Rail Safety & Standards Board

Research Programme

Engineering

Improving the efficiency of traction energy use:
Summary report

T618 –
IMPROVING THE EFFICIENCY OF TRACTION ENERGY USE - SUMMARY REPORT

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1 EXECUTIVE SUMMARY

As part of a wider industry and Government agenda for sustainability and energy savings, the way in which the railway industry consumes energy has been researched. Opportunities for saving traction energy have been identified, investigated and ranked in accordance with the potential savings, timescales and cost/benefit case.

From the data available annual consumption of electricity for traction on the GB railway network is approximately 2,900,000 MWh (measured at the substation). The fuel consumed by diesel fleets (including freight traffic) is calculated to be in the region of 720 million litres.

Four areas have been identified where quick wins can be made. These include reducing the stabling load on electric trains, running shorter trains off peak, improving energy efficiency through improved driving techniques including better train regulation and reducing diesel engine idling. It is estimated that the annual potential saving from these opportunities is in the region of 750,000 MWh of electricity (26% total consumption) and a further 70 million litres of diesel (10% total consumption). In financial terms this is worth around £70 million and could save more than 500 million kg CO_2 emissions.

A further eight areas have been identified where there are potentially significant savings to be made in the longer term. These include hybrid drives, improvements to heating and cooling systems, fuel additives, weight reduction of trains, dual power source trains, intelligent control of diesel engines and aerodynamic drag reduction. It is estimated that the annual potential saving from these opportunities is in the region of a further 200,000 MWh of electricity (7% total consumption) and a further 175 million litres of diesel (24% total consumption). In financial terms this is worth around £60 million and could save more than 460 million kg CO_2 emissions.

Some opportunities were identified where there is likely to be some saving of energy, but where there is not a financial business case for the changes (for example, where cost of implementation exceeds the benefit). Other opportunities which are not viable at all are also listed in brief.

This report provides a concise summary of the options discussed in order of the ranking established. This should be easily digestible by those in the industry responsible for implementing improvements. Further information, details of the calculation methods, appendices and case studies are provided in a separate detail report ITLR-T18659-004.

In order to optimise the prospects for energy efficiency it is vital that the approach is one of considering energy efficiency as an integral part of the rail industries decision making processes and seeing rail as a whole system. Some of the opportunities identified can be addressed in isolation but others will only meet their full potential with a systems approach.

It is therefore recommended that the GB rail industry works collaboratively to ensure that the appropriate level of integrated thinking takes place in order that energy efficiencies are optimised. In some cases this may require changes to contractual and regulatory arrangements to ensure energy efficiency is adequately considered, and the associated costs and benefits are distributed equitably. Two key points emerge:

- Each company should give consideration to making energy consumption reduction initiatives the responsibility of one of its senior executives. This should ensure that energy efficiency is proactively addressed, initiatives are followed through and then appropriately monitored to ensure ongoing benefits are delivered.

- To incentivise improvements, visibility of the energy savings is essential. This will only be possible through monitoring of electrical energy consumed and diesel fuel used. Improved measuring methods need to be developed in order to achieve this.

2 INTRODUCTION

This research programme has three distinct aspects. The first was to investigate the potential to make reductions in traction energy consumption and wastage across the spectrum of rail operations. The second aspect was to benchmark, in energy terms, and with selected metrics, rail traction and the alternatives of bus, car, and air travel. The third relates to investigating the potential to make reductions in non-traction energy consumption. Detailed reports have been produced for each of these three areas:

- ITLR-T18659-004 T618 - Improving The Efficiency of Traction Energy Use;
- ITLR-T18659-002 T618 - Traction Energy Metrics; and
- ITLR-T18659-005 T618 - Non Traction Energy Study

During the review process on the report on improving traction energy use, it has become clear that there are many (over fifty) opportunities that have been considered in reducing traction energy. The main report covers all of these in a systematic manner, where possible predicting potential savings and costs with each initiative. However, there are many interrelationships between savings (i.e. if a saving is made in one area, potential savings may be reduced in others). Further, whilst the structuring of the report follows a systematic approach, this does not necessarily clearly prioritise the actions in order of their respective business cases. This summary report has therefore been produced to provide an overview of the work and to clearly prioritise those actions that should be taken forward first. Cross reference between the two reports is made using codes S1 to S51.

The structure of this report therefore is as follows:

Rank 1 – The most viable quick wins where there is a case for commencing action immediately (Section 4.1);
Rank 2 – The most promising long term opportunities where action needs to be initiated in order to explore and deliver long term improvements (Section 4.2);
Rank 3 – Short and long term opportunities which are likely to deliver efficiency or environmental improvements, but without significant cost saving to the industry (Section 4.3); and
Rank 4 – Actions that are not currently viable, but are considered worthwhile to be kept under review (Section 4.4).
Not ranked – Other opportunities considered (Section 4.5)

A list of strategic recommendations is provided to assist the railway industry in delivering improvements in energy efficiency (Section 5).

Appendix 1 of this report, summarises the potential savings associated with each opportunity and equates these to MWh electricity saved (all GB electric fleets), litres of diesel saved (all GB diesel fleets), total costs savings (all GB fleets combined), and total saving in CO_2 emissions (all GB fleets combined)

Appendix 2 of this report, lists the key numbers, conversion ratios etc. that have been used consistently throughout the calculations of energy savings in this research.

3 WHERE DOES THE ENERGY GO?

From the available figures the annual rail traction energy use on GB Network Rail is shown below:

	Diesel (MWh) *Primary fuel energy*	**Electric (MWh)** *Energy at substation*
Passenger[1]	4.7 million	2.9 million
Freight[2]	2.7 million	0.1 million

It needs to be appreciated that the electric figures is energy from the substation and thus does not account for losses in generation and distribution. If these are factored in the approximate figures become:

	Diesel (MWh) *Primary fuel energy*	**Electric (MWh)** *Primary fuel energy*
Passenger	4.7 million	7.2 million
Freight	2.7 million	0.3 million

Whilst precise figures for where this energy goes do not exist, it is possible to apportion the energy use between losses in different parts of the system. Figure 1 below, shows in very broad terms where the total 14.9 million MWh is consumed.

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[1] ATOC 2005/2006 energy data

[2] Transport Watch GB – Road versus rail, fuel consumption across the GB

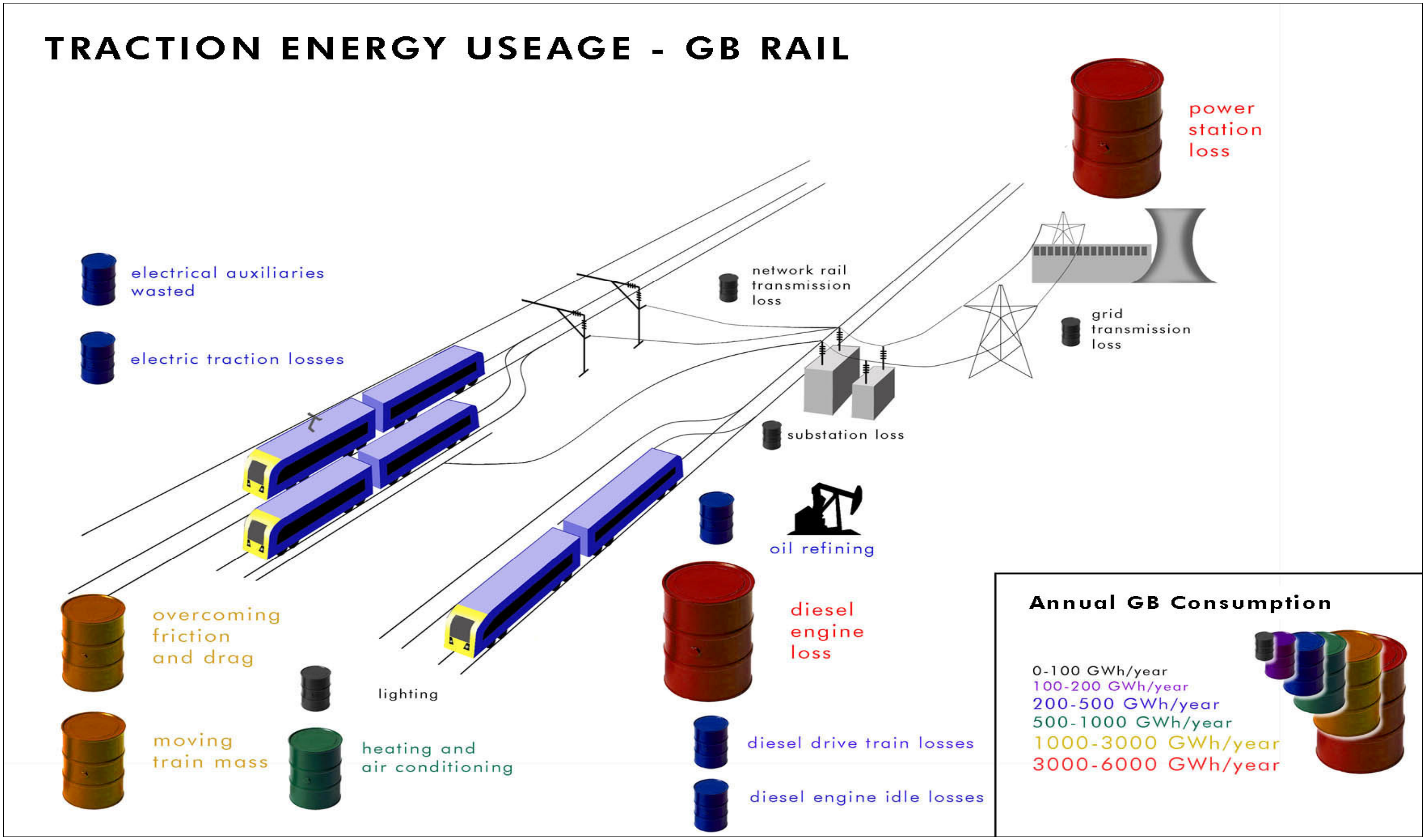


Figure 1 – A picture of the overall GB traction energy usage profile

4 OPTIONS FOR ENERGY SAVING

The following sections summarise the energy saving options as prioritised in Section 2 above. The reference in brackets after each heading refers to the coding used in the detail report ITLR-T18659-004.

4.1 RANK 1 – QUICK WINS

There are four areas where the research indicates substantial savings can be gained in the short term. These are:

- Reducing stabling loads on electric trains (S11);
- Energy efficiency through improved driving techniques and train regulation (S5);
- Running shorter trains off peak (S1);
- Reducing diesel engine idling (S12);

4.1.1 Reducing stabling loads on electric trains (S11)

Work undertaken by ATOC indicates that on electric railways, as much as 15% of the total traction energy demand occurs when trains are stabled. Extrapolated across the entire GB electric network this equates to around 430,000 MWh energy consumption per year. It needs to be appreciated that this figure was obtained through measurement at C2C which is a railway that is very dependent on the peak services into London. Independent calculations undertaken as part of this study indicate that the energy used for powering auxiliaries on stabled trains is estimated to be approximately 200,000 MWh across the entire GB network. We have therefore assumed the real number to be midway between these two figures and have used **321,000 MWh** as a realistic average.

This load is used in providing lighting, heating and powering other auxiliaries on trains that are stabled, mostly at depots and stabling sidings. Sometimes these auxiliaries are required, for example, when cleaners are working on the train, lighting and heating may be required. However, for a large proportion of the time, this energy is simply being wasted.

The simplest and most effective solution is to ensure the pantograph is dropped (or shoe gear isolated) and all lighting and heating turned off, as soon each train is stabled.

This may not always be practical, as cleaning activities are likely to be undertaken and also some pre-heating of the train may be needed in the morning. In this case, it would be possible to employ an additional person to manually attend to trains to ensure they are only 'live' when they need to be.

Alternatively, on modern trains with load shedding, software modification may be possible to allow minimum levels of lighting and heating to be retained, or to switch on pre-heating at a fixed time prior to service start-up.

An indicative business case example indicates that even if trains need to be modified to provide improved load shedding, the annual savings for a typical fleet of 40 trains could payback the modification costs in two years.

4.1.2 Energy efficiency through improved driving techniques and train regulation (S5)

Every time a train starts from standstill or is required to make a significant change in speed it uses a considerable amount of energy. A stop start journey will be less efficient than one where a steady speed is maintained throughout. Several studies have focussed on the potential for energy saving, some involving real time measurement of energy usage on a journey and some involving simulation. Typically the potential energy savings quoted are in the range of 5% to 15% of the total energy used in directly moving the train. In this study we have taken a conservative figure of 7.5% which equates to a figure of approximately **141,000 MWh electricity** and **33.5 million litres of diesel** across the GB network. It is estimated that about 5% of this reduction can be achieved through efficient driving techniques and around 2.5% through improved train regulation.

There are a large number of measures that can be applied to improving driving style and train regulation. Some of these may be applied relatively easily now and others require more investment and time to implement. To ensure effort is applied where it is most effective, it is essential that there is an adequate means of measuring the benefits of any change (accurate fuel measurement, electrical energy usage). Then by introducing the following approaches it will be possible to assess and review the impact of changes and determine where further effort is required:

- Introduce driver route cards with intermediate timings based on the minimum energy profile for a given journey time;
- Improve driver training, through use of energy measuring simulators;
- Consider introducing coasting boards;
- Introduce an automatic system that advises the driver an optimal speed to meet both timetable and energy criteria;
- Consider timetable review; and
- Timely removal of temporary speed restrictions.

There are other factors that will have an impact, but which are very unlikely to be justified on energy grounds alone. These should be considered during the implementation of any new or upgrade project:

- Optimised junction margins;
- Signalling systems;
- Provision of extra passing loops; and
- Reducing permanent speed restrictions through infrastructure changes.

Each railway will need to prepare a business case for each of the actions listed above. In broad terms though, it is likely that in most cases there will be a positive business case for driver route cards, improved driver training, energy measuring simulators and driver advice systems.

An indicative business case example indicates that with improved driver training, simulators and provision of an automatic driver advice system, a typical fleet of 40 trains could payback the modification and training costs in three to four years.

4.1.3 Running shorter trains off peak (S1)

Average load factors (all trains all day) across the GB industry range from approximately 20% up to a maximum of 50%. Since some peak trains are very full, this indicates that many other trains must be running with a large proportion of empty seats. There appears to be significant scope for running shorter trains off peak. Some trains may also benefit from splitting geographically where load at one end of the route is generally much higher than the other end.

The incentive on operators to control costs generally ensures that train size will be in line with observed demand, though there are some exceptions. A number of inner London off-peak services are now operated by eight car trains when a four car would be perfectly adequate. This unnecessary use of trains not only results in more train energy consumption but also increases wear and tear on both the track and the train. The operational forces behind this have been investigated and have their origins in a combination of coupler unreliability, loss of London-end stabling positions, less ECS working and penalties for failing to present the required capacity in the evening peak.

Track access costs and performance regime penalties are not currently providing adequate incentives for train operators to always run the most energy efficient train formation to provide the required number of seats.

Based upon a preliminary analysis of the timetables for the third rail fleets of trains running in to London alone it is estimated as much as **280,000 MWh** may be being wasted per year.

Splitting multiple unit trains off peak is a relatively simple solution, however there are barriers.

- Although the coupling and uncoupling procedure on modern multiple units is largely automatic, some additional staff may be required to oversee this activity;
- Retaining units coupled together is now seen as a means to reduce the number of reliability problems and impact on train performance;
- Timetables may need to be adapted to allow additional time for splitting and joining;
- Additional stabling space will be required (most likely in the London area), this will have cost implications;
- Depending on the location of the stabling, additional empty coaching stock miles may be accrued, and additional traincrews may be required.

Taking all these issues in to account to produce a business case clearly is a relative complex issue which needs to be addressed on a service by service basis. However, in simple terms our work indicates there is, in most case likely to be a clear positive business case for the change.

An indicative business case example indicates that running off peak four car units instead of eight could payback £5000 per unit per year after accounting for increased staffing costs.

4.1.4 Reduce diesel engine idling (S12)

The direct analogy to reducing stabling loads on electric trains is to reduce engine idling on diesel trains. Excessive idling of diesel engines is a major cause of poor energy usage and our calculations indicate that wasted energy equates to approximately **36.1 million litres of diesel** per year. The main reasons reported for idling are usually operational. For example:

- Engines are left running at stations to supply 'hotel services' and auxiliaries;
- Engines are left running as there is a long standing concern that if engines are shut down, there is a risk that they may not be reliably restarted when required;
- Engines are left running overnight to protect equipment against frost damage and to avoid coolant leakage as the pipes and joints contract;
- Engines are run overnight to supply 'hotel services' and maintain train heat;
- Engines are left idling during refuelling, servicing and running maintenance;
- Engines are started typically one hour prior to the start of work to preheat trains.

Some options to consider for reducing idling time are:

- During the summer time, it may be possible to reduce engine start-up time prior to diagram working;
- Consider the use of intelligent software to identify when engine restarts are necessary and the duration of running (based on ambient external temperature). This system could be used for train preheating and winter frost protection reducing the cycling between temperature extremes;
- Consider the re-scheduling of diagrams to avoid long layovers, e.g. use slower journey times to arrive ready for the next scheduled departure time. Cleaning services could be carried out en-route;
- When locomotives or units are brought onto the fuel point they could be shut down immediately after any running checks required for maintenance are completed. Shunting movements could be made by a pilot or shunting locomotive or on a reduced number of engines. This is particularly relevant where multiple units and HST power cars are concerned;
- Whilst not reducing energy consumption directly, shore supplies should be used for provision of hotel load when stabled, and waiting for extended periods. Shore supplies, are a cleaner and more efficient energy source than idling diesel engines;
- Large engine coolant and oil systems may be maintained warm and at near operational temperatures by using separate systems using intelligent software; and
- Modify fluid systems to reduce the likelihood of leakage when cool, so that engines can be shut down with confidence.

Again, there are a range of options here that need to be considered specifically for each railway when preparing a business case. However, in simple terms our calculations indicate there is likely to be a positive business case for most of these actions.

4.2 RANK 2 – LONG TERM OPPORTUNITIES

This section identifies areas where the research indicates that there appear to be substantial gains to be made in the future, but where more research and development is required, or where the improvements are only likely to be cost effective when introduced at the same time as new trains or infrastructure:

- Hybrid drives – diesel / battery (S16);
- Heating and air conditioning savings (S19);
- Fuel additives (S8);
- Weight reduction (S26);
- Hybrid drives – electric / diesel (S17);
- Intelligent engine control on distributed power trains (S7);
- Aerodynamic drag reduction – passenger (S31); and
- Regeneration and on train storage (S18).

4.2.1 Hybrid drives – diesel / battery (S16)

This section refers to configurations where a diesel engine is used in conjunction with batteries or other energy storage device (similar to the hybrid car concept with petrol engine and batteries).

The technology can be applied in different ways. Savings are predicted for shunting locomotives which traditionally spend a lot of their time idling since the engine can be used to generate sufficient power to charge the batteries and the engine can then shut down. The batteries are then used for shunting movements until they require recharging at which point the engine cuts back in. This technology is relatively well developed and hybrid shunting locomotives are commercially available. However, since the shunting locomotive fleet is relatively small this limits the potential energy saving.

Alternatively, for passenger stock the diesel engine can be used in conjunction with regenerative braking to charge the batteries at the same time as supplying some of the traction energy directly. This is an emerging technology, one of the main barriers being the performance of energy storage devices (batteries, supercapacitors etc). This concept is being trialled in both Japan and Italy. It is also understood that a joint initiative between Hitachi, Network Rail, Brush Traction and Porterbrook is working towards evaluating this technology in Great Britain using a converted HST. The modified train is due to commence operations in April 2007.

Experience to date indicates that a 10% saving on total diesel fuel consumed is a realistic target and this equates to **45.9 million litres of diesel** across the GB network. These figures need to be backed up by the results from trials. It should also be appreciated, that conversion of older diesel trains will probably not offer a positive business case, so savings will only be realised if hybrid drives are included in future train procurement specifications.

4.2.2 Reduce heating and cooling load savings (S19)

A considerable part of the auxiliary power supply is used for conditioning the passenger environment, either to heat the air in winter or to cool it in summer. It is calculated that under extreme conditions as much as 80% the auxiliary energy consumption is used for heating/cooling.

Considerable savings can be made in reducing the heating and cooling load when trains are stabled. This is discussed in Section 4.1.1 above. In addition, there is further potential for reducing the energy used for heating and cooling on trains in service. In particular, the following options exist:

Action	Approximate saving across all GB fleets
Reducing ambient air ingress through improving door seals and reducing the time doors are open at stations (S20)	24,000 MWh + 3.8m litres diesel
Reducing thermal transmission losses through improved insulation (S21)	41,000 MWh + 6.6m litres diesel
Reducing solar gain, by using light / reflective paint schemes (S22)	1,000 MWh + 0.2m litres diesel
Changing the interior temperature set point by one or two degrees (S23)	8,000 MWh + 1.3m litres diesel
Reducing the amount of fresh air intake, when trains are empty or lightly loaded (S24)	41,000 MWh + 6.5m litres diesel
Technology improvements in air conditioning systems to reduce steady state cooling load (S25)	1,000 MWh + 0.2m litres diesel
TOTAL	**115,000 MWh + 18.5m litres diesel**

Whilst the potential savings are relatively large, their delivery requires significant investment in modifications. Financial payback may take at least 17 years for modifications to existing vehicles. However, these improvements should be considered as a matter of course on all new trains. Improvements to existing fleets would need to be evaluated on a case by case basis taking due account of the age of the fleet and predicted savings that could be generated on the specific fleet in question.

4.2.3 Fuel additives (S8)

Fuel additives have been offered by various suppliers over the years, with claims of significant reductions in diesel engine fuel consumption of up to 20% and improved engine performance. However, when most of these claims are investigated further little substantiated evidence is available. However, recent independent tests on a rail diesel engine showed that using a catalytic fuel additive increases power by between 2 and 5%. This in-turn equates to a 4% saving in diesel engine fuel, dependant on load conditions. Further tests are proposed to add more confidence in the results obtained so far with a view to a service trial.

Whilst not directly comparable to rail, trials in the US road haulage industry indicate savings of between 4% and 12% fuel consumption. In this study we have taken a relatively conservative assumption that a 4% saving is achievable, and this equates to **28.9 million litres of diesel** per year across the GB diesel operated fleets. The cost of fuel additives typically increases the overall price of the fuel by 2% to 3% which indicates there is a positive business case. Further field trials are required to prove the savings are transferable to rail and it understood that at least one GB operator has already commenced such a trial.

4.2.4 Weight reduction (S26)

This scope of this project does not extend to considering how weight can be reduced to generate energy savings since there is a separate RSSB study considering this issue. However, we were asked to quantify the potential benefit in energy terms of additional or reduced train mass. This is a complex question, with the answer varying considerably from one train type to another depending on the proportion of the traction energy that goes into overcoming the train inertia and grade, and the presence or otherwise of regenerative braking on the vehicles.

Simplistically, train mass is broadly proportional to the inertia and grade resistance proportion of the train's total energy consumption. Ballpark calculations indicate that a two tonne reduction in average vehicle mass could deliver a saving of approximately **55,000 MWh electricity** and **8.8 million litres of diesel** across the GB network. There are also other benefits in terms of weight reduction such as reduced track forces. Put another way, a one tonne saving on a vehicle could save on average around £200 per year at today's electricity prices.

Clearly at this sort of figure, there is unlikely to be a business case for any vehicle modification aimed at reducing mass on energy grounds alone. However, when comparing alternative designs for modifications or complete new trains, the energy penalty associated with increasing vehicle mass should be considered.

4.2.5 Hybrid drives – diesel / electric (S17)

This section deals with electric/diesel traction packages on one train as envisaged as one of the configurations of the Department for Transport InterCity Express Project (previously HST2). A brief analysis of the passenger timetables indicates that across the GB rail network there are over 100 million vehicle kilometres per year of diesel traction on electrified routes

Provision of a dual traction train which can run on supplied electricity where it is available and on the diesel engine at other times can generate an improvement in energy efficiency. Our calculations show that if dual traction trains are used where diesel trains currently run on electrified routes a fuel saving of **49.7 million litres of diesel** could be achieved. Whilst this will increase electrical energy consumption by 195,000 MWh, in overall terms this would lead to cost savings and a reduction in CO_2 emissions of an estimated 42.2 million kg CO_2. This does not account for any increase in train weight which would offset some of the savings.

During commissioning of the Class 91 fleet, a single ended HST was run with an electric Class 91 locomotive which effectively produced a dual traction hybrid train. However, it is considered that it would not be commercially viable to convert existing trains. Future builds such as the InterCity Express Project need to factor in the energy and CO_2 benefits of providing dual traction, taking full account of the routes to be operated and any weight penalty for the additional equipment.

4.2.6 Intelligent engine control on distributed power trains (S7)

Some modern distributed power diesel trains incorporate significant amounts of traction redundancy. Procurement specifications often contain the requirement that the nominated timetable requirements can be achieved with one or more engines out of service. There is therefore potential to reduce power consumption by selectively shutting down some engines when the train is in traffic (shutting down of engines when idling in stations or stabling yards is considered in Section 4.1.4).

This is only possible where the train set contains multiple traction power supplies, although most modern multiple units are now fitted with a traction engine per car as standard. Clearly the control of this selective shut-down feature is very important whereby engines would need to be shut down and re-started based upon train utilisation, i.e. long periods of coasting, down hill travel, standing at signals or in stations. Control would be by intelligent software, programmed to identify periods of low demand and manage the supply of power according to the demand by starting and shutting down engines.

Our initial calculations show that this approach might save as much as **15.4 million litres of diesel** across the GB diesel operated network each year. There is work to be done, to develop the engine control systems so they are capable of this way of working. A simple business case estimates that for a fleet of 40 such trains the annual fleet saving expected is around £1.5 million compared to one off design and modification costs of £4.2 million, a payback of around three years.

4.2.7 Aerodynamic drag reduction – passenger trains (S31)

Train resistance is heavily influenced by the velocity squared term and the aerodynamic coefficient. As speed increases, the importance of the aerodynamic drag becomes much more significant. Drag is influenced by both the external geometry of the vehicles and the surface finish. Improvements can be made by changing the external profile, by shielding equipment, removing sharp edges and by controlling the air flow across the vehicles.

Options for improving aerodynamic drag on high speed trains include:

- Fitting of bogie skirts and shielding of underframe equipment;
- Improved aerodynamic profile of nose end; and
- Smoother body profile and aerodynamic farings at vehicle ends.

Based on a potential saving of 10% on aerodynamic drag, as demonstrated on the ETR500 train, a potential saving across the GB network of approximately **35,000 MWh electricity** and **7.5 million litres of diesel** could be achieved. This saving however needs to be balanced against any increase in mass as discussed in Section 4.2.7 above. Based on these figures, there is unlikely to a business case for retrofitting any existing vehicles. However, on any new build these options are likely to deliver financial savings (as well as energy savings) on a life cycle cost basis and therefore should receiver further consideration.

4.2.8 Regeneration and on train storage (S18)

All diesel electric and electric trains built for the GB market in the last ten years feature inverter drives and regenerative braking capability which either feeds power back into the infrastructure or to on board auxiliary systems. Up to now the advantage of feeding back into the supply network has not been fully realised since the infrastructure requires modification to avoid compatibility issues, particularly with the signalling and power supply systems

From simulation and practical experience it is estimated that a typical figure for the energy saved with effective regeneration into the supply network is in the order of 16%, however this will vary from railway to railway depending on the duty cycle and the receptivity of the infrastructure to absorb the energy regenerated. Recent figures from

Bombardier indicate on-train storage may save more than this and have indicated figures of up to 30% for Light Rail vehicles. GB Rail EMUs have more energy to dissipate because of their mass and speed and space available for energy storage devices would bring this figure down to around 20% but each case needs to be examined on its own merits.

If the electricity regenerated is not fed back into the supply network then an alternative is to store it on the train for re-use. Energy storage may take the form of supercapacitors, batteries or flywheels. The most promising of these energy storage options is supercapacitors.

In this research we have based our calculation on a possibly optimistic 25% saving for EMUs and 15% on DEMUs. Based on today's railway, these preliminary calculations show that for the electric fleets as much as 256,000 MWh of energy could be saved through on-train energy storage and for diesel fleets a further 16.5 million litres of diesel. This equates to a total saving of £21.8m and 160.2 million kg CO_2. However, it has been stated by the RSSB that the intention is to create a totally regeneration enabled railway. Clearly it is only possible to recover and re-use the energy once, so if this becomes the case (and all lines are fully receptive) then these savings will be achieved but through regeneration to the infrastructure and not through on-train storage. Furthermore, the savings for diesel electric trains are already included in the energy saving figure for hybrid-drives (since this is effectively what a diesel train fitted with energy storage capacity is) and should not be counted again here.

Whilst the true energy saving may be limited by increased regeneration there are some obstacles to be overcome in this regard and on-train storage may still provide a useful alternative in some specific scenarios.

4.3 RANK 3 – OPPORTUNITIES LIKELY TO DELIVER REDUCED ENERGY USE WITHOUT COST SAVINGS

The following options were also considered. Whilst these have a positive benefit in reducing energy consumption, there is little or no business case.

- Permanent reduction in light levels (S28);
- Rolling resistance and wheel/rail friction (S30);
- Low resistance conductor rail (S45);
- Reduce empty stock movements (S6);
- Improved lighting efficiency (S27);
- Selective Lighting (S29);
- Reducing battery mass (S33);
- Reducing aerodynamic drag on freight trains (S32);
- Reducing losses in 25kV insulators (S47); and
- Switching off transformers during no load periods (S49).

4.3.1 Permanent reduction in light levels (S28)

On some new and refurbished vehicles, a permanent reduction in light (lux) levels can be achieved without conflicting with the requirements in applicable standards. It is calculated that if all vehicles in GB are modified to reduce lighting levels to the minimum specified level a total saving of approximately **42,000 MWh electricity** and **6.3 million litres of diesel** could be achieved per year. However, on a per vehicle basis, this equates to less than £300 per year which is unlikely to justify the change given that it has the potential for reducing the customer environment with potential knock on to reducing passenger revenue. However, new trains should be designed to provide the best customer environment without over specifying the lighting level.

4.3.2 Rolling resistance and wheel/rail friction (S30)

From research undertaken it is estimated that a 2% reduction in rolling resistance may be a realistic target for improved track lubrication. This reduction in rolling resistance across the GB network could save a modest **9,000 MWh electricity** and **3.3 million litres of diesel** per year. It is considered that any scheme of improved track lubrication is unlikely to pay for itself in energy saved alone. Where high rail friction is known to be a problem, installation of improved lubrication may be a cost effective solution taking in to account wheel and rail life in combination with potential energy saved.

4.3.3 Low resistance conductor rail (S45)

Around 3% of the total energy consumed by the DC railway (from grid connection) is dissipated in the 3rd (conductor) rail which is made of steel. Composite aluminium-steel rails (CCR) are used routinely worldwide, especially on metro systems. They have lower resistance and it is calculated that there is a potential saving across the GB network of **23,000 MWh electricity** per year. However, on a national level calculations show the cost of replacement outweigh the savings generated many times over. Therefore, for Network Rail, CCR might be economically justified in the following circumstances only:

- Areas where the average Root Mean Square (RMS) current is high, which occurs near substation feeders feeding dense traffic; and
- During the normal renewal of a worn steel conductor rail (rather than removing healthy rail for the sake of fitting CCR).

4.3.4 Reduce empty stock movements (S6)

The widespread rationalisation of infrastructure has meant that many historical stabling and maintenance locations no longer exist. This has led to some TOCs having to run increased numbers of empty miles in order to get units to/from depots or stabling points. For a sample of four TOCs, the empty miles operated were 4.8% of the total miles and therefore a similar proportion of the total traction energy is consumed on ECS.

It is unlikely that there is a simple solution to this since in general TOCs will seek to minimise ECS moves from a cost (including traincrew) perspective. However, further consideration could perhaps be given to depot locations and routing of diagrams. In overall terms, although it may be more cost effective to undertake all routine maintenance at one particular location, this may be poor in energy terms. Similarly, improved and more efficient use of rail freight vehicles could reduce the number of empty or partially empty freight services currently running on the network. In order to size the potential saving it is estimated a 0.5% reduction in ECS miles might be an achievable target. This would save **9,000 MWh electricity** and **2.2 million litres of diesel** across the GB network each year. The financial cost of achieving this saving is difficult to quantify without studying the diagramming, maintenance and stabling requirements of each particular fleet. However, it is considered that on financial grounds alone, there is unlikely to be a positive business case.

4.3.5 Improved lighting efficiency (S27)

With new lighting technology it is possible to reduce the power consumption of the train lights without reducing the overall light (lux) level in the vehicle. For example, LED downlighters are a far more efficient alternative to the dichroic downlighters in common use on a number of recently built and refurbished fleets. Also, for a small cost premium there are more efficient fluorescent tubes available compared to standard tubes. Calculations indicate a potential annual saving of approximately **11,000 MWh electricity** and **1.8 million litres of diesel** could be achieved across the GB fleets if vehicles are modified to fit more efficient lighting. Generating an annual cost saving of under £100 per vehicle per year, any change requiring modification is likely to only be cost effective when done at the same time as vehicle refurbishment. There may be a business case for the 'like for like' replacement of tubes and bulbs for more efficient versions, especially as technology improves and the price of alternative luminaires decreases.

4.3.6 Selective Lighting (S29)

Another potential option for reducing lighting load is to switch of some lights during daylight hours, and/or to switch off lighting in some vehicles when the train is lightly loaded or travelling empty to the depot. A relatively simple solution to managing the lighting load would be to manually switch the lighting. Alternatively sensors could be used to monitor the passenger utilisation of a vehicle and/or the ambient light coming in from the windows to select an appropriate lighting level and configuration accordingly. Calculations estimate the energy saving to be in the order of **10,000 MWh electricity** and **1.4 million litres of diesel** per year across the GB network, which equates to less than £100 per vehicle per year. It is therefore very unlikely that there is a business case for any vehicle modification to achieve this. However, where practical, manually switching could be considered by TOCs as well as ensuring any new trains are designed with these opportunities in mind.

4.3.7 Reducing battery mass (S33)

The purpose of the battery is to maintain the functionality of electrical systems and equipment during periods of temporary power loss. There are two parameters which determine the size of the battery capacity:

- Loads on the battery which need to be supported during failure of the supply; and
- How long the load needs to be supported at the minimum battery temperature.

Energy savings, through improved batteries could be made in two ways:

- Improved battery technology, which provides equivalent battery capacity for less battery mass; or
- Reduce the battery loads or time requirement, thereby reducing the required battery capacity.

Based on the mass reduction it is calculated changing of the battery technology and/or the emergency load requirements could deliver annual savings of around **8,000 MWh electricity** and **1.3 million litres of diesel** across the GB network. However, since this equates to less than £100 per vehicle per year there is unlikely to be a business case for changing existing vehicles unless a lighter like for like battery replacement can be found, or the emergency load system is being modified for other reasons.

4.3.8 Reducing aerodynamic drag on freight trains (S32)

Although speeds are lower, air resistance accounts for a significant proportion of the energy usage on freight trains. It has been shown that by optimising the order of different types / sizes of wagon and by covering empty wagons, savings can be made in this respect. Calculations and estimates put the potential savings at approximately 10% of the total energy directly used for traction which equates to approximately **1,000 MWh electricity** and **2.3 million litres of diesel** across the GB network per year. Where vehicle modifications are required, or changes to operating practice are required (for example, fitting of hopper wagon covers) there is unlikely to be a business case for the change. Consideration should however be given to the practice of loading container wagons to ensure the best formation from an energy perspective.

4.3.9 Reducing losses in 25kV insulators (S47)

Deposits on the 25kV insulator surfaces contain substances that turn into conductive electrolyte in damp weather. The power lost across the GB network is calculated to be less than **8,000 MWh** per year. New polymeric insulators are claimed to reduce the current leakage and subsequent loss. These new insulators are being introduced already on Network Rail so in the longer term this could reduce losses. It is recommended that the improved insulators are fitted as a matter of course on new installations and where they need to be replaced for other reasons. There is no business case for a campaign change of otherwise serviceable insulators.

4.3.10 Switching off transformers during no load periods (S49)

Transformer no-load losses, though much smaller than the load losses, are always there even when no trains are running. For traction transformers, no-load (iron) and load (variable) losses are typically 0.05% and 0.5% of rating respectively. If all transformers could be switched off 4 hours per night, from say 01:00 to 05:00 modest savings could be made of approximately **3,000 MWh** per year across the GB network. However, Network Rail has already stated they would not support this option for the following reasons:

- It would increase wear and tear on the breakers, and hence increase maintenance cost;
- It increases the risk of failure to re-energise in the morning, with consequent delay in starting services;
- There is nightly train traffic on some routes; and
- There is potential for theft of conductors if switched off.

4.4 RANK 4 – NOT CURRENTLY VIABLE, BUT WORTH CONTINUING TO REVIEW

This section identifies areas which are not considered viable at the current time, but are worthy of continued review, if and when technology improvements are made.

- Local generation (S44);
- Inverting substations (S46);
- On-board solar energy (S34);
- Improved efficiency of traction drives – alternative motors (S36);
- Improved efficiency of traction drives – direct drives (S35); and
- Line side energy storage.

4.4.1 Local generation (S44)

There is a potential energy saving from local generation as a consequence of reduced losses in the distribution network. The maximum saving is calculated as **49,000 MWh** per year across the GB network if all traction energy is generated locally. However, it is considered very unlikely that it will be possible to implement local generation across the whole network and therefore actual savings may be significantly lower. There is no business case, since the cost for providing local generation would be many times more than the cost of the energy saved. Whilst there may be a separate argument for renewable energy, this is for the electricity generation companies to address. Whilst Network Rail may influence policy by buying from renewable energy sources it is not suggested that they should go into the business of generation themselves.

4.4.2 Inverting substations (S46)

Inverting substations allow energy produced during regenerative braking on DC systems to be supplied back to the three phase supply to feed in to the AC distribution network. It is calculated the potential for saving across the GB network could be up to **20,000 MWh per** year (assuming regenerating trains are running). However, with equipment costs in excess of £0.5m per substation there is no business case for this option on a retrofit basis. However, for new schemes, inverting substations should be considered on a case by case basis, as the additional cost during new build will be much lower.

4.4.3 On-board solar energy (S34)

Currently there is only a marginal energy saving calculated as **4,000 MWh electricity** and **0.7 million litres of diesel** per year across all GB fleets. This may equate to an overall energy loss once the mass of solar cells is taken into account. This option is only likely to become viable if there is a significant improvement in the energy / mass ratio of solar cells.

4.4.4 Improved efficiency of traction drives – alternative motors (S36)

There is a small energy benefit from multi-phase and permanent magnet motors (**3,000 MWh** per year across GB fleets). There is no case for retrofit, but these options should be considered as an option during new build taking due account of any increase in the mass of control equipment.

4.4.5 Improved efficiency of traction drives – direct drives (S35)

There is a small energy benefit from direct drive motors (**1,000 MWh** per year across GB fleets). So far the technology has been employed mostly on light rail applications. There is no case for retrofit, but direct drives should be considered as an option during new build.

4.4.6 Line side energy storage – 750V DC (S50)

Energy recuperated during regeneration is normally made available to other motoring trains nearby. When no motoring trains are in close vicinity of a braking train, then all the electric braking energy is wasted as heat, and the network is said to be non-receptive. One way to improve receptivity is to install a track-side energy storage device that would store the excess braking energy, for later use by motoring trains. Equipment could comprise flywheels, supercapacitors or batteries. In dense traffic areas the benefit is likely to be small since there will usually be other trains nearby that can use the energy. In sparse traffic however, there is little energy to be recovered. On a network wide basis the energy that would be saved is therefore estimated to be small and at an estimate £250k for each 1MW unit, there is no business case.

During the stakeholder workshop Network Rail indicated that they see no prospect for storage technology on their network because the incremental gain in energy recovery achieved by inverter technology is generally likely to be too small to justify the capital cost.

4.5 OTHER OPPORTUNITIES CONSIDERED

A number of other opportunities were also considered. However, no further discussion is provided in this summary report because either:

- There is no (or negligible) benefit in energy terms;
- The opportunity is totally covered by other options (for example, increasing the passenger load factor (S2) is dependent on reducing train mass and train length for a given passenger count, both of which are covered elsewhere;
- The opportunity is included in separate RSSB research work (for example, hydrogen fuel cells);
- The improvement is not driven by a technical change (for example, encouraging modal shift to rail (S4) could lead to improving energy use per passenger mile, but is not something that improves energy efficiency of the railway equipment itself).

Other opportunities:

Increasing passenger load factor (S2)	Depends on modal shift and train mass
Increasing freight load factor (S3)	Depends on modal shift and train mass
Encourage modal shift to rail (S4)	Modal shift improves energy/passenger
Better measurement of fuel / energy used (S9)	Not energy saving (see comments below)
Reducing traction demand in the peak (S10)	Marginal energy saving
Shore supply versus on board supply (S13)	Covered under diesel engine idling
Loco hauled trains versus multiple units (S14)	Depends on application
Auxiliary engines on trains (S15)	No case for energy saving
Re-equipping mid life traction packages (S37)	Marginal benefit, high cost
Power factor improvement (S38)	Marginal benefit, high cost
Main transformer efficiency (S39)	Marginal benefit, high cost
Hydrogen fuel cells (S40)	A separate RSSB study
Passenger amenities (S41)	Trade-off, revenue versus energy
High frequency machinery (S42)	Marginal benefit, high cost
Auxiliary converter efficiency (S43)	Small saving, short time for payback
Reducing losses in 750V insulators (S49)	Marginal benefit, high cost
Substation spacing (S51)	Marginal benefit, high cost

Note: Better measurement of fuel / energy used (S9)

Although there is no direct saving from better measurement, this is considered an essential requirement for reviewing the effectiveness of the other energy saving strategies being adopted. Without accurate measurement, the savings are likely to be invisible to both operators and network rail, and the incentive for improvement lost as a consequence.

5 STRATEGIC RECOMMENDATIONS

Throughout this report we have identified opportunities that could be implemented now on existing trains, improvements that should be incorporated into new / refurbished trains or on new infrastructure, and areas where further research and development is required. This section summarises these key strategic recommendations.

In order to optimise the prospects for energy efficiency it is vital that the approach is one of considering energy efficiency as an integral part of the rail industries decision making processes and seeing rail as a whole system. Some of the opportunities identified can be addressed in isolation but others will only meet their full potential with a systems approach.

It is therefore recommended that the GB rail industry works collaboratively to ensure that the appropriate level of integrated thinking takes places in order that energy efficiencies are optimised. In some cases this may require changes to contractual and regulatory arrangements to ensure energy efficiency is adequately considered, and the associated costs and benefits are distributed equitably.

Each company should give consideration to making energy consumption reduction initiatives the responsibility of one of its senior executives. This should ensure that energy efficiency is proactively addressed, initiatives are followed through and then appropriately monitored to ensure ongoing benefits are delivered.

In order to better understand where these energy efficiencies can be gained, improved measurement and recording of energy and fuel use is an integral requirement.

The specific opportunities identified by this report can be translated into strategies for the future which can be conveniently categorised under:

- Train operation and maintenance
- New train procurement and design
- Infrastructure design and upgrade

5.1 TRAIN OPERATION AND MAINTENANCE

Electric trains should, where reasonably practicable, be fitted with an energy measurement system. For diesel trains, fuel monitoring should be implemented. This action is essential to ensuring the benefits of other changes are visible and can be measured and reviewed.

Unit timetabling/diagramming should ensure the smallest multiple unit train should be used consistent with passenger demand/load factor.

Trains stabled by day or by night should be stabled in a minimum energy consumption mode consistent with cleaning and security requirements.

Each TOC operating diesel trains should ensure engines of stationary trains are shut down whenever practicable.

Each TOC should seek to improve the efficiency of driving techniques. This should include provision of detailed route cards to drivers and a programme of enhanced driver training. Opportunities for real time advice to drivers on energy consumption and driving performance should also be pursued. Further consideration should also be given to the energy efficiency benefits of improved train regulation and timetable development, and any associated regulatory regime changes to promote efficiency whilst safeguarding punctuality and reliability.

Each TOC, in conjunction with the vehicle owners and suppliers, should evaluate and deploy, if beneficial, diesel fuel additives.

Train owners, manufacturers and operators should work together to undertake further investigation into potential improvements to heating and air conditioning systems, including altering set point temperatures and potential modifications to reduce the fresh air heating load.

Train diagrams and maintenance facilities should be re-evaluated in order that empty train working can be minimised.

Container trains should always be loaded such that there are no gaps within the train, thus giving minimum drag.

5.2 NEW TRAIN DESIGN

Energy efficiency should be given an appropriate level of importance during the train design process when evaluating the relative trade off between different options.

New diesel train designs should consider the merits of hybrid drives incorporating some form of energy storage media that is configured to minimise prime energy consumption. The planned trials in this area are endorsed as a positive step forward. Advances in Energy storage technology should be monitored and the appropriate devices adopted to optimise weight and energy saving performance.

New train designs should have the highest practicable standard of thermal insulation. Thermal imaging of a selection of modern rolling stock is recommended to enhance understanding of where losses occur and to determine where improvements can be made.

Trains that run over both electrified and non-electrified lines for a significant part of their journey should be considered for a dual mode traction configuration.

Braking energy should be conserved as much as practicable. Diesel electric and electric trains should regenerate into their auxiliaries, to the infrastructure or to on-board storage devices as appropriate.

Distributed traction diesel trains should have intelligent control of traction engine power such that overall traction demand is matched by some engines dropping back to idle or shutting down so that the remaining engines run at optimum fuel economy.

New trains should be designed to minimise overall train weight and to maximise passenger/freight capacity per tonne of tare mass.

New trains should be designed to have the lowest practicable aerodynamic drag factor consistent with keeping train overall weight as low as practicable.

Trials of improved wheel/rail lubrication are recommended so that any potential benefits can be better evaluated.

New and refurbished trains should present lighting levels compliant with, but not in excess of, relevant standards. The technology of the lighting system should be chosen to minimise energy consumption. Consideration should be given to providing selective lighting for lightly loaded trains, reduced artificial lighting during daylight hours and to provide only the minimum level of lighting when trains are stabled.

Traditional engineering principles should be reviewed as technology advances in order that energy savings might be optimised.

5.3 INFRASTRUCTURE DESIGN

The policy on using low resistance conductor rail for all new installations, especially in high current areas, should be re-evaluated since this has the potential for generating moderate savings if implemented selectively.

Lineside energy storage should be considered for specific locations on 750V d.c. lines where a number of trains regenerate but where other trains are unable to take regenerated energy.

6 APPENDIX 1 – SUMMARY OF SAVINGS

6.1 QUICK WINS AND SHORTER TERM OPPORTUNITIES

Quick Wins and Shorter Term	GWh electricity	Million litres of diesel	Million £	Million kg CO2
S5 Energy Efficient Driving and Train Regulation	141	33.5	19.9	152.3
S11 Disconnect Electrical Vehicles from Supply when Stabled	321	0.0	19.3	146.3
S1 Running Shorter Trains Off Peak	280	0.0	16.8	127.6
S12 Reduce Diesel Engine Idling	0	36.1	12.3	95.1
Total	**742**	**70**	**68**	**521**
Percentage of GB Total	**26%**	**10%**		

6.2 LONGER TERM OPPORTUNITIES

Longer term opportunities	GWh electricity	Million litres of diesel	Million £	Million kg CO2
S16 Hybrid Drives (diesel / battery)	0	45.9	15.6	120.7
S19 Reduced heating and cooling load (Summary Numbers)	115	18.5	13.2	101.1
S8 Fuel additives	0	28.9	9.8	76.0
S26 Weight reduction	55	8.8	6.3	48.1
S17 Hybrid drives (electric / diesel)	*-195*	49.7	5.2	42.2
S7 Intelligent Engine Control	0	15.4	5.2	40.4
S31 Aerodynamic drag reduction - passenger trains	35	7.5	4.7	35.8
S18 Regenerative Brake - On train storage	*Would only be of benefit if power supply unreceptive to regenerated energy. See hybrid drives for on train storage on diesel trains*			
Total	**206**	**175**	**60**	**464**
Percentage of GB total	**7%**	**24%**		

6.3 OPPORTUNITIES LIKELY TO DELIVER REDUCED ENERGY USE WITHOUT COST SAVINGS

Opportunities likely to deliver reduced energy use without cost savings	GWh electricity	Million litres of diesel	Million £	Million kg CO2
S28 Permanent reduction in light levels	42	6.3	4.7	35.8
S30 Rolling resistance and wheel-rail friction	9	3.3	1.7	12.8
S45 Low resistance conductor rail	23	0.0	1.4	10.3
S6 Reduction in Empty Stock Movements	9	2.2	1.3	10.2
S27 Improved lighting efficiency	11	1.8	1.3	9.9
S29 Selective lighting	10	1.4	1.1	8.1
S33 Reduction in battery mass	8	1.3	0.9	7.2
S32 Aerodynamic drag reduction - freight trains	1	2.3	0.8	6.4
S47 Losses in insulators - 25kV	8	0.0	0.5	3.9
S49 Switching of transformers during no-load periods	3	0.0	0.2	1.5
Total	**125**	**19**	**14**	**106**
Percentage of GB total	**4%**	**3%**		

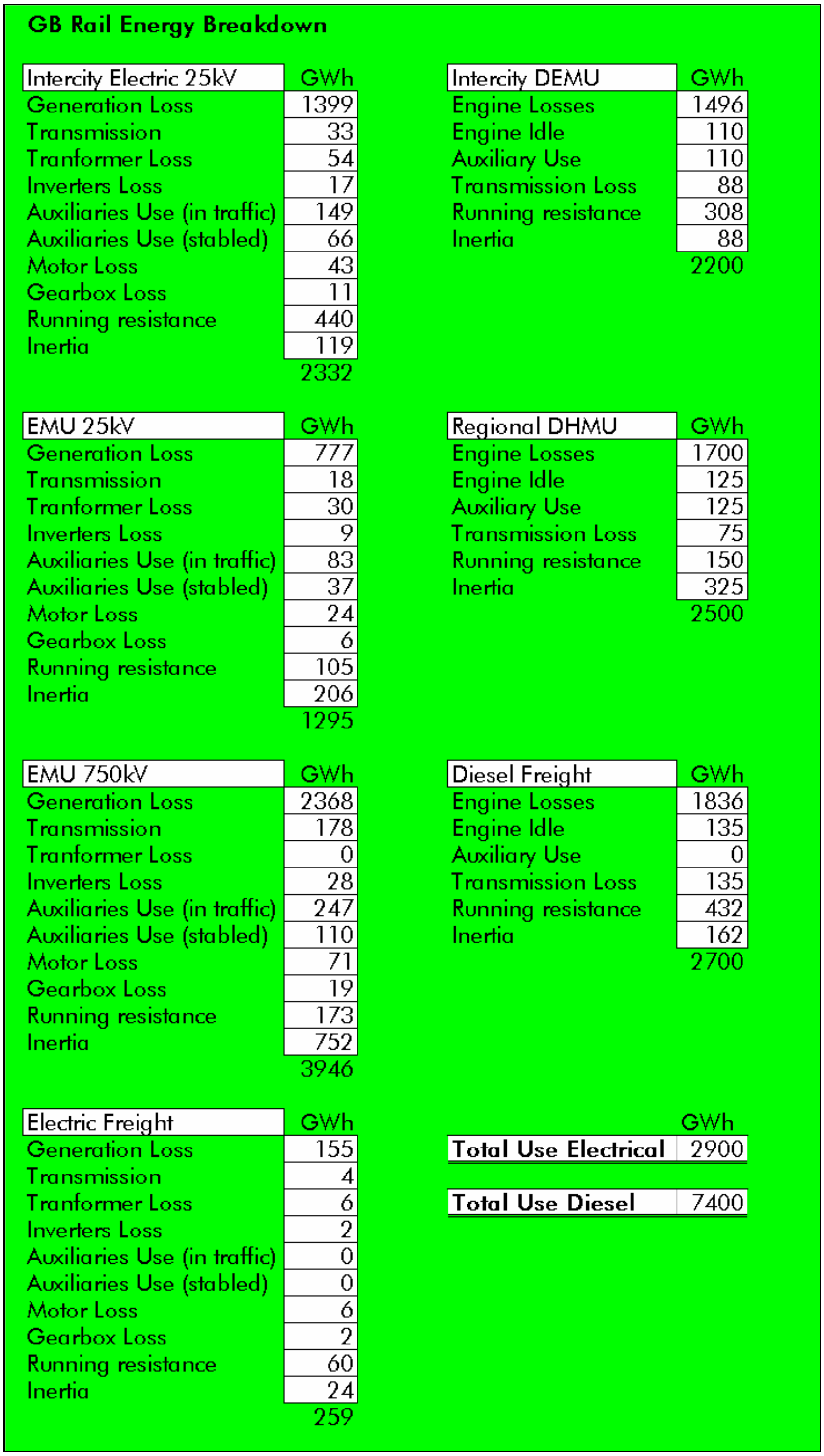
6.4 NOT CURRENTLY VIABLE, BUT WORTH CONTINUING TO REVIEW

Not currently viable, but worth continuing to review	GWh electricity	Million litres of diesel	Million £	Million kg CO2
S46 Inverting substations	20	0.0	1.2	9.1
S34 On board solar energy	4	0.7	0.5	3.6
S36 Improving the efficiency of traction drives - alternative motors	3	0.0	0.2	1.4
S35 Improving the efficiency of traction drives - direct drives	1	0.0	0.1	0.7
S44 Local generation	*Some savings from reduced distribution losses*			
S50 Line side energy storage	*Would only be of benefit if power supply unreceptive to regenerated energy*			
Total	**29**	**1**	**2**	**15**
Percentage of GB total	**1%**	**0%**		

6.5 OTHER OPPORTUNITIES

Other	GWh electricity	Million litres of diesel	Million £	Million kg CO2
S43 Auxiliary converter efficiency	3	0.0	0.2	1.4
S10 Reducing traction maximum demand	1	0.0	0.1	0.4
S48 Losses in insulators - 750V	1	0.0	0.0	0.3
S2 Increasing passenger load factor	Not quantified	Not direct energy saving, depends on modal shift and train mass		
S3 Increasing freight load factor	Not quantified	Not direct energy saving, depends on modal shift and train mass		
S4 Encourage modal shift to rail	Not quantified	Not direct energy saving, modal shift improves energy/passenger		
S9 Better measurement of fuel / energy used	Not quantified	Not energy saving (but essential to measure benefits)		
S13 Shore supply versus on board supply	Not quantified	Covered under diesel engine idling		
S14 Loco hauled trains versus multiple units	Not quantified	Depends on application		
S15 Auxiliary engines on trains	Not quantified	No case for energy saving		
S37 Re-equipping mid life traction packages	Not quantified	Marginal benefit, high cost		
S38 Power factor improvement	Not quantified	Marginal benefit, high cost		
S39 Main transformer efficiency	Not quantified	Marginal benefit, high cost		
S40 Hydrogen fuel cells	Not quantified	A separate RSSB study		
S41 Passenger amenities	Not quantified	Trade-off, revenue versus energy		
S42 High frequency machinery	Not quantified	Marginal benefit, high cost		
S51 Substation spacing	Not quantified	Marginal benefit, high cost		

7 APPENDIX 2 – SOURCE INFORMATION USED FOR CALCULATIONS



GB Rail Energy Breakdown

Intercity Electric 25kV	GWh
Generation Loss	1399
Transmission	33
Tranformer Loss	54
Inverters Loss	17
Auxiliaries Use (in traffic)	149
Auxiliaries Use (stabled)	66
Motor Loss	43
Gearbox Loss	11
Running resistance	440
Inertia	119
	2332

Intercity DEMU	GWh
Engine Losses	1496
Engine Idle	110
Auxiliary Use	110
Transmission Loss	88
Running resistance	308
Inertia	88
	2200

EMU 25kV	GWh
Generation Loss	777
Transmission	18
Tranformer Loss	30
Inverters Loss	9
Auxiliaries Use (in traffic)	83
Auxiliaries Use (stabled)	37
Motor Loss	24
Gearbox Loss	6
Running resistance	105
Inertia	206
	1295

Regional DHMU	GWh
Engine Losses	1700
Engine Idle	125
Auxiliary Use	125
Transmission Loss	75
Running resistance	150
Inertia	325
	2500

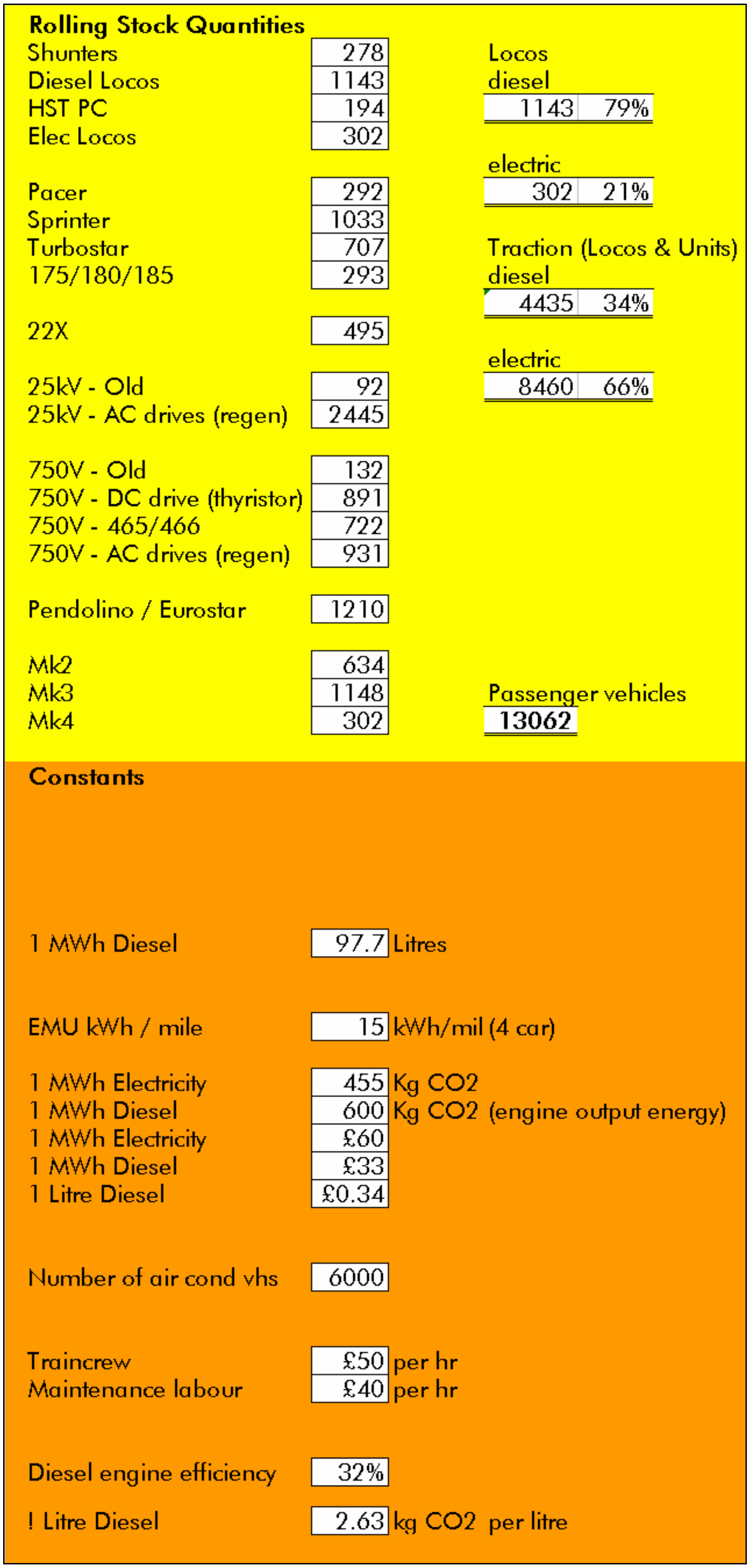
EMU 750kV	GWh
Generation Loss	2368
Transmission	178
Tranformer Loss	0
Inverters Loss	28
Auxiliaries Use (in traffic)	247
Auxiliaries Use (stabled)	110
Motor Loss	71
Gearbox Loss	19
Running resistance	173
Inertia	752
	3946

Diesel Freight	GWh
Engine Losses	1836
Engine Idle	135
Auxiliary Use	0
Transmission Loss	135
Running resistance	432
Inertia	162
	2700

Electric Freight	GWh
Generation Loss	155
Transmission	4
Tranformer Loss	6
Inverters Loss	2
Auxiliaries Use (in traffic)	0
Auxiliaries Use (stabled)	0
Motor Loss	6
Gearbox Loss	2
Running resistance	60
Inertia	24
	259

	GWh
Total Use Electrical	2900
Total Use Diesel	7400

The GB Rail Energy Breakdown is based upon ATOC energy consumption figures, apportioned in accordance with the typical sub-system efficiencies.



Rolling Stock Quantities

Shunters	278
Diesel Locos	1143
HST PC	194
Elec Locos	302
Pacer	292
Sprinter	1033
Turbostar	707
175/180/185	293
22X	495
25kV - Old	92
25kV - AC drives (regen)	2445
750V - Old	132
750V - DC drive (thyristor)	891
750V - 465/466	722
750V - AC drives (regen)	931
Pendolino / Eurostar	1210
Mk2	634
Mk3	1148
Mk4	302

Locos

diesel	1143	79%
electric	302	21%

Traction (Locos & Units)

diesel	4435	34%
electric	8460	66%

Passenger vehicles
13062

Constants

1 MWh Diesel	97.7	Litres
EMU kWh / mile	15	kWh/mil (4 car)
1 MWh Electricity	455	Kg CO2
1 MWh Diesel	600	Kg CO2 (engine output energy)
1 MWh Electricity	£60	
1 MWh Diesel	£33	
1 Litre Diesel	£0.34	
Number of air cond vhs	6000	
Traincrew	£50	per hr
Maintenance labour	£40	per hr
Diesel engine efficiency	32%	
! Litre Diesel	2.63	kg CO2 per litre

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