading land compared with composting. From an economic point of view, this alternative seems not to be viable for the Timrå plant, and may even be regarded as impossible for the reason that there is no agricultural land available close enough for recycling of the digestion waste. AD-plants operate more or less continuously and have no ability to cope with seasonal variations, and this even more when the process requires a certain temperature to proceed. This means that all biogas applications require that the plant does not provide all of the heat and therefore require some other source for peak heat loads. From the point of view of emission, an AD-plant will be the most advantageous, because it will both recycle the nutrients and produce some methane gas which can be used for heating with lower emissions of NO_x than direct combustion of the horse manure, which gives in the order of 225 mg NO_x MJ^{-1}. The disadvantage is the relatively high annual cost due to the fact that it only can serve as a supplement to other heating sources.

The most economically attractive alternative is to replace oil- or electric heating by installation of a heating plant near the stable facilities and use the horse manure as fuel. This will result in several important benefits such as

- Reduced annual cost for space heating and hot tap water preparation and at the same time a significant reduction of the volume of waste
- Fewer transports of waste and oil or other fuels required
- Possibility of using the ash as fertiliser on forestlands

Additionally, the concept possesses a unique feature in that the more energy in the form of heat that is used, the more money is saved. It would even be an interesting idea to install a larger furnace dimensioned for the total annual production of waste and thereby be able to deliver or sell the surplus heat to other facilities in the vicinity or to an adjacent district heating network.

The major drawback of the combustion alternative is that the nitrogen in the manure cannot be used as fertiliser on agricultural land, because all of the nitrogen leaves the chimney. In principle the ash could be used as a fertiliser on agricultural land as well as forestlands. The ash contains substantial amounts of phosphorus, which ought to be recycled to farmland in many cases in order not to lower the depot of phosphorus in the ground. It has been shown that the phosphorus after combustion in the ash exists in chemical structures less accessible to plants than in manure. It has been claimed that this is a drawback of ashes, but Linderholm (1997) stated that only 0.01 % of the phosphorus in the ground is accessible to the plants, and that it is of little importance in which chemical form the phosphorus is added to the depot. More ash analysis is however needed, before it can be stated whether the quota between phosphorus and heavy metals is higher or lower than in the phosphorus products from the fertiliser industry. If the quota were found to be acceptable, the ash could be considered for agricultural land as well.

It is difficult to make a general comparison of combustion of horse manure with other alternatives from the viewpoint of the environmental influence. It depends for example strongly on what kind of heating system the stable uses. If the manure-based heating system replaces an oil boiler, more than 108 000 kg of CO_2 will be reduced annually for the case in

Timrå. All management and heating alternatives contribute more or less to soil acidification. It is however very difficult to give a general estimation of the differences.

The main conclusion is that combustion of the residue for heat generation may be an economically and practically attractive alternative for a large portion of the horse stables in Sweden and other countries with similar climate conditions and regulations, provided that the combustion process is environment-friendly.

Acknowledgements

The authors would like to thank Mr Mikael Jansson, Swebo Flis och Energi AB for fruitful co-operation and discussions during the project. The authors also gratefully acknowledge our colleagues at the Division of Energy Engineering, Luleå University of Technology and Energy Technology Centre (ETC) in Piteå.

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