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HOW ENERGY EFFICIENT CAN WE GET?

By

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Abstract

A key contributor to the financial viability of sugarcane factories is the availability of bagasse to be used as boiler fuel. It is difficult to see how Australian factories could be financially viable if the crop had to be processed using steam generated in boilers using alternative fuels.

In most factories and for most cane varieties, the bagasse supply from the milling train is more than what is needed by the boiler station to generate the steam required for factory operations. That is, sugarcane factories can be energy self-sufficient even without being particularly energy efficient.

The existing and potential revenue from electricity export and the sale of bagasse derived by-products will increase when factories become more energy efficient. This paper looks at some of the factors that limit factory energy efficiency and how factory energy efficiency can be maximised.

Introduction

Increasing demands for energy, reducing stocks of fossil fuels and concerns about global warming have made biomass an increasingly important source of energy for heating and electricity generation (IPCC, 2012). Bagasse, the residue from processing sugarcane, is a significant biomass resource. Furthermore, sugar milling operations already have the infrastructure for harvesting and processing sugarcane and burning the bagasse produced. The heat produced from bagasse combustion is used to produce steam for factory operations and generate electricity. In most cases, the quantity of electricity produced is surplus to factory requirements. This simultaneous use of the heat produced by burning bagasse for factory operations and electricity generation is known as cogeneration.

In the past, however, there was little financial incentive for sugarcane factories to export electricity to the grid and for that reason, having surplus bagasse was seen as a problem that had to be managed or avoided. The majority of sugarcane factories around the world were set up to avoid producing large quantities of surplus bagasse. Factory operations required large quantities of steam and sugar factory boilers were inefficient, which gave rise to the cliché paradigm that sugar factories ‘waste energy very efficiently’. This mode of operation significantly increases wear and the associated maintenance costs of boiler station components (Mann, 2016).

The advent of the mandatory renewable energy target (MRET) in 2001 made it possible for Australian sugar factories to generate additional income through the sale of renewable energy certificates (RECs) (Hodgson and Hocking, 2006). This was one of the main drivers for the recent cogeneration projects at Australian sugar factories (Hodgson *et al.*, 2014; Palmer *et al.*, 2009; Trayner, 2008).

Procedure

A spreadsheet model was set up to calculate the steam and bagasse side flows and electricity exports for three different cases:

- A typical 600 t/h crushing rate factory not set up for large scale cogeneration (case 1);
- A 600 t/h crushing rate factory set up for maximum power export using Australian best practice conditions (case 2); and
- A 600 t/h crushing rate factory set up for maximum power export using sugarcane factory best practice conditions (case 3).

The calculations for all cases assumed 50% bagasse moisture content and a bagasse gross calorific value (GCV) of 9 500 kJ/kg. For all cases the boiler station efficiency based on the bagasse GCV was assumed to be five percentage points lower than the bagasse flow weighted average efficiency of the factory boilers, to account for bagasse loss associated with stops and start-ups. The electricity exports for cases 2 and 3 were adjusted so that the calculated boiler station bagasse consumptions would match the calculated bagasse consumption for case 1.

Results

In a sugar factory that has not been modified to maximise electricity export via large scale cogeneration, high pressure (HP) steam produced by the boiler is used by back pressure turbines to provide mechanical power to drive the shredder, milling train, boiler auxiliaries (forced draft fans, induced draft fans and feedwater pumps) and alternators to meet the electricity generation requirements of the factory. Low pressure (LP) steam is sourced primarily from the exhausts of these turbines and is used for process heating. The main users of LP steam are the factory juice heaters, juice evaporators, and crystallisation pans. The process is a standard Rankine cycle with the evaporators, pans and juice heaters performing the condensing role for the cycle. The return condensate from the evaporators, pans, and juice heaters is normally flashed to remove dissolved gasses before being sent to the boiler station (Wright, 2001).

A typical sugar factory steam cycle arrangement with calculated energy and fluid flows for a 600 t/h crushing rate factory (case 1) is shown in Figure 1. Typical HP (280° C, 18 bar g) and LP steam (1 bar g) conditions were used in the calculations. The calculated flows assume that LP steam is used for all process heating except primary juice heating, which typically uses vapour 1 (Broadfoot, 2001), no boiler blowdown and no venting of LP steam. Steam and condensate leaks are ignored in the calculations. The factory LP steam requirements are higher than the HP steam requirements so, to satisfy the factory’s LP steam requirement, a flow through the make-up valve of 8.3 t/h is required. Spray water is used to reduce the superheat in the turbine exhausts and steam downstream of the make-up valve to 3° C. Note the feedwater make-up is less than 4% of the boiler steam output. The feedwater make-up would be greater than this if leaks and boiler blowdown were taken into account.

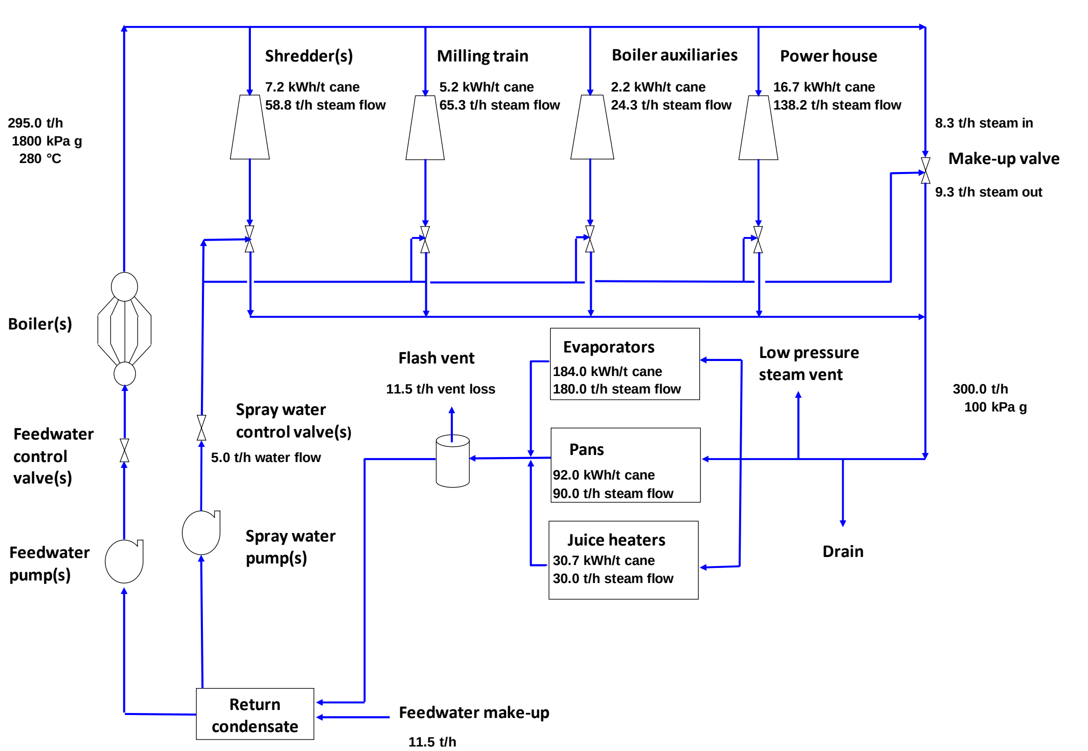

Fig. 1 - Typical arrangement of a sugar factory steam cycle without large scale cogeneration (case 1).

The bagasse energy use calculations summarised in Figure 2 show what happens to the energy produced when bagasse is burnt in a case 1 configuration sugar factory with 55% boiler station efficiency (five percentage points less than a typical boiler efficiency of 60%) and 50% steam on cane. More than half the energy is used for process heating and most of the remaining energy is lost by the boiler station. The proportion of bagasse energy used in the factory turbines (shredder, milling train, and boiler auxiliaries) is very small by comparison (2.3%). Less than 3% of the energy from bagasse combustion is used to generate electricity. Most of this electricity is used by the factory leaving only 0.4% of the energy from bagasse combustion converted to export electricity. The calculations summarised in Figure 2 do not take into account energy losses due to venting of LP steam. It is likely that a typical factory without modifications for cogeneration and a good balance between HP and LP steam usage will have to vent LP steam due to pan stage steam requirements reducing more quickly than the boiler station can respond (Broadfoot and Mann, 2014). If these vent losses are taken into account, the energy used for LP heating would reduce by the heat loss associated with this venting.

The calculated bagasse consumption for case 1 is 144.5 t/h, which gives just over 433 500 t used over a 3 000 h season. The calculated electricity export over this season length is 4.5 GWh.

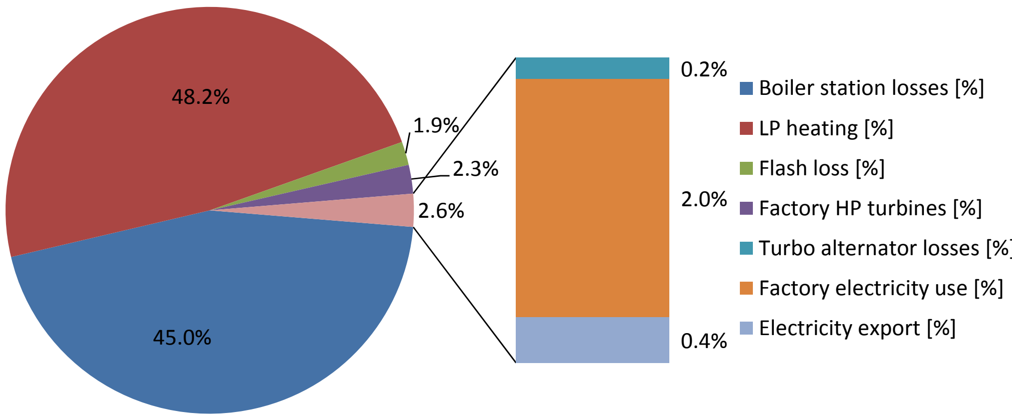

Fig. 2 - Crushing season bagasse energy use in a typical sugarcane factory (case 1).

Figure 3 shows a possible arrangement of a sugar factory configured for increased electricity export (case 2). For this factory, all steam from the high pressure boiler(s) (525° C, 80 bar g) is sent to high pressure multi-stage turbine(s). These turbine(s) exhaust intermediate pressure (IP) steam that is sent to a deaerator that removes dissolved gases from and heats the boiler feedwater, and low pressure steam used by the factory evaporator set(s). All other heating in this factory (juice heating and pan heating) is carried out by vapours bled from the evaporator set(s). The exhaust from the turbine is sent to a condenser before it is returned via a deaerator to the boiler(s). All the factory prime movers are electrically driven so that no HP or IP steam is used for factory operations. The LP steam extraction from the turbine(s) can adjust according to factory requirements so that all HP steam is used to generate electricity and no make-up valve is required.

The conditions for Figure 3 (case 2) correspond to Australian best practice with 40% steam on cane (Trayner, 2008) and high pressure (Hodgson *et al.*, 2014) and high efficiency (Palmer *et al.*, 2009) boilers. The steam economy measures required to achieve 40% steam on cane include extensive vapour bleeding, substitution of process water with clarified juice and electrification of mill turbines. The modelled boiler station efficiency was 67% which is five percentage points lower than the highest reported boiler efficiency for Australian bagasse boilers (Palmer *et al.*, 2009). Boiler blowdown is included in Figure 3 because continuous blowdown is normally required for high pressure boilers. The calculated flows do not take leaks into account. The 20 t/h IP extraction flow at 200 kPa g pressure heats the boiler feedwater to just under 134 °C to minimise the risk of dew point corrosion of boiler economiser tubes (Hodgson *et al.*, 2014). Spray water is used to restrict the superheat in the LP extraction steam (at 100 kPa g pressure) to 3 °C. The deaerator in Figure 3 has a vent rate of 1%, which corresponds to a 3.1 t/h loss of steam. When added to the 3.2 t/h blowdown water loss this gives a feedwater make-up requirement of 6.3 t/h.

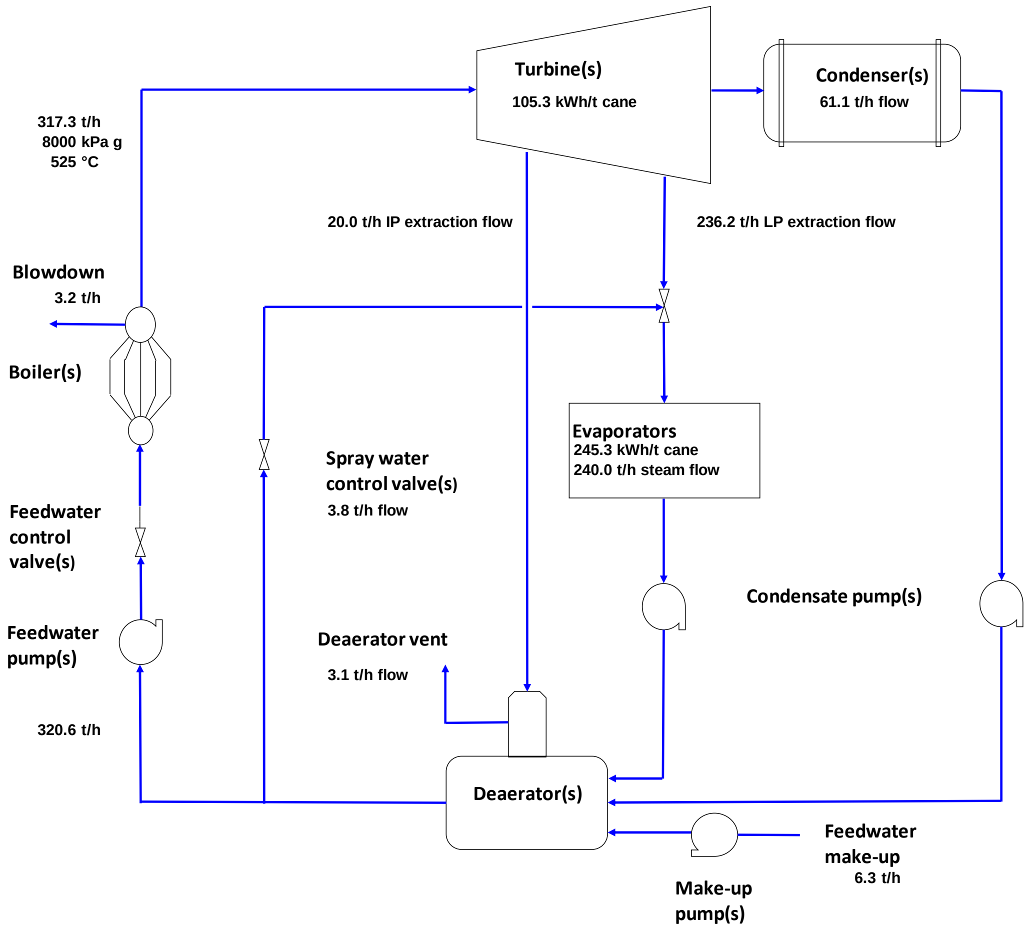

Fig 3 - A possible arrangement of a steam cycle for a sugar factory set up for cogeneration using Australian best practice conditions (case 2).

The calculations summarised in Figure 4 show the calculated bagasse energy usage distribution for a factory set up for cogeneration with configuration of Figure 3 (case 2). Most of the bagasse energy is still used for LP heating or lost by the boiler station but electricity export (12.9%) accounts for a greater proportion of bagasse energy use than factory electricity use and all other losses combined. Note the energy loss from the deaerator vent of 0.9% is less than half the energy loss due to condensate flashing of 1.9% (Figure 2).

For the same bagasse consumption as for case 1 over a 3 000 h season, the calculated electricity export over this season length for the case 2 configuration is 147.2 GWh, an increase of 142.7 GWh relative to case 1.

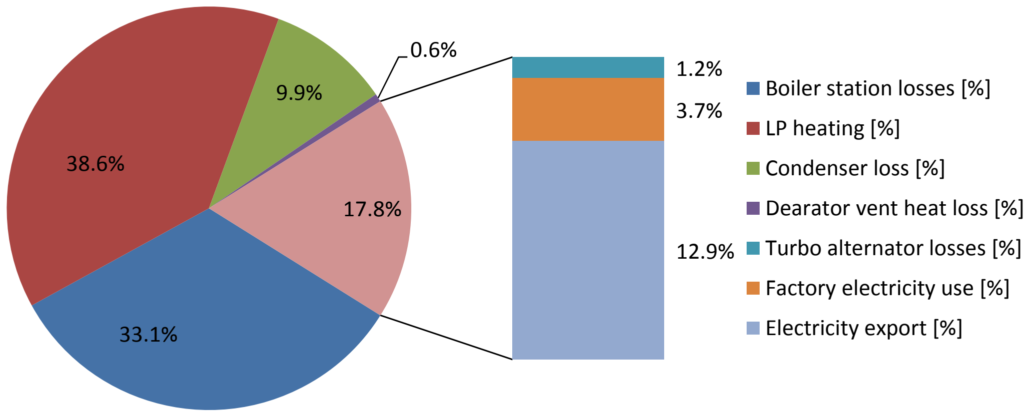

Fig. 4 - Crushing season bagasse energy use in a sugar factory set up for cogeneration using Australian best practice conditions (case 2).

Figure 5 shows a possible arrangement of a sugar factory configured for increased electricity export (case 3) and using sugar cane factory best practice conditions. The arrangement is the same as for case 2 but the conditions are changed to 26% factory steam on cane (made possible by optimising the factory back end heating arrangement, stepwise flashing of condensate and using condensate for heating (Morgenroth and Pfau, 2010)), final flue gas bagasse drying to reduce the final flue gas temperature of the boiler(s) to 75 °C (Sosa-Arnao *et al.*, 2006) and higher steam pressure and temperature (10 400 kPa g, 540 °C) boilers (Subramanian and Awasthi, 2010). The modelled boiler station efficiency is 70%, which is five percentage points lower than the efficiency of 75% calculated for a boiler with a final flue gas temperature of 75 °C.

With the very low steam on cane, just over 43% of the steam produced by the boiler(s) passes through the condensing stage of the turbine(s). As a consequence the average temperature of the condensate returned to the deaerator is lower, which means more IP extraction steam (31.4 t/h) is required to heat the boiler feedwater to just under 134 °C.

The calculations summarised in Figure 6 show the calculated bagasse energy usage distribution for a factory set up for cogeneration with configuration of Figure 5 (case 3). Compared with case 2, there is a reduction in boiler losses due to the higher boiler station efficiency, a large reduction in LP heating, which is a consequence of the very low steam on cane of 26%, a large increase in the condenser loss due to the reduced extraction from the turbine(s) and an increase in the electricity export to 16.1% of the bagasse energy.

For the same bagasse consumption as for cases 1 and 2 over a 3 000 h season, the calculated electricity export over this season length for the case 3 configuration is 184.0 GWh.

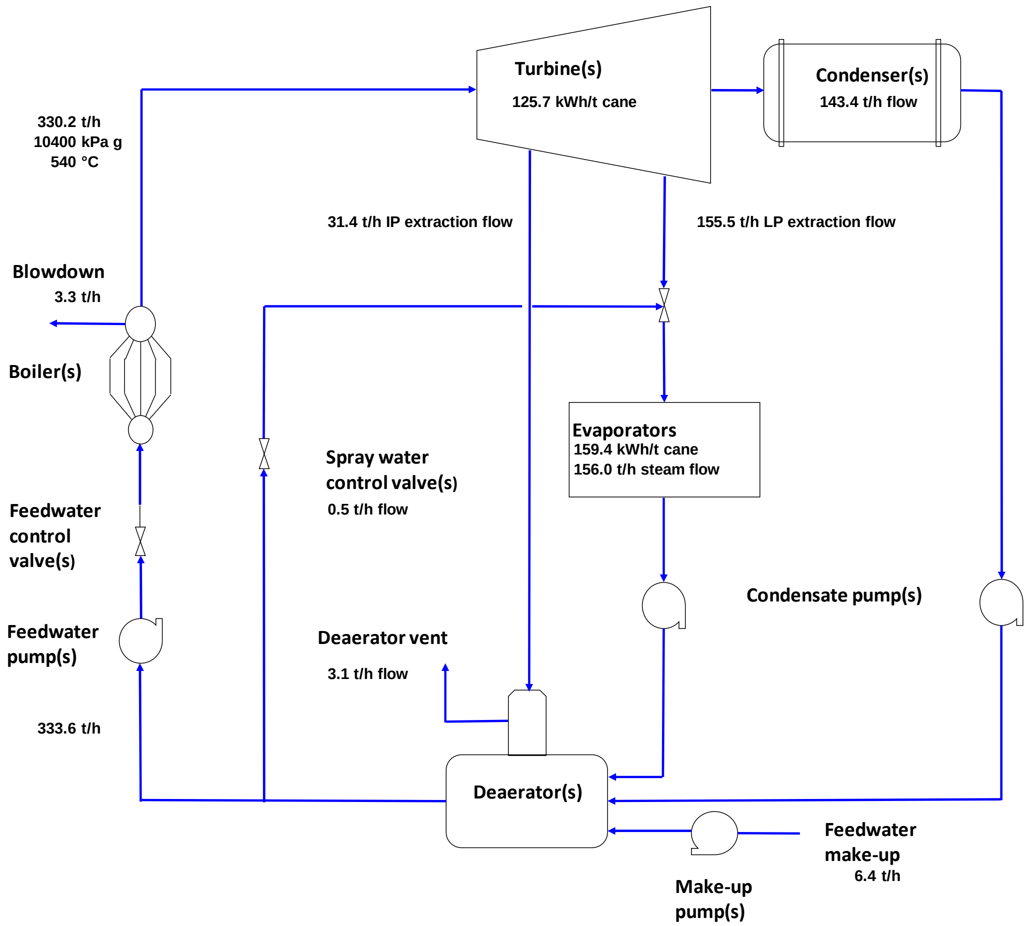

Fig. 5 - A possible arrangement of a steam cycle for a sugar factory set up for cogeneration using sugarcane factory best practice conditions (case 3).

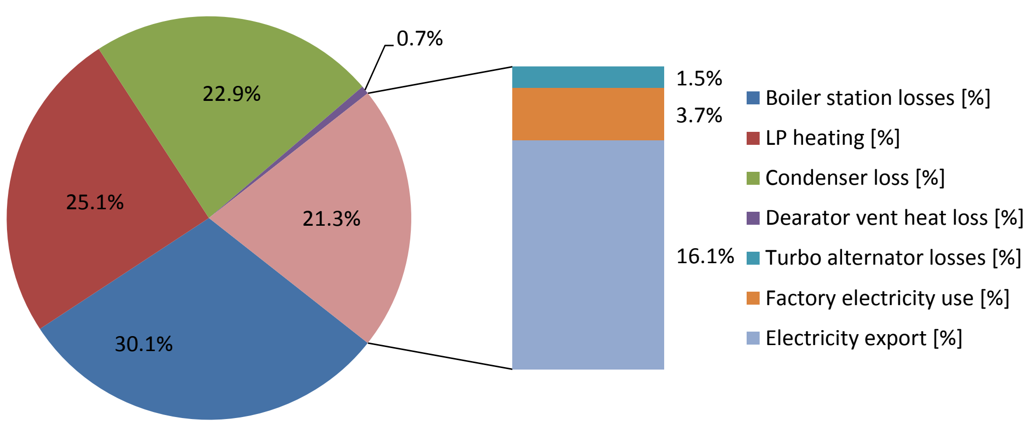

Fig. 6 - Crushing season bagasse energy use in a sugar factory set up for cogeneration using sugarcane factory best practice conditions (case 3).

Figure 7 compares the predicted income from electricity export over a 3 000 h crushing season as a function of electricity price for the three cases. For a typical factory not set up for large scale cogeneration (case 1), the income from electricity export is insignificant relative to the other cases. For the extensive cogeneration factory configurations and conditions (cases 2 and 3) the income from crushing season electricity export exceeds $14 million and $18 million, respectively, for a power price of $100 per MWh.

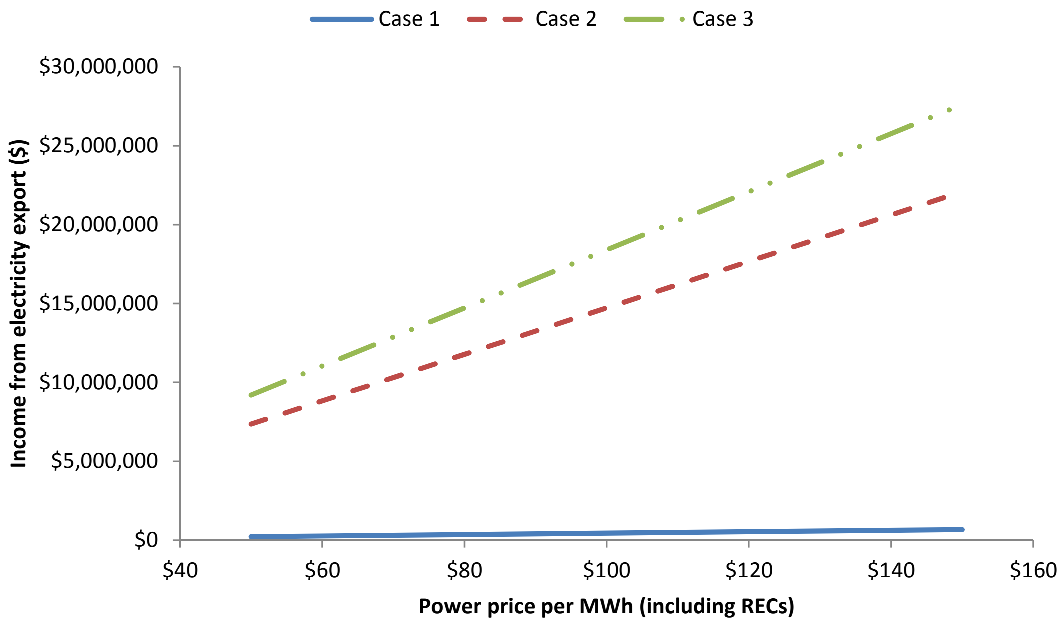

Fig. 7 - Calculated electricity export over a 3 000 h crushing season for the three cases using the same quantity of bagasse (just over 433 500 t).

Conclusions

The calculations summarised in this paper show how the energy self-sufficient, but not particularly efficient, mode of operation of factories not set up for large scale cogeneration foregoes significant income from electricity export. With the most efficient factory configuration studied in this work just over 16% of the energy in bagasse can be exported to the grid. Although this fraction of fuel energy exported to the grid is small compared to most advanced power stations it is energy that has been wasted in most sugarcane factories.

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