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Research of a Modern Freight Traffic-System by Using Computer Simulation

E. Böhm, E. Jehlicka
Steinbeis Transfer Center

G. Willmerding
Mercedes Benz AG
Germany

ABSTRACT

A modern freight traffic system for an alpine transit route based on electrically driven vehicles was studied and optimized. This was achieved by a detailed computer simulation. Therefore the topography of the route and speed-profiles were measured and a lot of simulations were done on this basis.

Nearly any kind of electric vehicles were simulated and compared to diesel engined vehicles. The results of simulation showed that the respective driving performance was roughly the same. Due to this the consumption of primary energy of both kinds of drive will probably differ only slightly.The advantages of the electric drive are:

- no pollution of the vehicle, which is of great importance regarding the numerous road tunnels of the transit route,
- less noise.

1 INTRODUCTION

The process of European unification causes falling trade barriers. Therefore the region of Alps becomes important for freight traffic politics, because in the Alps an extraordinary increase of freight traffic with a high percentage of transit is expected. The "traffic barrier Alps" needs a solution in the near future, which is up to requests of residents for an acceptable environment, the requests of freight traffic and the limited financial ability of the European Community.

Only if solutions will be found, which will not cause more vehicle emissions and more noise, a remarkable increase of freigt traffic and especially of transit-freight-traffic will be accepted by the alpine countries.

Well known solutions, which propose to shift freight-traffic from the road to the railway, will lead to extremely high costs because of the expensive buildings (tunnels) and will need long time for realisation. And there is a lot of uncertainty due to the unknown geological situation. Furthermore the capacity of one railway-line ist very limited.

The intention of the here presented work is to put up a concept for an ecological and economical sensible freight traffic system, which extensivly uses existing roads. No pollution of the vehicle and reduced noise should be the result. This system is based on an electric powertrain, which ist supplied by overhead wires. City busses also are using such technical solutions but the installed power is only half of the needed power for a through the Alps transit truck.

The technical concept here presented is a result of the work of an interdisciplinary project group. Computer simulations of the vehicles using an existing Alps route topography enabled to calculate and to judge a lot of powertrain variants.

2 SYSTEM-OVERVIEW

2.1. Freigt traffic concept

The idea of the traffic-concept is to use only electric trucks for transit freight traffic. Other vehicles are not allowed for this use. Consequently at the beginning of the transit route the freight has to be taken from the conventional truck to the electric truck and back again at the end of the route.

At both ends of the transit route there are terminals located, where equipment for the fast change of semitrailers and interchargeable platforms is available. An idea of such a terminal gives fig. 1. There is a lot of special equipment available for the fast change of semi-trailers and interchargeable platforms.

Fig. 2 shows the two vehicle configurations for the E-truck concept, which needs only one type of semi-trailer truck.

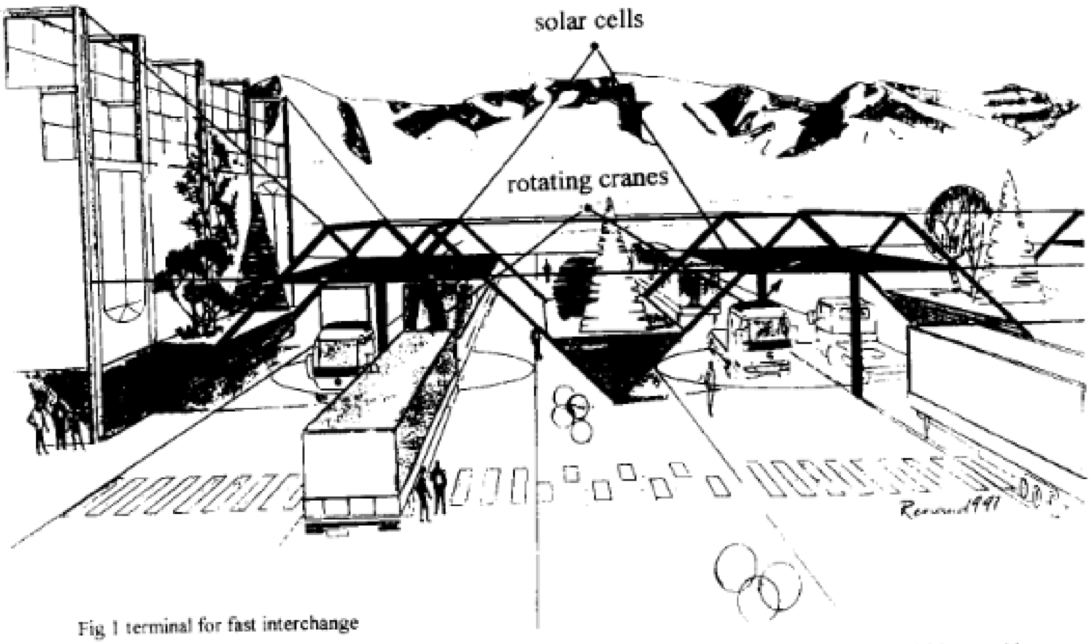

Fig 1 terminal for fast interchange

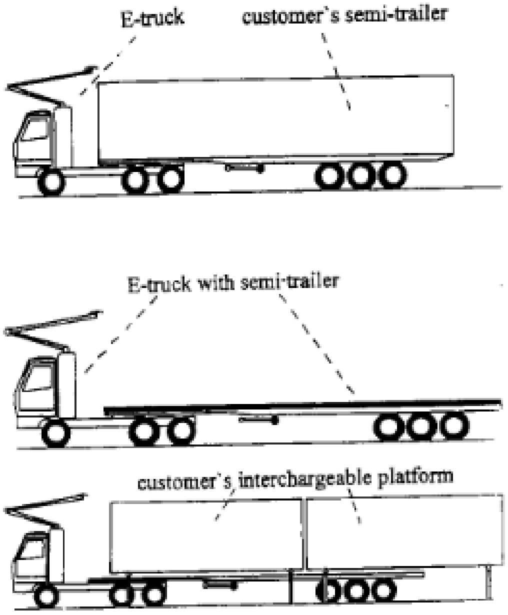

Fig 2 vehicle concept for articulated trucks and plattform trucks with interchargeable platforms

The integration of E-truck in an exisiting road is shown in fig. 3 for a highway. The E-truck is able to drive on both lanes. The other traffic is not more disturbed by the E-truck than by any other truck. Special vehicles with a height of more than 4 meters can drive on the right lane, where no overhead wires exists. The position of the overhead wires on the left lane means a reduction of the number of pylons, because the overhead wires for both directions needs only one pylon in the middle of the road

The organisation and the use of E-truck is partially similar to the railway. A central organisation - an E-truck company - is needed to guarantee the safe, punctual and economic operation . The drivers of the E-trucks need a special education and driving liscense because they have to follow special rules and signals on the road. Probably they are employed by the E-truck company.

The position of every E-truck must be known at every time in a central computer and the signal and information system has to guarantee, that the limitations of energy supply by overhead wires are not exceeded.

An advantage for the customer is that the information about the arrival time at the goal-terminal can be immediately updated if a delay is registrated. Planning in advance for the continuing truck at the directed terminal is possible.

The distance of the route in one direction is 295 km, the topography is shown in fig. 4. For the transit freight on the here researched route for the traffic of today a number of 250 E-trucks are needed. In result every two and a half minute an E-truck can start from every end of the route. To support the load-change at every end of the route about 10 interchange terminals are needed.

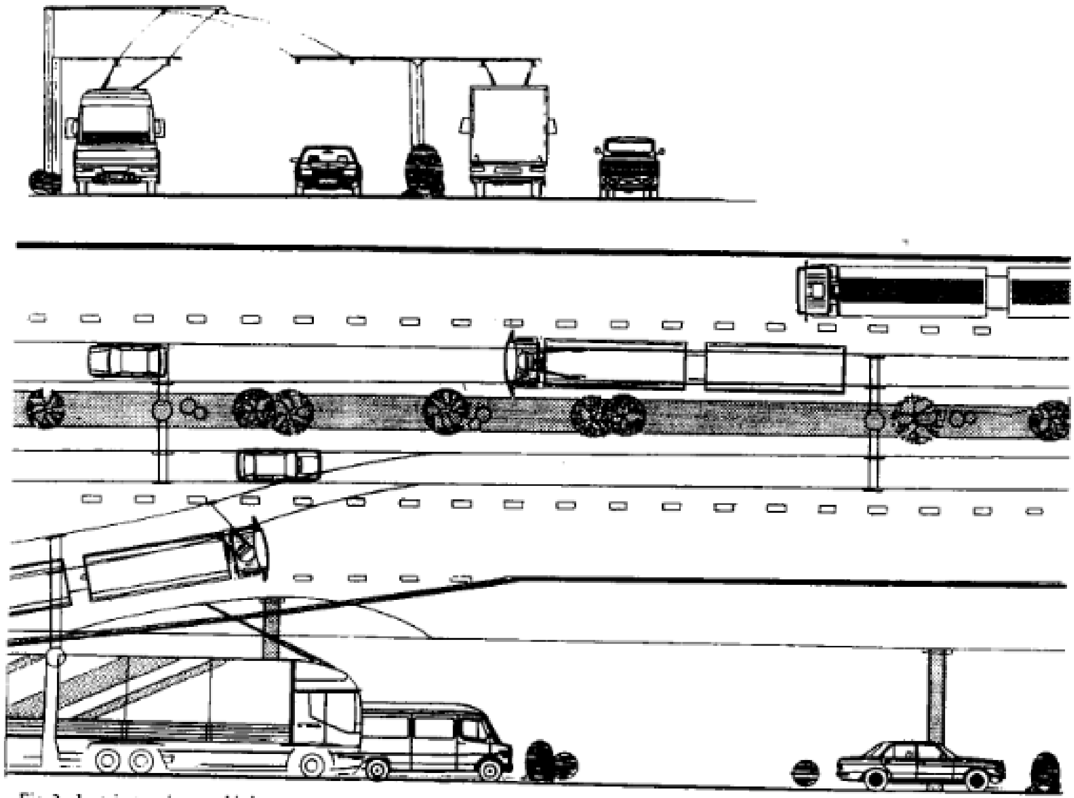

Fig 3 electric truck on a highway

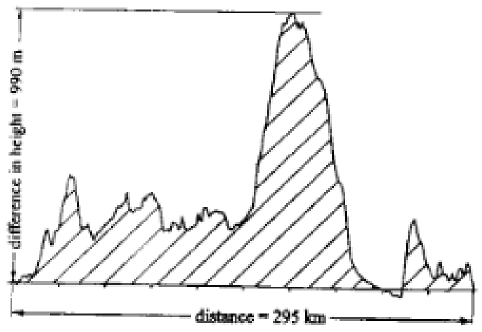

Fig 4 topography of the road

2.2. Concept of vehicle

City busses are well known examples for the successful use of electric transmission. The power needed for the city busses is very much smaller than that needed for the E-truck system. This depends on the significantly lower weight of a city bus. Therefore a lot of experiences of electrice power transmission can be considered without having to modify the technical system for electric trucks.

The E-Truck has to substitute a conventional semitrailer truck/platform truck of Merecedes Benz 2448 with a power of 362 kW and a total weight of 40 t. Technical data see table 1. The goal is to realize the same driving ability in the E-truck as in the conventional truck.

Apart from the main electric motor described in table 1 a second engine in combination with an automatic transmission must be installed. This would be a conventional diesel fuel engine with a power of about 100 kW. The second engine ist used in a case of emergency and when driving in the terminal area. The conventional power-transmission can work to the front axle or on the same axle where the electric motor works.

Instead of the use of a conventional automatic transmission for the second powertrain, a diesel engine in combination with an electric generator can be used. The electric energy produced by the generator supplies the main electric motor and enables the vehicle to drive without overhead wires supply.

table 1 shows the components of the power-train of the conventional truck and the E-truck, fig. 5 shows the torque speed characteristic of the electric motor and the diesel engine, fig 6 the maximum of traction force over the speed.

table 1: Data of the E-truck and conventional vehicle

	conventional	electric
Type	MB 2448	E-Truck
Engine	OM 442	electric
energy supply	diesel	overhead wires
Power	362 kW	360 kW
max. rpm.	2200	5000
gear-box	G 180/16 11,9	direct drive
gear-speeds	16	1
vehicle speed at max eng. speed	130 km/h	110 km/h
speed at 8% inclin.	36 km/h	36 km/h
max. traction force (unlimited)	170 kN	35 kN
weight	40 t	40 t

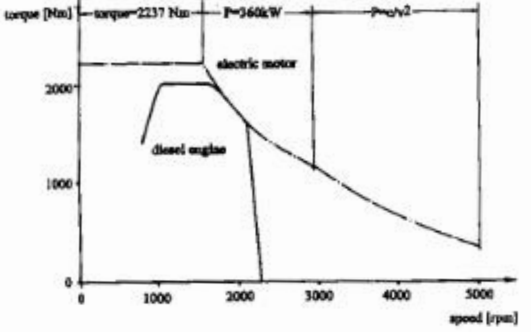

Fig 5 torque speed characteristics of electric motor and diesel engine

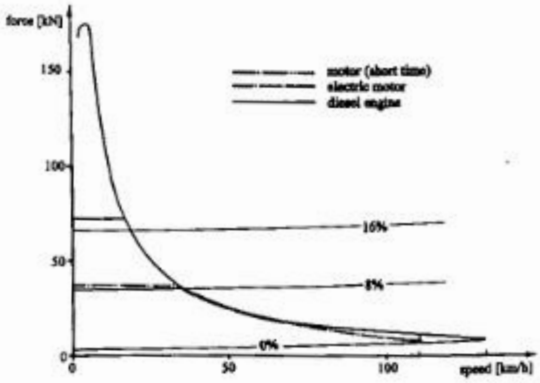

Fig 6 maximum of traction force over the speed

The electric motor has a high output torque over the speed range which means nearly constant output power. Only in the low speed range the maximum torque is limited in fact of the electric current. This characteristic enables to use a constant transmission ratio.

Electric transmissions are able to restore energy while braking to reduce total energy consumption. This ability is used in the E-truck concept too. Beside the reduction of energy consumption there is an advantage because no breaking resistances are needed.

The use of two independend transmissions leads to an additional weight compared to conventional trucks. The calculation of weight was mostly based on the use of components available today. It is expected, that by optimization of the components a weight reduction that can be compared to that of conventional vehicles can be achieved.

2.3. Road-power-stations

There are a lot of power stations needed at the road which supply the overhead wires with electric energy. The voltage drop due to the resistance of the wires caused by high currents due to the power consumption of the electric motor caused a reflection of technical parameters. First, the idea was to use the same technical components, which are available in city-busses. There is a voltage of 750 V useful. Because of the double power of the E-truck the double amount of current will occur. The result in wear out and the voltage drop due to the wire resistance seemed unacceptable.

As result a Voltage of 1500 V was chosen in spite of exceeding the important limit of 1000 V concerning the safety requirements. The selection of this high voltage reduces a lot of problems respectively enables to find a solution. A further important advantage of this voltage is the reduction of road power supply stations to the half number. The wear out of the current collector is acceptable thanks to the high voltage.

2.4. Current collector

The construction of the current collector must allow the vehicle to use two lanes on the road. Furthermore other vehicles must be not obstructed by the side movement of the current collector. A difficulty for the construction of the current collector is the height ot the tunnels, which is partialy only 4.5 meters. A solution can be found only by a total new design of the current collector - a sufficient safety against derailing probably needs an activ lead system.

3 BEHAVIOR OF THE SYSTEM

3.1. Vehicle performance

For the research the topography of an existing route with a distance of 295 km in one direction was measured and used as basis for computer simulations (fig. 4). This measurement made by a special car which registrated the height, speed and in addition the buildings on the road (tunnels, bridges) by video-registration. For these objects with probably critical heigt the blue prints were obtained.

A computer simulation model for the prediction of vehicle performance, fuel consumption and emissions was used [3,4]. The computer-model consists of a relatively simple mechanical model of the vehicle including the powertrain and a driver model. The driver model reads the data of the environment and calculates use of gas, brake and gear-speed. The results of these driver-activities are calculated by the mechanical model of the vehicle, which gives also informations about all interesting quantities in the drivetrain. The computer program solves the equilibrium of forces for a short interval. In addition a traffic model is available, which enables to predict the influence of traffic to the speed cycles.

Three speed-cycles were determined for powertrain design as basis for the computer simulation. The following scenarios were simulated:

no traffic cycle:driver is not disturbed by traffic and wants to reach the permissible speed.

traffic cycle: driver is in the flowing traffic and tries to reach the permissible speed

extreme cycle: starting from standstill with maximum load up to permissible speed and breaking down to standstill and repeating over the total distance.

The first both cycles were used for the calculation of vehicle performance, fuel consumption and pollutions. The traffic cycle was used for the design of the elements of the powertrain for the E-truck.

The extreme cycle was used for the sufficient design of road power stations for energy supply in this case, if some vehicles are in the same road power station interval starting at the same time.

Considering the weight and volume of the electric motor a design for permanent use of maximum power is not useful. A limit is the thermal load, which depends on the driving cycle and the topography. The simulation could help to find out the critical conditions for thermal limits of the electric motor. This road interval with a long distance, high inclination and driven with maximum power over a long time leads to the maximum temperature in the motor.

Fig. 7 shows the topography, speed, consumed energy, actual power output of the electric motor for the "no traffic cycle". The energy consumed can be used for the design of the road power stations and the distance between them. Fig. 8 shows the comparable data for the conventional truck under the same conditions.

The results of road simulations show that the E-truck and the conventional truck have the same vehicle performance. This is expected due to nearly the same maximum power of electric motor and diesel engine.

3.2. Load statistics

The load statistics of the electric motor and the diesel engine are shown in fig. 9 and fig. 10. In result the totaly different range of revs of the electric motor leads to very different loads and revs of all other elements of the driveline. Consequently the lifetime of driveline components had to be calculated.

Various axle transmission ratios were analysed. A higher transmission ratio of 11.1 benefits a lower thermal load of the electric motor but leads to problems in life-time of availables axles. Reducing the transmission ratio to 8.8 leads to limits of thermal effects but solves life-time problems of the axle.

3.3. Energy consumption and pollutions

To enable a comparison of the conventional truck to the - E-truck computer simulations were made to calculate the pollutions and energy consumptions. This was made by simulating the "traffic-cycle". For every calculation step the simulation- system calculates the torque and revs of diesel engine/electric motor and calculates for this step the emission, fuel consumption or energy consumption. Detailed data of the engine concerning fuel consumption and emissions could be used, the electric motor was described by its efficiency.

To judge the results, it is necessary to distinguish the emissions of the vhicle on the road from the total emissions. The difference ist very important, because the diesel vehicle emissions pollute the near environment while the electric vehicle emissions occur in the electric energy producing power station.

table 2 shows the comparison of the E-Truck to the diesel-truck concerning road emissions and energy consumption. To enable a comparison of energy consumption the diesel fuel was calculated into the units of electric energy. Obviously the energy consumption of the E-truck *on the road* is significantly lower. Furthermore no emissions of E-Truck occur.

table 2: fuel consumption and road emissions by driving in the traffic (total distance 590 km)

(conventional vehicle Mercedes Benz 2448)	T = 29615 s B = 267.52 kg= 3046 kWh
	CO_2= 860 kg CO = 647 g NOx = 8.688 kg HC = 371.9 g
Electric truck 360kW/i=8,8	T=29447 s B=1247 kWh no road emissions

T= time in seconds
B = total fuel [kg]/total electric energy consumption [kWh]
CO_2,CO,NOx,CH = emissions [g] or [kg]

In regard of global effects it is necessary to watch the primary energy consumption and the total emissions including those of the power station. This was done for the total distance of 590 km and is shown in table 3.

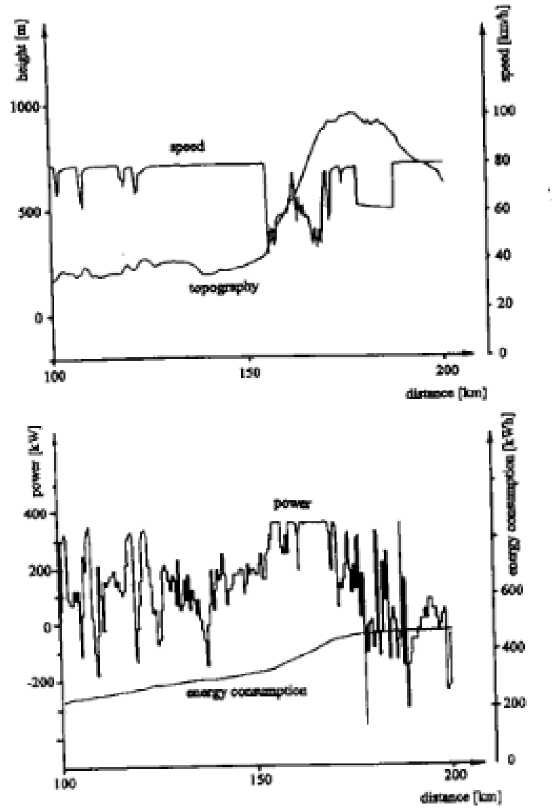

Fig 7 E-truck: topography, speed, consumed energy, actual power output of electric motor for the "no traffic cycle".

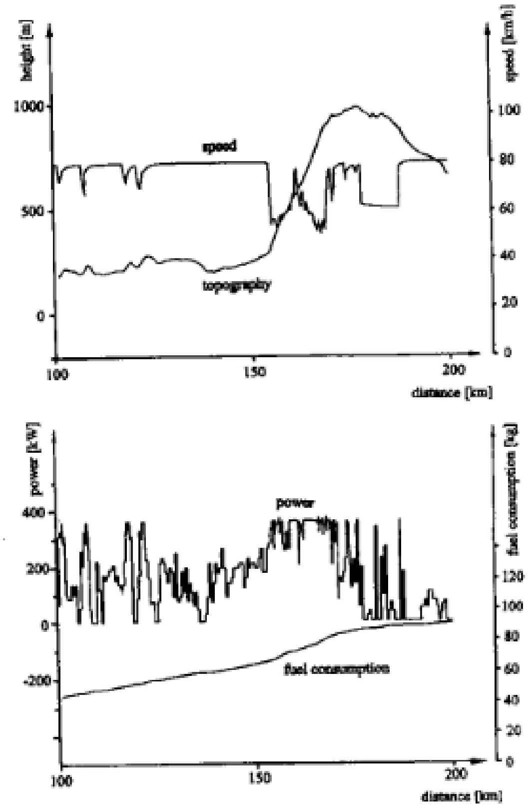

Fig 8 conventional truck: topography, speed, consumed energy, actual power output of diesel engine for the "no traffic cycle".

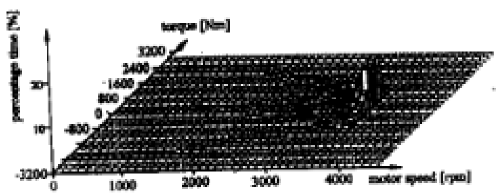

Fig 9 load statistics of the elektric motor driving the traffic-cycle

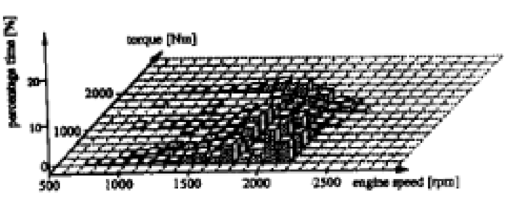

Fig 10 load statistics of the diesel engine driving the traffic-cycle

The production and transmission from the power station to the E-truck is combined with energy losses so that this total chain of losses has to be mentioned. It has to be calculated the primary energy, which the power station needs to produce the energy for the E-truck. Basis of calculations was a coal fired power station. Other power stations - nuclear energy or water energy - would have significantly reduced emissions. Nuclear power stations would have nearly the same need of primary energy while water-based power stations have no consume of limited resources.

The basis considered here - the coal fired power station - is the most unfavourable but in Europe the most accepted type.

table 3: vehicle energy consumption, primary energy consumption and *total emissions* into the environment

	energy consumpt. [kWh] of the vehicle	equivalent primary energy [kWh]		CO_2 [kg]	CO [g]	NO_x [kg]	HC [g]	SO_2 [kg]
		crude oil	coal					
conventional vehicle	3047,05	3385,61		955	718	9.6	412	-,-
E-Truck	1184,65		3384,71	1050	-,-	1,3	-,-	1,8

Assumptions:
a) $H_{uDiesel}$ = 41000 kJ/kg
b) efficiency of producing diesel fuel out of crude oil =90%
d) energy losses from the coal fired power station to the E-Truck is 65%
f) because of the use of breaking energy by restoring the reduction of energy consumption of the E-truck is 5%
g) energy losses by the transmission from the coal fired-power station to the E-truck are 10%
h) 1 kWh output energy by a coal fired power station produce 800 g CO_2, 1 g NO_x, 1,4 g SO_2 emissions
i) 1 kWh output energy by a coal fired power station don't produce HC und CO emissions
j) 1 kg diesel fuel produces 3,2 kg CO_2-emissions

In the future the ability to improve the efficiency of producing and transmitting electric energy is greater than the improvement of the efficiency of diesel engines.

4 SUMMARY AND OUTLOOK

Electric driven trucks supplied by overhead wires are economically and technically realistic. The advantages are zero-emissions and reduced noise of the electric motor compared to the combustion engine.

In regions like the Alps , where the topographic situation is hard, an additional railway needs extraordinary high investment and a long time for realisation.

The E-truck seems to be an attractive alternative.

Concerning primary energy consumption an advantage compared to the diesel engine is at the moment not possible but it is expected due to better energy tramission and production in the power stations.

Using water energy the E-truck concept would bear enormuous advantages. Unfortuantely in Europe an increase in the energy production by water energy is not expected.

5 ACKNOWLEDGEMENT

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