Improving Overall Energy Efficiency of Traction Vehicles
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Abstract
The proposed energy storage on board of a Railway vehicle was selected as the technology with the highest energy saving potential. Up to 30% energy saving has been measured in a prototype light rail vehicle, at the same time reducing the peak power demand drastically. Additionally, operation without catenary for several hundred meters was successfully demonstrated with the prototype light rail vehicle driving with switched off pantograph. This prototype vehicle is in passenger operation since September 2003. About two years experience is available and the results are convincing. Applying the energy storage system, the so called MITRAC Energy Saver, to Metro systems results in similar range of energy savings, special for 600V and 750 V Metro systems, but the savings occur in slightly different areas. A considerable amount of energy savings occur on reduced line losses while the energy savings on the vehicle is slightly less due to better regeneration capability of a Metro system. Applying the Energy Saver to Diesel-Electrical Multiple Units leads to fuel savings and provides a “booster” effect on the acceleration performance. The stored energy is adding additional power on top of the diesel engine power during acceleration. Compared to original Diesel power, this additional power can be provided with a relatively low additional weight. Finally, the energy savings of up to 30% and the corresponding emission reduction will already fulfill the targets of various local and global energy saving programs set up by e.g. European Union and big railway operators.

Introduction
Energy is a limited resource on earth, especially cheap extraction of energy will be more and more difficult. Moreover most of the industrialized countries have committed on the environmental conference in Kyoto to reduce CO₂ emissions. A reduction of energy consumption is therefore ecological and – in the near future – economical reasonable. In order to derive the technology with the highest energy saving effect the contribution of components in the energy consumption must be known. Here the example of the Swiss passenger loco RE485 was chosen, for details see [1]. Of course the distribution of losses differs with the application, e.g. for high speed train applications see [2], anyhow the application will not change dramatically.

- Transformer: Energy losses in real application are contributing with about 4% to the total energy consumption. An improvement of the transformers efficiency by a factor 2 would result in an energy saving of 2% (Values for high speed trains with underfloor mounted transformers are higher, may be 12%, resulting in 6% energy savings).
- Motor: Energy losses in real application are contributing with about 15% to the total energy consumption. An improvement of the motors efficiency by a factor 2 would result in an energy saving of 7%.
- On board energy storage: The measured energy saving effect on a prototype light rail vehicle as outlined in this article is 30%.

This basic overview shows clearly that the biggest energy saving potential could be achieved with energy storage. On board energy storage makes most sense where the braking energy of vehicles can not be regenerated or reused [3, 4]. In the case of traction vehicles with diesel supply, there is presently no possibility to use braking energy. Modern railway vehicles operating at DC voltage are principally able to regenerate the braking energy into the network. The kinetic energy of the braking vehicle is transformed by the traction motors into electrical energy and transferred via the traction inverter to the DC link of the converter. A small part can be used for the supply of the own auxiliaries. The remaining energy can be used by other vehicles in the network, as far as they are nearby the braking vehicle and have an according demand of energy,
e.g. if they are just accelerating. Unfortunately these phases – one vehicle brakes while the other accelerates – will mostly not fit together. The line is not receptive for the braking vehicle, the voltage increases and the excessive energy must be fed to the braking resistors. Especially in DC-networks with low voltages and therefore high currents and typically non regenerative substations, usually only 30 to 50% of the available braking energy can be used. In AC networks, the situation is different. Thanks to the higher voltage, lower currents and regenerative substations, the braking energy can be used in those networks quite well.

The improvement of the overall energy efficiency of traction vehicles was one of the main development goals of industries and research for years. New concepts for usage of the available braking energy of vehicles became more important in the last years not only in railway traction, but also in automobile industry [16]. This was partly influenced by the development of double layer capacitors (alternative names: SuperCaps, Boostcaps, UltraCaps). High power- and energy- density and especially the high load cycling capability are the outstanding properties of these storage elements, which makes them especially qualified for usage as braking energy storage.

Bombardier has developed an onboard energy storage system based on this technology: the Bombardier MITRAC* Energy Saver! (*Trademark of Bombardier Inc or its subsidiaries)

Together with MVV Mannheim, Bombardier has equipped a tram with the MITRAC Energy Saver storage system (Figure 3). The existing IGBT traction system has been extended with an energy storage system with associated chopper and control for charging and discharging. The vehicle is equipped with two motorized bogies and was for testing reasons only equipped with one out of two planned MITRAC Energy Savers. This gives the opportunity to compare directly the energy consumption of one powered bogie with energy storage to the one without energy storage. The objective of the MVV prototype vehicle was to prove the energy reduction functionality and reliability in the field. Since 5th of September 2003 this vehicle is in daily passenger service. There has been very good experience with this new technology, no failure within the UltraCap energy storage system and promised values have been proven to be right. With more than 2 years operational experience the MITRAC Energy Saver can already be called a proven technique.

Other conceivable applications could be the installation of energy storages on board of Metros or diesel-electric vehicles.

**Advantages for train operation**

Advantages of the new technique are not only the reduction of the direct energy costs - for a tram they are today about 15'000€ - 20'000€ per year, for a Metro about 80'000€ to 150'000 Euro per year, for a typical diesel multiple unit even up to 200'000€ per year – and looking on the continuously growing energy costs and upcoming costs for emission, becoming an increasing part of the life cycle costs.

In addition there are even more advantaging aspects for electric vehicles like:

- Reduction of the emissions, especially CO\(_2\) reduction (which is an important contribution to the Kyoto protocol), due to less energy to be generated in the feeding power stations
- Possible savings on infrastructures (increased distance between substations resulting in less substations, decreased line cross section)
- Possibility of increasing the number of vehicles on existing networks without additional upgrading of the supply infrastructure
- Possibility to drive short distances without catenary or in case of failed power supplies. E.g. Rescue in a tunnel could be considerably improved

In addition for diesel-electric vehicles:

- Reduction of the emissions, especially CO\(_2\) reduction
- Reduction of traveling time due to the booster effect
- Possibility to drive short distances with switched off diesel engines
Prototype tram with **MITRAC Energy Saver at MVV**

**Principle of Brake Energy Storage**

The energy storage is charged during braking of the vehicle while the stored energy will be reused during the next starting phase of the vehicle. This leads to one load cycle for each stop. At high speed a lot of energy can be saved during braking, while at low speed the braking energy is less. This could be simply derived from the kinetic energy of the vehicle, which is given by $E=0.5\times m\times v^2$. To keep the losses in the system as low as possible the energy storage will be discharged only to a degree which can be charged up during the next braking phase. Deviations from this simplified control concept are possible when other tasks beside the energy saving are considered, such as stabilisation of the catenary voltage.

Remarkable are the numbers of load cycles necessary for storage of brake energy. A typical light rail vehicle has 100'000 up to 300'000 load cycles per year depending on e.g. the stopping distance and usage of the vehicle. Bombardier selected to use double layer capacitors - alternative names widely used are UltraCaps, SuperCaps, BoostCaps, etc, see also [6, 7, 9, 10]. Batteries were not selected because of the poor load cycling capability and flywheels were not selected because of costs, questions on safety and limited flexibility in dimensions, power capability and energy content. E.g. the motor, typically a permanent magnet motor, is not flexible regarding voltage and power adaptations. In addition, the low leakage inductance of the typically high speed permanent magnet motors results in higher demands on the feeding converter, see also [8, 18].

![UltraCap Evolution](image)

**Fig. 1: Energy Storage Technology, Evolution of UltraCaps**

Top left: Technology 2001: Single cell: 2,5 V, 1800F, Box: 160 in series, 4 II $\rightarrow$ 1,0 kWh

Below left: Technology 2004: Single cell: 2,7 V, 2700F; Box: 192 in series, 3 II $\rightarrow$ 1,5 kWh

The technical progress on UltraCaps during the last years is enormous. Five years earlier such an energy storage would have been five times heavier, see Fig 1 (1kW/kg in 1998 to 5 kW7kg in 2003). Energy- and performance density are suited for the application “brake energy storage”. The UltraCap is very flexible regarding dimensions of the energy storage and permits a simple adaptation to different voltages, power ranges and installed energy content, just by adapting the number of UltraCaps connected in series and in parallel. The storage principle is on a pure electrical basis and achieves high load cycling capability leading to low maintenance costs.

An energy storage system requires the functions of power conversion and control beside the energy storage function. The proposed energy storage system links the traction dc-link with the energy storage via a bidirectional step down chopper to enable power flow independent from the line voltage and the charging state of the energy storage, see red part in Fig. 2.
Measurement results

The measurements from the prototype vehicle with Bombardier MITRAC Energy Saver fit very well to the calculations and simulations done in advance. Both powered bogies of the prototype vehicle have been equipped with an energy measuring system. The rear-bogie traction system has been equipped with a MITRAC Energy Saver system, while the front bogie traction system was kept standard without energy storage. Therefore the comparison of the measured energies leads directly to the energy savings due to the MITRAC Energy Saver, under exactly the same load conditions. The energy measurement is on traction power, the auxiliaries are not taken into account, thus making the measurement independent from widely varying customer dependent applications with big differences in power for air condition and heating.

In Figure 3 on the right side the relative energy gain of the Energy Saver on vehicle level (blue curve) is shown. The values are directly received by comparing the measured energy consumption of the bogies with and without Energy Saver. In the winter 2004, slightly lower energy gain has been observed. One reason for this is the fact that during this period the line receptivity was higher due to cold temperatures. More steady consumers are available in the line due to vehicle heating systems or heating of track switches. Therefore the amount of used braking energy by the vehicle itself and the line is increased and normal vehicles can recuperate more energy and thus the advantage of storing energy is slightly less. If complete vehicles with and without Energy Saver are compared, the advantage would be even higher for vehicles with Energy Saver because a vehicle without Energy Saver provides roughly double the braking energy to the line with its limited receptivity, compared to our
vehicle where half of the braking energy is stored in the Energy Saver. This improves the receptivity conditions for the non-storage traction bogie in our vehicle. The advantage of energy saving is therefore slightly underestimated when we compare both bogies in our vehicle.

The green curve in Figure 3 is considering the additional line losses and the red curve shows the results of the measurement corrections from the prototype vehicle to the relative energy gain of a hypothetic vehicle, which is completely equipped with Energy Saver to a vehicle totally without Energy Saver.

In Figure 4 left side the measured line power consumption of one single axle drive system (half of the bogie drive with one out of two traction motors) of the prototype vehicle is shown on a track with 50 km/h maximum speed without Energy Saver (front bogie drive without Energy Saver). During acceleration the drive is taking a high power between 80 to 100 kW out of the line. The braking energy can only partly be recuperated to the network. Two peaks can be seen at 870 s and 880 s, when energy can be fed back.

In Figure 4 right side the line power of the drive with MITRAC Energy Saver (rear bogie drive with Energy Saver) is shown. The measurements have been done simultaneously on the same track. The power consumption of the vehicle during acceleration is reduced to only 55 kW. During braking nearly all the braking energy can be reused. A big amount is stored into the Energy Saver (green line) and the remaining energy is fed back into the line.

In the upper part of Figure 5 the sum of line currents vehicle with and without Energy Saver are compared. The usage of the Energy Saver leads to a line current reduction of about 50%. In addition the voltage drop over the line resistance is reduced by 50%, which is shown in the bottom of Figure 5.

Advantages of the reduced line power consumption of the whole traction system are:

- Reduced energy costs – The peak power dependant costs for electrical energy are reduced by the lower peak power, see also [18]. Because of the averaging of all vehicles, the reduction of the system peak power is equal to the reduction of energy consumption (30 %)
- Reduced peak power – The dimensioning of the whole energy supply chain, substations and catenary is influenced by this.
The possibility of reduced line power and the resulting lower voltage drop on the catenary lead to clear advantages in network infrastructures. They will be explained by the following examples:

- **Scenario 1:** In comparison to the usage of conventional vehicles the distance between two substations can be increased. The distance between substations is depending on several requirements. One requirement is the maximum voltage drop over the line, which can be reduced to 40%. Regarding the voltage drop over the line the distance between two substations could be increased by a factor of 1.7. In case of additional requirements as redundancy of substations fulfilled, this would reduce the number of substations to 60%. This scenario requires 100% vehicles equipped with Energy Saver (for new system, vehicles and infrastructure).

- **Scenario 2:** An increased number of vehicles in an existing network can be realized, in parallel with a change to vehicles with Energy Saver, which reduces the power consumption of one vehicle. A headway (cycle time) reduction leading to more vehicles or expansion of a network normally means an adaptation of the infrastructure to the increased power consumption of the vehicles. By using the MITRAC Energy Saver expensive adaptation of the infrastructure can be avoided.

### Partly Catenary Free LRV

The prototype vehicle in Mannheim is optimized on energy savings and released for passenger operation. In special demonstrations the autonomous mode – no external power supply - with pantograph taken down has been demonstrated. Even so the vehicle is only equipped with one MITRAC Energy Saver box and not with the planned two boxes, the vehicle is able to demonstrate a travel over 500 m at speeds up to 26 km/h with pantograph taken down. The autonomous mode of the vehicle with Energy Saver allows therefore catenary free sections requested by some operators. Background could be the intention to install a new line where an unsightly overhead line is forbidden (due to so called visual pollution), e.g. in front of historical buildings. In such situations energy storage is not only nice to have but necessary to allow such a new line at all. For details see [5, 14]
Metro Application with *MITRAC* Energy Saver

The principle of an on board energy storage for a Metro application is very similar to the demonstrated principle on a Light Rail Vehicle (LRV). There are a few effects which become more significant, especially for Metro applications with 600 V or 750 V systems:

- Metro system normally have higher regeneration rates than LRV's, when the line is coupled through, due to more vehicles in the network
- The relative losses in the line are considerably higher, therefore the infrastructure must be considered in energy saving estimations - comparison Metro to LRV:
  - Lower line resistance, about 60% of the LRV value
  - Higher line currents, about 4 times higher in 600V and 750V lines
  - Resulting in higher line losses, about factor 10 higher ($P = R \cdot I^2$)
  - Higher train weight, about factor 5 higher
  - Resulting in higher relative line losses, about factor 2 higher ($P = V / \text{weight}$)

We did detailed simulations for a European Metro system, to evaluate the effect of high regeneration. The average distance of substations is about 2.5 km, while the average distance between stations is 1.4 km. In simulations we considered the losses in the infrastructure. A 5.4 km long representative section of the track in the tunnel area is shown in Fig. 6. The resistances of the substation are split in a real resistance producing losses and a fictive resistance simulating the voltage drop of the diode rectifier, not resulting in losses (marked in blue).

![Figure 6: Infrastructure of one section of a Metro system](image)

The system was simulated during rush hour with a train every 2 min → 8 trains in the described section, and in the evening, with still a train every 4 min → 4 trains in the section. The simulation conditions were chosen to be: 8 car train, 165 t tare weight, 45 t average load, 7 kWh Energy Saver, max acceleration 1.2 m/s², max deceleration -1.2 m/s².idle line voltage 670V, brake chopper activation at 790V.

The simulation results shown in Fig 7 have been calculated during rush hour with a train every 2 min → 8 trains in the section. The line current from the vehicle is given in the bottom part of Fig. 7, without Energy Saver in green and with Energy Saver in black, the difference is of course a current supplied by the Energy Saver. Please note that the line current with an Energy Saver is considerable lower, in the example Fig 7 about 70% of the line current RMS value, leading to reduction of line losses to about 50%.
The line voltage is plotted in red without Energy Saver and in blue with Energy Saver. It is quite complex to explain the variations in the line voltage since the power demand from the other 7 vehicles present in this section of the line also influence the line voltage. Anyhow it is obvious that the vehicle with Energy Saver stabilizes the line voltage, since it does not demand such high currents from the line. The same section of the line was also simulated in the evening, where there is still a train every 4 min → 4 trains running in the section. In this case the regeneration capability is reduced, so more losses are wasted in the brake resistor or stored in the Energy Saver, while the current flow in the line is reduced, which reduces the line losses. Both effects nearly compensate each other, so the energy saving effect remains nearly constant.

The main energy savings of a Metro system with Energy Saver are expected in the reduction of losses in the brake resistor by reusing the brake energy and in the infrastructure due to the reduced power demand from the line. A typical energy flow diagram is shown in Fig. 8.

On the left side the energy flow of a vehicle without Energy Saver is shown. On vehicle level the Metro without Energy Saver takes up 100 % energy from the line, there are losses during the motoring phase of about $E_{Vd} = 35\%$, during braking of about $E_{Vb} = 20\%$. So that the remaining braking energy of 40 % is split e.g. between losses in the brake resistor $E_{BR} = 20\%$ and regeneration into the line $E_{back} = 20\%$. In this case the regeneration is 20 % ($E_{back} / E_{IN} \rightarrow 20\% / 100\%$). In this example the line losses of $E_{VI} = 20\%$ are compensated by the regenerated Energy of $E_{back} = 20\%$. The Energy supplied by the substation is 100 %.

On the right side of Fig 8 the Metro with Energy Saver is presented. On vehicle level the energy taken from the line is reduced to to $E_{IN} = 79\%$, since braking energy stored in the Energy Saver is reused $E_{ES} = 21\%$. The losses during driving and braking are the same, while the remaining braking energy of 40 % is split between reduced losses in the brake resistor $E_{BR} = 5\%$, reduced regeneration into the line $E_{back} = 10\%$ and the storage of $E_{ES} = 25\%$ in the Energy Saver. In this case the regeneration is still 13 % ($E_{back} / E_{IN} \rightarrow 10\% / 79\%$). The losses in the Energy Saver are in the region of 4% (round trip efficiency 85 %). In this example the line losses of $E_{VI} = 10\%$ are compensated by the regenerated Energy of $E_{back} = 10\%$. The Energy supplied by the substation is 79 %.

Figure 8 shows an example of a Metro with high regeneration, where high losses in the infrastructure are expected. In that case the energy saving effect on vehicle level as well as on substation level are both in the same region, e.g. 21 % energy savings (79 % consumption) as shown in Fig 8.
In Metro systems where the line is not “coupled through”, or to less extend, the situation changes a bit. “Coupled through” means that the 3rd rails of several sections of the line are connected via “coupling switches”, a train in one section could principally regenerate into another accelerating vehicle in another section. In a system which is not coupled through, the regeneration becomes less. Energy wasted in the brake resistors is higher while losses in the infrastructure are less.

Table 1: Energy split in the system and expected energy savings due to MITRAC Energy Saver

Table 1 presents the expected energy savings when using a MITRAC Energy Saver in different applications, while Fig 8 presented a detailed energy split for one single application. The application Diesel Multiple Unit (DMU) will be explained in the next chapter.
The first 3 rows indicate a typical energy distribution split in different applications, showing only the main indicative values relevant for energy savings – a subset of Fig. 8, values underlined were used in Fig 8 - e.g. 15...20% of the consumed energy is losses in the infrastructure (substation, 3rd rail), regeneration rate in such a system is 20%...25% (regenerated / consumed energy of a vehicle), 15...20% of the energy is wasted in brake resistors. From the first 3 rows the energy saving potential in the rows 4 and 5 are derived, e.g. half of the infrastructure losses can be saved (10% saved from the 20% losses in the infrastructure) with the Energy Saver and most of the losses in the brake resistor (15% saved from the 20%). Losses in the Energy Saver of about 4% are added and leading to the overall “Saving with Energy Saver” of e.g. 21% as indicated in Fig 8.

For Metro applications considerable energy savings are expected in the infrastructure (substation and 3rd rail), up to half of the total energy savings (Table 1 states e.g. 10% savings in infrastructure compared to the 23% total savings). Therefore energy storage on board of the vehicle is principally preferable compared to wayside energy storage. Wayside energy storage might be the only possibility when there is no space on the vehicle available, see also [17] and [18]. Please note that on board energy storage compared to substation storage might be cheaper. Existing infrastructure could be reused, such as line protection, control, housing (just another box on the vehicle), discharging by brake resistor.

For Diesel Multiple Units there is even only the choice of on board energy storage.

The energy storage of brake energy on board of vehicles delivers several further advantages over and above the energy saving.

- Reduced power demand from the line – the Energy Saver delivers additional power – could result in Metro systems with less substations (less voltage drop allows bigger distance between substations), could avoid upgrades of infrastructure or could enable more or more powerful vehicles in an existing network
- Booster Effect: The additional power from the Energy Saver could also be used to “boost” the vehicle when the line current is limited. Assuming e.g. 30% power from the Energy Saver could result in 30% higher power keeping the same line current. This results in 30% higher tractive effort in the region between base speed and a speed when the storage is empty of e.g. 90km/h, depending on the size of the Energy Saver
- Rescue in tunnel, becomes possible in case of e.g. a power loss. In this case the vehicle could move to the next station by using the energy stored in the Energy Saver. Typical distance achieved is about 1000 to 1500 m from standstill to stop in a flat area, depending e.g. on the size of the Energy Saver. The principal has been demonstrated by the LRV prototype vehicle
- Feeding gaps in the 3rd rail system due to track switches or isolation between different sections in the track, could be bridged by the stored energy in the Energy Saver even without reducing the traction power
- Vehicle movement in a depot or workshop without 3rd rail becomes possible

**Diesel Multiple Unit (DMU) with MITRAC Energy Saver**

For a Diesel Multiple Unit there can be two main reasons for using the MITRAC Energy Saver.

1. **Booster Effect:**
   - The MITRAC Energy Saver leads to higher performance (adding power during acceleration)
2. **Energy Saving:**
   - The MITRAC Energy Saver stores braking energy and reuses it during acceleration
The effect of the MITRAC Energy Saver will be illustrated by using a typical 3 car DMU with a weight of about 100t and the following traction variants:

- With two diesel power packs and without MITRAC Energy Saver (2*315kW)
- As above but with an additional 4,4 kWh MITRAC Energy Saver

**Booster effect**

The MITRAC Energy Saver is providing additional power where the power coming from the diesel engines is limited and insufficient. The stored braking energy is reused during the acceleration phase to boost the power and the tractive effort.

The “booster” effect can be very well seen in the tractive effort curves, leading to additional power (in Fig. 10: blue with and red without Energy Saver) and tractive effort in the range of between 20km/h and 100km/h (Fig. 10: black with and green without Energy Saver). At about 100km/h the storage is empty - using the example of a 3 car unit with a 4,4 kWh Energy Saver. The booster effect becomes even more obvious when comparing the average acceleration from 0 to 50km/h and from 0 to 100km/h once with and once without an installed MITRAC Energy Saver, see right part of Fig. 10.

**MITRAC Energy Saver “booster” effect compared to a hypothetical equivalent diesel power pack**

On a flat track with 6 km stopping distance the equivalent diesel power pack should have a power of about 300 to 500 kW, depending on the maximum operational speed, see Fig. 11.

The MITRAC Energy Saver provides the additional power equivalent of roughly one additional diesel power pack. The additional weight of the Energy Saver though is typically quite lower than the weight of an additional power pack. This is a very interesting approach especially for applications with short stopping distances and limited operational speed, e.g. diesel multiple units with 100 to 120 km/h maximum operational speed. Further advantages compared to a diesel power pack are e.g. less
vibration problems (critical motor speeds can be avoided) and some degree of freedom in the physical dimensions.

Even when the primary goal of the MITRAC Energy Saver is the booster effect, several secondary benefits come with it. The fuel saving is about 10% when comparing the “boosted” vehicle with MITRAC Energy Saver and the same vehicle not “boosted” - without MITRAC Energy Saver, both at their performance limits on a 6km flat track (resulting in different runtimes). Comparing two vehicles with the same performance, one with MITRAC Energy Saver and one with a fictive additional diesel power pack, is leading to fuel savings of about 15% for the solution with the MITRAC Energy Saver.

Energy Savings and Emission reduction

In the previous sections the booster effect was explained. To get an optimization towards energy savings the higher power will not be used for runtime savings. The vehicle will have the same runtime with and without MITRAC Energy Saver. The higher power of the vehicle equipped with MITRAC Energy Saver in this case can be used to allow for extended coasting of the vehicle. During coasting of the vehicle the diesel engine is more or less switched off. This results in considerable fuel savings since the coasting phase, where the fuel consumption is nearly zero, could be extended from 4% to 38% of the load cycle time.
By introducing coasting, a vehicle with higher performance can achieve energy and fuel saving of 33.6%. Emission Savings in the same range are expected. The reduction of emissions might be even more important, the achieved price on “emission trading” is heavily discussed at the moment.

In addition several railway operators took up the topic “reduction of emissions” in their strategic plans, e.g. the German railways DB just announced a further 15% reduction of carbon dioxide until 2020.

The conversion between “booster effect” = runtime saving and energy saving should be noted. Converting the runtime effect of 4.7% into coasting is equivalent to additional 20% fuel and emission savings. The relative effect on runtime is obviously less than on energy savings. In principal this effect is well known and it seems that customers see similar financial benefits, since high performance vehicles have been sold.

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Table 2: Conversion of MITRAC Energy Saver benefits

Main advantages of using the MITRAC Energy Saver for DMUs:
- Reduced energy consumption which leads to a reduction of operation costs.
- Reduced emissions (especially CO₂).
- Better acceleration due to the booster effect, therefore shorter traveling time – as diesel power packs are big and heavy, the power of a vehicle is limited due to that. The relative light Energy Saver leads to a clear power increase.
- High power flexibility with low weight influence – with the right choice of the storage size, the power of the vehicle can easily be adapted to the specific application.
- 4 part train with 2 diesel engines and middle car with Energy Saver – with the additional power the same acceleration as a 3 part train can be achieved.
- 2 part train with 1 diesel engine and Energy Saver – the Energy Saver replaces one power pack and lowers the energy consumption and weight.
- The stored energy can also be used to travel short distances without diesel power. A 4.4 kWh Energy Saver gives the possibility to run up to 2.3 km on a flat track with 20 km/h, when the auxiliaries are switched off. This could lead to competitive advantages in areas where emissions should be avoided, e.g. in stations or in tunnels.

Return of Investment (RoI)

The “booster” effect as well as the energy saving effect can be turned into financial benefits for the end customer:
- Energy Saving: Here the reduction of fuel consumption and the resulting emission savings can be turned into savings on life cycle costs
- Booster Effect: Runtime savings can be converted to life cycle cost savings
  - Reduced vehicle fleet (less vehicles and less staff)
  - Passenger benefits: Passengers are either willing to pay a higher ticket price or the higher attractiveness of the vehicle will attract more paying passengers

The Return of Investment is calculated on the basis of a 3 car diesel multiple unit train, operating 150'000 km a year with 1.6 liter/km and 8% interest rate. The saved emissions per train are in the range of 100t CO₂ per year [11, 12, 13, 15]. The RoI calculation is leading to 2 to 4 years depending on
the variant, either a) the energy saving using 0.95 Euro/liter fuel (high tax in Germany) or b) the runtime optimized “booster” variant using a customer time benefit of 5 Euro/hour/passenger.

**Future Trend**

The MITRAC Energy Saver will get even more beneficial  
We expect on one hand increasing energy costs and increasing costs for emissions and on the other hand decreasing costs for the main components of the MITRAC Energy Saver the UltraCaps. Expectations from UltraCap manufacturer decrease to as low as 0.005 Euro/Farad as soon as the automotive industry is creating mass production of the UltraCaps”, expected time frame varies from 2006 to 2010.

**Conclusions**

The new traction system with Energy Saver leads to an energy saving of up to 30% and a reduced peak power demand from the line of up to 50% compared to a modern regenerative Light Rail or Metro vehicle. With the prototype Light Rail in Mannheim the benefits have been proven in daily passenger operation. With the good experience in more than 2 years daily passenger operation the new MITRAC Energy Saver can be considered as a reliable proven technology.  
In addition to the energy savings several cost benefits due to reduced power demand on the infrastructure can be taken into account case by case. Furthermore the on board energy storage allows an autonomous operation. Also without power supply or even without a catenary or a 3rd rail a short distance operation can be maintained which leads to further system advantages.  
The new MITRAC Energy Saver leads to a further big step in environmental protection and raising the already established advantage of public rail transport as an environmental friendly public transport medium. The proven energy savings of 30% by the LRV prototype and the corresponding emission reduction should already fulfill the targets of various local and global energy saving programs set up by e.g. European Union and big railway operators. Therefore the on board energy storage belongs to the main future technologies - and being commercially interesting, it will enter the market very soon. The consideration of all features of the new vehicle with on board energy storage should lead to an outmost attractive system which is also promising concerning economics.  

**References**


MITRAC Energy Saver* is a Trademark of Bombardier Inc or its subsidiaries