Ethanol Hybrid Electric Truck (EHET)[1]

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Abstract

This paper describes a project of a heavy duty ethanol hybrid electric truck (EHET) for the transportation of sugar-cane from the plantations to the distilleries. It presents the basic design concepts and the advantages to be obtained from its employment. The author believes that this is the best way to reduce both operational costs and the fossil fuel consumption of ethanol industry, which is mostly due to sugar cane transportation. This advantage tends to increase in the coming years, since the ratio of fossil fuel consumption per ethanol unit produced will increase, as new distilleries capacity is four to five times larger than the present average. Hence, transportation distances will increase as harvesting areas increase. The project will be developed in two phases, starting with the conversion of three diesel-powered trucks into EHET, to be used regularly in order to provide significant experience data.

Keywords: Hybrid Electric Truck, Ethanol, Sugar Cane, Energy balance.

1. Background

1.1 Ethanol in Brazil

Since the 80´s, when the Brazilian automotive industry began to manufacture ethanol-powered cars, hydrated ethanol (E100) is sold in all Brazilian fuel pump stations. Anhydrous ethanol is also blended into gasoline (24%) as an octane enhancer and to reduce environmental damage.

Ethanol, as produced in Brazil, is competitive with gasoline. Over 80% of the new light vehicles sold in Brazil are bi-fuel and the international demand for ethanol fuel is also growing at fast pace. While fossil fuel prices are expected to grow in the long term, ethanol's costs is expected to reduce as breakthroughs in land yield and harvesting techniques develop. Distilleries are also becoming multi-product industries with important scope-economy gains. Their sales of electric power to the grid might supply up to 20% of the country's needs. Since sugar-cane is also a renewable, it is a very important and strategic primary energy source in Brazil. After years of stagnation SC industry is now booming with the addition of 80 new distilleries. SC harvest is expected to increase from 480×10^6 t in 2007 to over 800×10^6t by 2010[2].

1.2 Ethanol energy balance

A great advantage of sugar-cane over corn and sugar-beat as the basic input for the ethanol industry is that it uses small quantities of fossil fuel. Ethanol from sugar-cane has a favorable energy balance because the energy content of the bagasse and leaves is twice the energy content of the juice (sugars). These biomasses are used as fuel to co-generate the distilleries´ steam and power needs.

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[1] Selected for presentation in the **EVS-23 – 23rd International Electric Vehicle Symposium**, December 2-5, 2007, Anaheim, California, USA.

[2] As estimated by UNICA, the association of sugar-cane enterprises of São Paulo State. Together, they produce more than 50% of Brazil's ethanol production.

Using efficient high pressure boilers, this industry can also export important amounts of electric power to the grid.

Sugar-cane industry, nevertheless, relies on the use of diesel as the main fuel used for plantation, harvesting and transportation from field to the distilleries. The latter average distance is presently of 25 km. Trucks normally carry loads from 20 to 60 tons. The author estimates that during the 2007/08 season an estimated total of 700 million l of diesel will be used to produce 20 million m^3 of ethanol. Hence, if the total present diesel oil consumption of this industry (which includes sugar production) were displaced by ethanol, about 5% of the total ethanol production would be required to fuel its truck fleet.

The fossil fuel content of ethanol in this industry will increase because with existing technologies, the optimal size of the new distilleries is four to five times larger than today's average. As a consequence, transport distances will at least double and also the diesel needs thus increasing the fossil fuel content of this elsewhere "clean" fuel.

This is a theme should be of concern for the SC ethanol industry that needs to be as independent as possible from the use of fossil fuels.

2. Hybrid electric drive trains as the solution

The obvious solution to the problem will be to use the locally produced ethanol to fuel the trucks. As ethanol requires Otto cycle ICE, they are not adequate to power these trucks (350+ HP). The only way to use ethanol is using hybrid electric drive-trains (HEV), where an ICE powers a gen-set and the wheel is directly driven by electric motor that has high starting torque.

Hybrid electric drive-trains will power a great number and variety of vehicles in the near future. This trend has been growing consistently, pushed both by their higher efficiency and by their capacity to reduce both local effect emissions and green house gases.

HEV drive-train can make possible the use of Otto-cycle ICE in heavy trucks used by the SC industry because:

1. In this activity, the trucks are driven in very short hauls and have a high proportion of stop and start driving;
2. Peak power requirements in a HEV are half to one third of the peak power requirement for the conventional ICE truck with the same performance because the wheels peak energy demand is supplied by the on board gen-set and the battery system. The batteries, in turn, are charged when the demand for power from the wheels is less than the gen-set capacity and/or when regenerative breaking is used, as the electric motors are switched to work as generators;
3. In hybrid drive trains, it is possible to install one or more gen-sets to operate in parallel, thus allowing the use of ICE ethanol Otto cycle motors that exist in the market;
4. The technology for bus control systems can be adapted to be used for the trucks, since they are independent of size or weight of the vehicle;
5. The use of the heavy lead-acid batteries – a burden in light vehicles – is not a significant problem in these trucks;

These factors show the technical feasibility of the construction of an EHET. As a further advantage, these trucks could be built to meet some special requirements of the SC industry difficult to be met

with conventional diesel power trains - such as moving at very low speeds during plantation operations.

It will probably take a long time before HEV drive trains are used in general purpose heavy-duty trucks because they are used for long haul transportation where the advantages are less significant in the present state of technology. It is important to remark that there is at least one bus manufacturer using HEV drive train using as primary mover an Otto ICE[3] and also that an ethanol fuelled HEV prototype bus is being experimented in Sweden[4].

3. EHET Project

The author's organization INEE[5] has been working for a long time to develop the electric power potential of SC distilleries and, at the same time, is leading a campaign to introduce electric vehicles in Brazil, to increase efficiency in transportation. Working in these dissimilar but complementary subjects made easy for INEE to propose EHET as the obvious solution for the reduction of the SC industry operating costs and fossil fuel dependency.

Best results with HEV drive trains are obtained in a "stop and start" driving. Therefore HEV is being initially used for light vehicles and buses that operate in urban areas. It may take a long time before heavy duty HEV for highway trucks are offered by the traditional manufacturers and this will probably start in countries where the headquarters of traditional manufactures are located.

Brazil has a reasonable experience with serial HEV drive-trains for mass transportation buses, the older ones operating for over six years. Two local bus manufacturers have designed and developed serial HEV with diesel ICE, one of them with Plug-in capacity. Control technology used in some buses was exported to New Zealand.

The immediate objective of the project is to convert three conventional diesel-powered trucks to use a HEV drive-train having one or more Otto-cycle ICE as prime movers. They will be used for demonstration, initial marketing and as prototypes for EHET production design optimization in order to reduce costs and to accelerate their development. The prototypes will use existing components and the optimization will be left for a second stage. The duration of this phase is estimated to be between six and eight months.

The experience to be acquired from this utilization will provide a sound basis for going on to the second phase, where especially designed trucks should be manufactured, incorporating the improvements to be identified in the first phase.

The substitution of diesel by ethanol has also a clear economical advantage for the distillery. The fuel cycle will be more efficient and the fuel cost will be much cheaper as it will be equivalent to production cost. Besides, it will pay no taxes and transportation fees. Maintenance costs of EHET are also reduced and the reduction or GHG emissions that it causes can also be used to increase the economic attractiveness of this solution.

[3] Thundervolt HG 40, manufactured by ISE, California.
[4] Manufactured by SCANIA using a Diesel-cycle adapted to run with ethanol.
[5] Portuguese acronym for "Energy Efficiency National Institute"

4. Potential Associates

INEE invited as head-designer of the EHET project Antonio Vicente Silva, the Brazilian engineer and designer of the HEV ELETRA bus that is running in Brazil since 1999. This bus was awarded the 2nd prize on Energy by the "**World Technology Awards 2003"**.

INEE has also held meetings with stakeholders that might take advantages of this project – manufacturers of motors/generators, lead- acid traction batteries, gen-set manufacturers and one of the most important ethanol distilleries - to present the project. It was well received, by representatives of leading industries that manifested their will to participate, supplying components, and/or expertise infrastructure for the development of the demonstration project.

The total cost of the demonstration part of the project is estimated to be about US$ 1,5 million. Stakeholders would supply equipments the equivalent to 30% of this budget. To cover engineering, management and initial marketing, the project needs to put together all necessary inputs and seed money to increase the odds of success for the initiative.

At present INEE is contacting investors and although the project does raise their interest, lack of Brazilian venture capital managers are not familiarization with the concept of HEV tends to increase their perception of technological risk. However, they have shown a great interest on the theme for its merits on reducing GHG emissions.

INEE is presently working to demonstrate that the development of the EHET has a very low technological risk as it is basically an assemblage of well known and already experienced technologies. Two Brazilian bus manufacturers have developed HEV buses and a former trolleybus manufacturer has announced its intention to come into this market. All HEV components are manufactured in Brazil.

5. EHET prototype - main characteristic

Using data from an important sugar cane distillery that has been following the project, a first draft of the project was prepared in order to obtain de the basic initial data.

Table 1 presents the characteristics of the EHET to substitute a conventional truck that operate at present.

Table 1: EHET prototype characteristics

Characteristic	
Maximum load	75,2 ton (including dead weight)
Top speed (in plane)	80 km/hr
Max. acceleration	1,2 km/s^2
Steeper ramp	5%; maximum distance 1,8 km

Table 2 presents the main characteristics of the EHET

Name plate power / electric motor	200 KW @ 1800 rpm
Maximum power / electric motor	400 KW @ 1800 rpm
Maximum electric motor speed	3600 rpm
Steeper ramp and distance	5%; maximum distance 1,8 km
Gen set Output	1 with 200 kW; 2 with 100 kW each
Battery system capacity	100 AH (300 A for 2 minutes

6. EHET Market

At present there are approximately 10,000 trucks in the SC based industry. Demand is growing at fast pace due to the increase of planted area and we estimate that the market for new trucks is in the range of 2 – thousand trucks/year.

7. Future Developments

Considering that road transportation is dominant in Brazil, including for very large loops such as soy beans for export, HE trucks, whether ethanol or diesel oil powered may have a very significant market, mainly if one considers that traffic conditions are far from satisfactory.

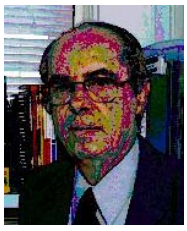
The architecture of hybrids allows increase the overall efficiency and maneuverability of the trucks using of existing technologies. A few examples are:

- Wheels can be powered by independent electrical motors with much better performance.
- Tow-trucks can also be powered ;
- Escape gases' energy – that carry one third of the original energy content of the fuel - can be partially transformed into electric power through the use of a turbine, a widely used technology to turbo

8. About INEE

INEE is a private, non profit organization founded in 1994 to foster the efficient supply and use of all energy forms. Its activity enabled it to anticipate significant issues by several years and to select relevant targets that helped to undermine hindrances to the improvement of energy efficiency. It helped to consolidate new players in the energy market and supported the development of legislation, regulations and standards in order to overcome hindrances to cost-effective conservation measures. It has become a national reference on energy efficiency and has often been requested to advise the Ministry of Mines and Energy regarding energy efficiency policy. Its efforts have been concentrated on issues in which avoidable energy losses are important and are not covered by the official agencies.

9. Authors



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