HARVESTING TECHNICAL NOTE

HTN06-04
2013

Alternative Power Sources for Cable Yarders

Summary

The objective of this study was to investigate the potential of alternative power sources for cable yarders. High energy prices have increased the potential savings from using wood residues to power the hauler. Results showed that there is sufficient energy present in wood residues on the landing. Different types of heat engines that could be used to power the hauler using residues were investigated. None of the currently available options for heat engines was found to match the price, portability and convenience of a diesel engine. The feasibility of a hybrid diesel/electric hauler was then investigated. This type of machine was expected to have advantages, including simplicity of power distribution, lower maintenance and excellent control with easy implementation of interlocks and semi-autonomous control loops such as speed control or torque control. The cost of producing a full-scale prototype diesel/electric hauler would probably exceed one million dollars excluding the cost of the base machine.

Paul Milliken and Dzhamal Amishev, Scion

Introduction

High energy prices have increased the potential cost savings from using wood residues on the landing to power a hauler. The objective of this study was to investigate the potential of alternative power sources for cable yarders. This was undertaken in two parts: firstly to investigate the feasibility of using wood residues to power a hauler; and secondly to investigate the application of modern three-phase electric drive systems to a hybrid diesel/electric hauler.

Some advantages of electric drive systems include:

- Power transmission is simplified, as electrical power can be transmitted over copper wires instead of clutches, shafts and chains.
- An electric hauler will make control, semi-autonomous functions, speed ramping and interlocking much easier to implement. For example, one axis of the operator's joystick could be configured to raise and lower the grapple, while another axis could control in-haul and out-haul. Another example would be to autonomously reverse the drum positions from the most recent in-haul so that the grapple ends up at its original location.
- Maintenance costs of the transmission system are likely to be lower, as squirrel cage motors are very robust and reliable.
- It is easy to recover energy from a drum that is feeding out rope under tension.
- Brakes on the drums may not be required for certain gearbox configurations.
- Teleoperation would be considerably easier for an electric system.

Feasibility of using Energy from Wood Residues on the Landing to Power the Hauler

The feasibility of two options was evaluated to determine if there is sufficient energy in wood residues on the landing to power a hauler by:

1. converting the chemical energy of the wood to mechanical or electrical power by burning it as a solid fuel and using an external combustion engine, or
2. turning the wood residues into a gas (gasification) or making a liquid fuel (bio-diesel) and using an internal combustion engine.

The energy content of residues on the landing for a typical cable harvesting operation was estimated to be 156 GJ per day. This estimate was made using the EECA landing residue calculator tool[1]. The residue proportion was estimated to be 8.4 percent of the total mass of wood extracted to the landing. This assumed hauler-based harvesting with manual log making and average crop quality. The EECA Biomass Calorific Value Calculator[2] estimates the net calorific value of *Pinus radiata* hog fuel to be 9.28 MJ/kg.

Visser[3] gave a typical productivity value of 28.9 tonnes per hour for cable logging in New Zealand. If the hauler operates for seven hours per day, the energy content of the residues on the landing will be around 156 GJ.

Typical fuel consumption for a swing yarder was estimated to be around 350 litres per day [4]. Since diesel contains U = 36 MJ of energy per litre[5], the daily fuel energy requirement is around 12.6 GJ. If the diesel engine had an average thermal efficiency

Future Forests Research Ltd, PO Box 1127, Rotorua. Ph: 07 921 1883 Email: info@ffr.co.nz Web: www.ffr.co.nz

of 30 percent then the brake energy requirement of the hauler would be 3.8 GJ per day. Therefore, powering a hauler from the residues on the landing of a cable-yarding operation would require a thermal efficiency of at least 2.4 percent. This requirement is very low and compares with typical thermal efficiencies of 17 to 35 percent for the most common types of heat engines [6].

The potential diesel fuel savings from using wood residues to power a hauler are 100% of the current fuel usage. At an estimated fuel cost of $1.28 per litre giving a daily fuel cost for a swing yarder of $450 per day and 230 operational days per year, then the potential savings are around $104,000 per annum.

Options for Wood-fuelled Heat Engines

Modern haulers are powered by diesel internal combustion engines. Internal combustion engines are well suited to fluid fuels because fluids mix well with air and can easily be injected into the combustion chambers. Wood residues are a solid fuel for which an external combustion engine is more suitable. Two types of heat engines, the steam engine and the Stirling engine, were evaluated for their potential to power a hauler using energy from residues on the landing.

Steam Engines

Multiple expansion steam engines can achieve thermal efficiencies of around 17% [6]. This easily exceeds the requirement of 2.4 percent specified earlier. James Watt's original steam engine achieved a thermal efficiency of 2.5 percent [6]. Steam engines can be either a turbine or reciprocating configuration.

Dell Challenge[7] gives a cost estimate of US$459,000 (NZ$550,000) for an installed 500 kW steam turbine plus boiler system. The output of the turbine could be used to generate electricity for an electric drive system, or transmitted through a system of clutches, chains and/or shafts. This cost would be additional to the cost of the steam turbine and boiler.

While a steam turbine is expected to have lower maintenance costs than a reciprocating steam engine, steam turbines have poor efficiency when running at partial power.

Steam Systems Pty Ltd [8] estimated the cost of a modern reciprocating steam engine with brake output of between 250 kW and 500 kW at around 300,000 Euro (NZ$480,000). As with the steam turbine, the power would then have to be transmitted to the drums via an electrical drive system or a mechanical transmission system. They also estimated between 8 and 15 days per year of maintenance time for a reciprocating steam engine compared with 3 to 6 days per year for a steam turbine. Additionally, there would be costs associated with running the boiler, such as supplying water and loading fuel into the furnace. The costs associated with steam engines were considered too high to be an economic option for powering a hauler and are believed to be not worthwhile at this time.

Stirling Engines

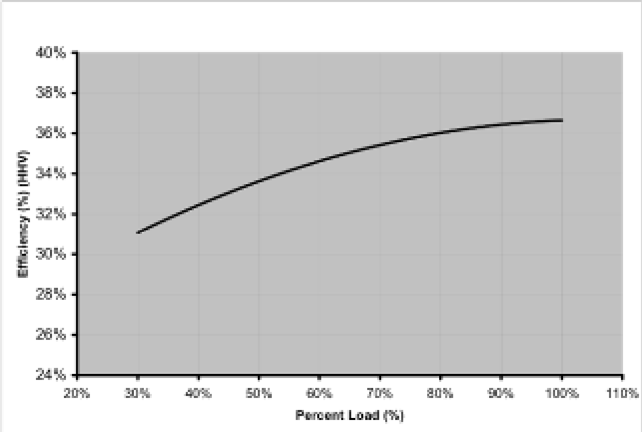
Stirling engines are simple, low-cost, low-maintenance, efficient external combustion heat engines. However, they have large cylinders and require a good cooling system such as a large water-cooled radiator. This means Stirling engines are suitable only for stationary or semi-mobile applications such as a hauler. Stirling engines work best at constant speed and load, so continuously charging batteries to power an electric hauler would be the preferred configuration.

This would require an additional cost of developing an electric drive system for the hauler. Furthermore, the main disadvantage of Stirling engines is that they are not widely used, so sourcing a suitable engine would be difficult. The Stirling engine is not recommended as a good solution for running a hauler at present.

Feasibility of Building and Running a Hybrid Diesel/Electric Hauler

Fuel Savings

In order to estimate potential fuel savings from a hybrid diesel/electric hauler, the concept of using a battery to store energy to allow a diesel engine to be run at optimal thermal efficiency was explored. It was found that the potential gains are small.



Source: Caterpillar, EEA/ICF

Figure 1: Part load efficiency performance for typical modern diesel engine [9]

A typical example of the performance of a diesel engine is shown in Figure 1. The figure shows that "the efficiency curve for diesel engines is comparatively flat between 50 and 100 per cent load" [3]. This means the potential gains from running the engine at optimal thermal efficiency are smaller than from other engines such as a petrol-powered Otto engine.

The energy used by a heat engine (E) is given by:

$$E = \frac{tP}{\eta}, \qquad (1)$$

Where t is the run-time of the engine, P is the power output and η is thermal efficiency. It was assumed that:

- maximum engine power is 400kW,
- excluding idling time, a hauler's engine would run for three hours per day at 30 percent load and 2 hours per day at 80 percent load, and
- the engine efficiency is characterised by Figure 1 so the thermal efficiencies at 30 percent and 80 percent loads were 31 percent and 36 percent, respectively.

Applying these assumptions to equation 1 resulted in a requirement of 10.58 GJ of energy per day. Since diesel contains U=36 MJ of energy per litre [5], the fuel requirement is 294 litres per day. At a price of $1.57 per litre, this is $461 per day.

Suppose a hypothetical no-loss energy storage system was implemented so the thermal efficiency of the diesel engine could be maintained at 36 percent. Using the same method, the fuel cost was calculated to be $436 per day. So the maximum possible daily saving is $25. Assuming an operation for 5 days per week and 36 weeks per year, this is less than $5,000 per annum in fuel savings. This is a small saving so it appears that converting diesel hauler to hybrid will not result in large fuel savings.

Electric Hauler Concept Design

There are many types of cable yarder and a number of rigging configurations. For simplicity only one configuration was chosen – a large two-drum yarder with a radio-controlled grapple in a running skyline configuration as shown in Figure 2.

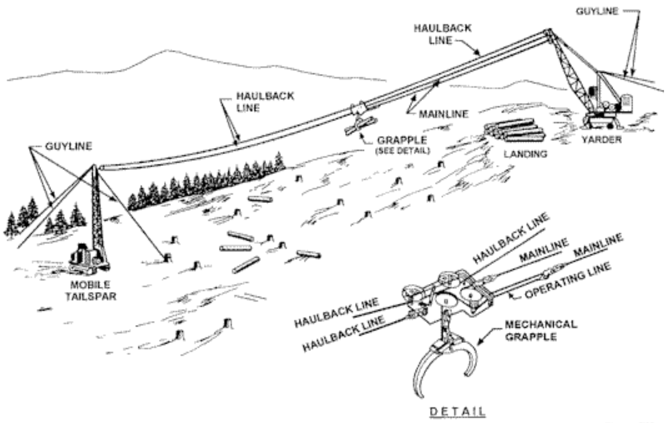


Figure 2: Diagram of a running skyline (scab) rigging configuration [10]

For this exercise it was assumed that the machine will consist of a base which is diesel-powered with hydraulically-driven tracks and slew ring. A diesel/electric base may be considered at a later stage. The winch drum set housing will be entirely electrically powered and will consist of:

- One main drum containing 600 metres of 22-mm diameter rope. Line tension is up to 200 kN even when the drum is full. This drum should be capable of 200 kW brake power output for up to 60 seconds. The drum diameter and drum width are not specified, but the bare diameter will probably be around 450 mm.
- One haul back drum containing 1200 metres of 22-mm diameter rope. Line tension is up to 200 kN when there is less than 600 metres of rope on the drum. Brake power output should be 200 kW for up to 60 seconds. Again, drum diameter is not specified.

Future Forests Research Ltd, PO Box 1127, Rotorua. Ph: 07 921 1883 Email: info@ffr.co.nz Web: www.ffr.co.nz

- One straw line drum containing 1400 metres of 9-mm diameter rope. This drum should be capable of 10 kN of tension when the drum is full. A top speed (with a load of only 1 kN) of 15 metres per second is specified. Any drum diameter up to a bare diameter of 600 mm will be satisfactory.
- Three guy rope drums, each with 80 metres of 28.6 mm diameter rope. Bare drum line tension is at least 40 kN. Bare drum top speed with no load is at least 0.8 metres per second. Drum diameter can be up to 400 mm. This drum should not be able to freewheel. This could be achieved by using a worm gearbox. The drum/gearbox system will be able to tolerate a bare-drum force of 760 kN on the cable without failure.
- No drum is specified to raise the mast at this stage.
- A diesel generator. Ideally this would be powered by the diesel engine on the track base, but a separate diesel engine is also a possibility.

Initially, control of the drums will be via a 3-axis joystick where the axes are:

- Forward/backward corresponding to moving the carriage forwards and backwards.
- Left/right corresponding to slewing the drum set housing to the left or right.
- Anticlockwise/clockwise twist corresponding to raising and lowering the grapple.

A touch-screen or similar is the preferred way to operate the guy rope drums. A PLC or similar will be used to communicate with the motor drives. This will allow interlocks and semi-autonomous control loops to be implemented during the development stage. A diagram showing a pictorial representation of the electrical subsystems is shown in Figure 3.

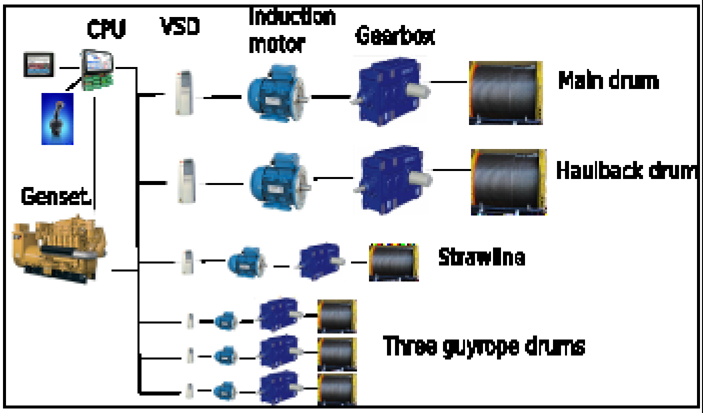


Figure 3: Diagram showing electrical subsystems for a 2-drum hybrid hauler.

Prices for developing an electric hauler were estimated using a budgetary quotation from ABB (March 2013) and correspondence with Clayton Penny at Transmission House Limited (Hamilton).

Price estimates for the development of an electric powered hauler excluding the cost of the base machine, tower, ropes and rigging are given in Table 1 below.

Table 1: Price estimates for the development of an electric powered hauler

Item	Price estimate (NZ$ ex-GST)
Two 250 kW AC motors for main and haulback drums	157,422
Two two-speed gearboxes for main and haulback drums	200,000
Electrical cabinet, configured complete with motor drives	294,778
One 55 kW AC motor for straw line drum	16,143
Gearbox for straw line drum	60,000
Three 22 kW AC motors for guy rope drums	25,488
Three gearboxes for guy rope drums	60,000
250 kW diesel genset.	150,000
Total	963,831

These costings exclude local freight, onsite engineering, installation and commissioning costs. Assuming a minimum of $50,000 for these costs, the total cost of developing a full-scale prototype diesel/electric hauler would probably exceed one million dollars,

It is important to note that:

- The operation of a hauler results in fluctuations in power output and speed of the drums. Since electric motors are able to be run for up to a minute at 150 percent of their rated power, the variable speed drives have been sized to allow this to occur.
- A single ratio gearbox would have provided the simplest and cheapest solution for the main drums. Unfortunately, the requirements for high speed operation on outhaul and high torque low speed operation at breakout made it difficult to design electric drives for the main and haulback drums with only one gear ratio.

- A gearbox with two selectable gear ratios has been specified for the main and haulback drums: 6 to 1 for returning the empty carriage and 25 to 1 for hauling stems. Performance curves for these two ratios have been provided by ABB. Note that the main and haulback drums are identical except that the haulback drum has up to eight layers of rope and the main drum has up to four layers.
- If the Variable Speed Drives corresponding to the main and haulback drums take power from a common rail then energy can be instantaneously recovered when rope is being pulled out under tension from one drum and used to provide supplementary power to the other drum. This means a battery or energy storage system is not required.

Conclusions

The results of investigations undertaken as part of this study show that residues on the landing contain more than enough energy to power a hauler. Different types of heat engines that could be used to power the hauler using residues on the landing were investigated. Unfortunately, there is no practical and cost-effective way to power a hauler using wood residues, as none of the currently available options for heat engines can match the price, portability and convenience of a diesel engine.

The feasibility of a hybrid diesel/electric hauler was investigated. Advantages from this type of machine include simplicity of power distribution, lower maintenance and excellent control with easy implementation of interlocks and semi-autonomous control loops such as speed control or torque control.

A diesel/electric hauler appears to be a feasible option. Costings undertaken as part of this project indicate that the cost of developing a full-scale prototype diesel/electric hauler would probably exceed one million dollars, excluding the cost of the base machine, tower, ropes and rigging.

References

1. EECA (2012a): Landing Residue Calculator. (http://www.eecabusiness.govt.nz/wood-energy-resources/landing-residue-calculator). New Zealand Energy Efficiency and Conservation Authority, Wellington, New Zealand.
2. EECA (2012b): Biomass Calorific Value Calculator. (http://www.eecabusiness.govt.nz/wood-energy-resources/biomass-calorific). New Zealand Energy Efficiency and Conservation Authority, Wellington, New Zealand.
3. R. Visser (2011): 2010 Benchmarking of Harvesting Cost and Productivity. Harvesting Technical Note Volume 3, No. 10. Future Forests Research Limited. January 2011.
4. S. Hill (2012): Personal communication - discussion on 27 November 2012.
5. J. J. Eberhardt (2002): Fuels of the Future for Cars and Trucks. Technical report, US Department of Energy, 2002.
6. D. Steinberg (2013): Some Power Sources Compared. http://www.houseofdavid.ca/engine.htm.
7. Dell Challenge Steam Turbines (2013): http://www.dellchallenge.org/sites/default/files/groups/19786/documents/Steam_Turbines.pdf.
8. Steam Systems Pty. Ltd. (2013): Compare - Steam Engines - Steam Turbines. http://www.steamsystems.com.au/site.cfm?/steamsystems/5/
9. Energy and Environmental Analysis Inc. (2008): Technology Characterization: Reciprocating Engines. Report for Environmental Protection Agency, Combined Heat and Power Partnership Program, Washington DC, 2008.
10. D. D. Studier and V. W. Binkley. (1974): Cable Logging Systems. Technical report, Forest Service, U.S. Department of Agriculture, Portland, Oregon, 1974.