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ENERGY EFFICIENCY OPPORTUNITIES

ENERGY– MASS BALANCE: TRANSPORT

VERSION 1.0

National Framework
for Energy Efficiency

Energy Efficiency
Opportunities

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1 INTRODUCTION

Transport operations are highly energy-intensive, diversified businesses. Energy use in transport operations is inherently complex due to the range of different routes, vehicles, customer, freight/passenger types and other (e.g. climatic) factors affecting energy use. This case example will demonstrate one suitable approach to developing an energy-mass balance (EMB) for a transport system to meet the requirements of the Energy Efficiency Opportunities (EEO) program as detailed in the EEO legislation.[1]

This case example uses data that are indicative of a real transport operation to illustrate the EMB process for a transport system. The approach described examines the transport operation as a system to ensure an efficient and effective EMB process that helps to identify, evaluate and implement opportunities. This is one of a series of EMB guidance documents, including guides for commercial buildings and mining operations.

1.1 ENERGY EFFICIENCY OPPORTUNITIES REQUIREMENTS FOR EMBS

Key Requirements 3.2d, 3.3b and 3.3c of the program's Assessment Framework, which is at Schedule 7 of the Energy Efficiency Opportunities Regulations 2006 (and also outlined in the *Industry Guidelines*), require that:

- the data collection process includes 'The energy and material flow through the site/fleet (e.g. through using an EMB or similar technique)'
- the energy analysis process includes 'Application of a range of methods of data analysis (e.g. EMB, review of graphs and charts) to explore relationships between energy use and variables that may influence it, using data collected at appropriate time intervals'
- a comparison of performance to theoretical and actual energy use benchmarks be undertaken, at the relevant level (process, technology, site, or indicator). Where appropriate, other detailed numerical analysis or the application of indicators and other comparative techniques are used to fully understand energy consumption, including its variability.

Box 1 provides further detail of the requirements for EMBs in the regulations.

BOX 1. EMBs IN THE ENERGY EFFICIENCY OPPORTUNITIES REGULATIONS 2006

Regulation 1.3 defines an energy-mass balance as a method of accounting for:

a) the materials and energy entering and leaving a site or fleet and its processes, systems or equipment; and

b) the energy and material flows, energy conversions and energy use within the site or fleet and its processes, systems or equipment.

Note 1 To enable an appropriate coverage, an energy-mass balance should define, to an accuracy of ± 5%, at least 80% of a site's energy use and all processes not already included in the 80% that use at least 0.1 PJ of energy per year.[2]

Note 2 An energy-mass balance should provide a thorough understanding of:

(a) the material flows and energy use through a site, its processes and systems, and items of equipment including items such as pipes and ducts; and

(b) the specific services and products the energy use delivers; and

(c) the energy conversion processes within a system, and identification of conversions that are essential and efficient; and

(d) the identification of energy waste and energy efficiency opportunities.

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[1] The EEO program was established under the *Energy Efficiency Opportunities Act 2006*, and detailed requirements are outlined in the Energy Efficiency Opportunities Regulations 2006. The EEO *Industry Guidelines* explain in plain English what participating corporations need to do to meet the program's requirements.

[2] 0.1 PJ, or 0.1×10^{15} joules, is equivalent to approximately 2.6 million litres of diesel fuel.

There is scope for error margins larger than 5% within some parts of a fleet, consistent with being able to prepare a business case with sufficient rigour to meet the overall assessment data accuracy requirement.[3] Accuracy requirements should not be seen as a disincentive to detailed investigation of processes in the EMB.

More broadly, Key Requirement 3 sets out requirements for data collection and analysis, which provide guidance for developing an EMB. Energy consumption and cost data is required for each energy source. Data should be entered at the frequency that bills and other records are received (typically monthly) for a total of 24 months. The accuracy of total energy consumption data must be within ±5%. A less accurate level may only be used if this was approved in the Assessment and Reporting Schedule (ARS).

For verification purposes an EMB will be good evidence of having addressed key requirements 3.2(d) and 3.3. Assumptions, calculations, equations used and decision processes should all be documented and kept for at least seven years.

This case example provides guidance on the level of detail required in an EMB (or similar approach) to satisfy these requirements and indicates the standard that industry should attain. The document complements the *Assessment Handbook*, which outlines the complete EEO assessment process on pages 10–12. This EMB guidance also complements the *Energy Savings Measurement Guide* (ESMG), which provides guidance on how to estimate, measure, evaluate and track energy and financial savings from opportunities.

1.2 WHAT IS AN EMB?

In principle, an EMB is an approach used to understand the efficiency of energy conversion and how other inputs are used to deliver goods and services. Box 2 explains the technical underpinnings of the EMB. Preparation of an EMB involves a number of steps that are discussed in Section 2.

BOX 2. TECHNICAL BASIS OF AN EMB

An energy balance is a mathematical statement of the conservation of energy, and a systematic accounting for energy flows and transformations in a system. The theoretical basis for the energy balance is the first law of thermodynamics, which states that 'energy cannot be created or destroyed, only modified in form'. Contrary to mass balances, a system can only have one energy balance that describes it, since different types of energy are considered, mathematically, to be interchangeable. Specifically, the change in energy for a system equals the heat transferred into the system minus the work done by the system plus the net energy input associated with mass flows. Mass flows carry enthalpy[4], kinetic and potential energies.

An EMB is a model, from an energy perspective, of how a process or system works. It helps to understand the energy flows, mass flows, and other factors influencing energy efficiency, to determine the efficiencies of processes and equipment and to evaluate the effects of external factors. For road transport, these may include vehicle payloads, delivery schedules, traffic congestion, road conditions, engine characteristics, contractual arrangements, vehicle aerodynamics and driver behaviour and operating procedures. For example, if the delivery deadline is sufficiently flexible, it may be possible to drive more slowly. This saves fuel and wear-and-tear, although it increases driver time and cost, if the driver and/or vehicle could have been allocated to other tasks.

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[3] For example, while the fuel use for local delivery vans should be known to within ±5% from fuel bills, the proportion of this energy used by ancillaries might have a higher error margin.

[4] Enthalpy is a measure of the 'heat content' of a material, and is tabulated in engineering texts and handbooks. It equals the sum of the internal energy and the product of the pressure and volume of the material.

1.3 WHAT ARE THE BENEFITS OF AN EMB?

Thorough EMBs reveal significant energy and cost savings by identifying:

- how much energy is being used, wasted or lost—and where this occurs
- whether the systems and equipment are operating according to design and work schedules
- energy use variability and its underlying causes
- whether usable waste heat is being produced or whether processes could be alternatively fuelled
- the efficiency of energy-using processes within a business.

EMBs also provide a structure for examining interactions between the different components of a business operation. For example, an EMB can be used to examine whether energy use adjusts to the demand for services. An EMB can also help to identify interactions between people, technologies and energy use, rather than looking independently at the technical performance of individual items of equipment. Accounting for these interactions and human factors helps to ensure that identified opportunities can be effectively and reliably implemented.

An EMB requires a company to look at its business or site as a whole system. This can provide the data required to question assumptions about existing patterns of energy use and production. In the process, an EMB can help to identify novel or innovative new ways of producing products or services with substantially lower energy and resource inputs. The EMB can potentially incorporate other resource constraints such as water usage, use of non-renewable resources, waste, logistics and driver behaviour.

As with other business improvements, the benefits from an EMB depend on the level of detail in the analysis involved. Experience with the EEO program to date suggests that detailed EMBs that analyse the way in which energy is used by specific processes, sub-processes and items of equipment deliver favourable benefit–cost ratios. By comparison, companies that merely develop high-level energy use breakdowns, for example limited to pie charts of energy end uses by technology, derive much less benefit from the process.

1.4 WHERE DOES AN EMB FIT IN THE ASSESSMENT PROCESS?

As noted in Section 1.1, an EMB is a major element of the data collection and analysis component of an EEO assessment. An EMB systematically collects and analyses data on energy use, and investigates where losses occur. It is therefore a useful input to a background paper, workshops, meetings, specialist studies and other activities used to identify and investigate opportunities. Developing a preliminary EMB for opportunities identification workshops focuses the opportunity identification process on those areas with the greatest energy-saving potential.[5] This enables workshop participants to develop more rigorous ideas and opportunity savings estimates.

Once companies have identified an initial list of opportunities, the preliminary EMB should be improved to build up a detailed and accurate understanding of the energy and material flows through the fleet or site. The first iteration of the EMB should provide the highest accuracy obtainable with the available data and analysis tools, plus a clear plan to improve accuracy over time so as to better understand energy use and identify further opportunities. A detailed EMB will determine the energy use of specific processes, ancillary equipment, and the variables that influence energy use.

In addition, a detailed EMB will be very useful for evaluating the opportunities already identified to an accuracy of 30% or better (as specified by Key Requirement 4.3 and Key Requirement 4.4 of the program's Assessment Framework). Thorough EMBs can be used to estimate energy savings and other whole-of-business costs and benefits for an opportunity. Following opportunity implementation, EMBs can also be used to measure the actual savings realised from implementing projects, and to examine interactions between different projects. Vehicle energy models are especially valuable for opportunity investigation.

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[5] Providing a more detailed EMB for workshops will produce more realistic and feasible ideas and opportunities.

1.5 IS THERE A PRESCRIBED METHOD FOR A TRANSPORT SYSTEM EMB?

Under the EEO program, companies are required to analyse energy and mass flows sufficiently to satisfy the EEO requirements for an EMB or equivalent. Subject to this constraint, there is flexibility to adapt the EMB or equivalent approach to company circumstances to meet program requirements efficiently.

In addition to physical factors, the EMB approach may be determined initially based on data/measurement availability as well as company organisation, for example to align with fuel data records or fleet organisation and operational control. The optimal approach for any company will depend on initial data availability, measurement systems and the personnel available for the EMB process. For verification purposes companies should be able to justify the chosen approach to collecting and analysing energy and material flows and should make sufficient resources available to satisfy program requirements. Section 1.6 presents a general approach to developing an EMB for a transport system.

1.6 WHAT DOES AN EMB LOOK LIKE FOR A TRANSPORT SYSTEM?

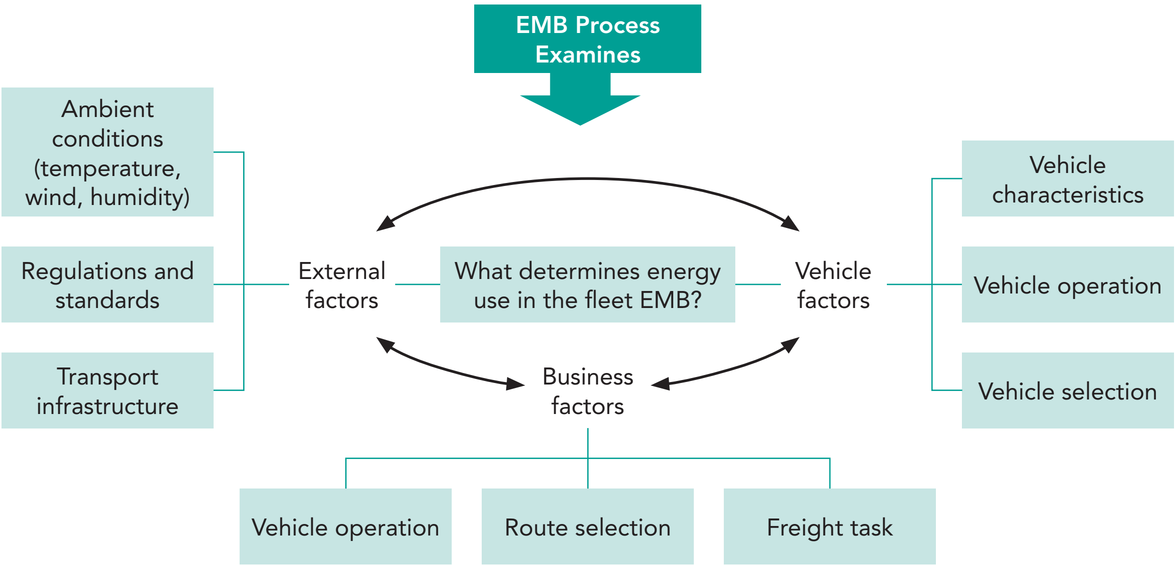
An EMB involves looking at the transport company as a transport system. Energy use by the system is influenced by a number of organisational, vehicle-specific and external factors, many of which also affect productivity. The EMB process aims to identify and analyse the impacts of these factors on energy use and how these factors interact.

While the concept of an EMB is most intuitive in manufacturing and thermal processing activities, the benefits of the EMB process are equally applicable to transport systems. This document presents one possible approach to a transport EMB which has general application and accounts for both energy use and the impact of vehicle mass and loading on energy use and productivity. Due to a relative lack of specific guidance in the engineering literature on the task of analysing fleet and vehicle energy use, the case example also discusses other components of the EEO assessment process that may be helpful when analysing the energy use of a fleet.

As a first step, it is recommended to map out the transport system to identify the key factors that will affect energy use. This mapping is a brainstorming process that helps to identify how operational factors, external influences and vehicle characteristics interact and contribute to energy use. Mapping these influences will help to establish which data need to be collected and may indicate which elements of the transport system have the strongest interactions. Figure 1 presents a high-level schematic of a process map of factors affecting energy use in an EMB for a transport fleet.

Having mapped out the various factors that influence energy use, the next step is to determine how best to organise the analysis and which parts of the system should be given priority. The proposed approach is to consider the fleet as a transport system that is broken down into three broad levels for analysis, as discussed in Section 4.1.

Figure 1: Influences on a transport system EMB



1.7 MASS FLOWS AND EFFECTS IN TRANSPORT SYSTEMS

The mass of material transported and the mass of the vehicle are important determinants of energy use for a transport system. Accounting for mass 'flows' through the fleet is therefore necessary to gain an effective understanding of overall fleet energy use. The mass of freight or passengers transported relative to vehicle weight is an important indicator of transport system efficiency. Loading rates relative to vehicle capacity can indicate the efficiency and productivity of vehicle usage.

Improved vehicle usage and loading will often yield larger energy savings than improvements such as engine modifications to the vehicles themselves.[6] Efficient routing, vehicle utilisation and driving practices can provide fuel efficiency benefits that are equivalent to, and sometimes greater than, improved engine technologies, often at lower cost. For example, aggressive driving can raise fuel consumption by around 30%, poor tuning increases fuel consumption by between 4% and 40%, and suboptimal tyre inflation and clogged air filters can raise fuel consumption by up to 3% and 10% respectively.[7] Undertaking an EMB incorporating the three different system levels from Section 4.1 allows a wide range of options to be investigated.

An EMB can use a variety of modelling approaches, such as engineering calculations, regression analysis or direct measurement. These and other methods are described in this document and detailed in the *ESMG*. The *Representative Assessment Guide* also provides guidance on assessing energy usage and opportunities in multiple, similar operations, including statistical sampling techniques relevant to transport systems.

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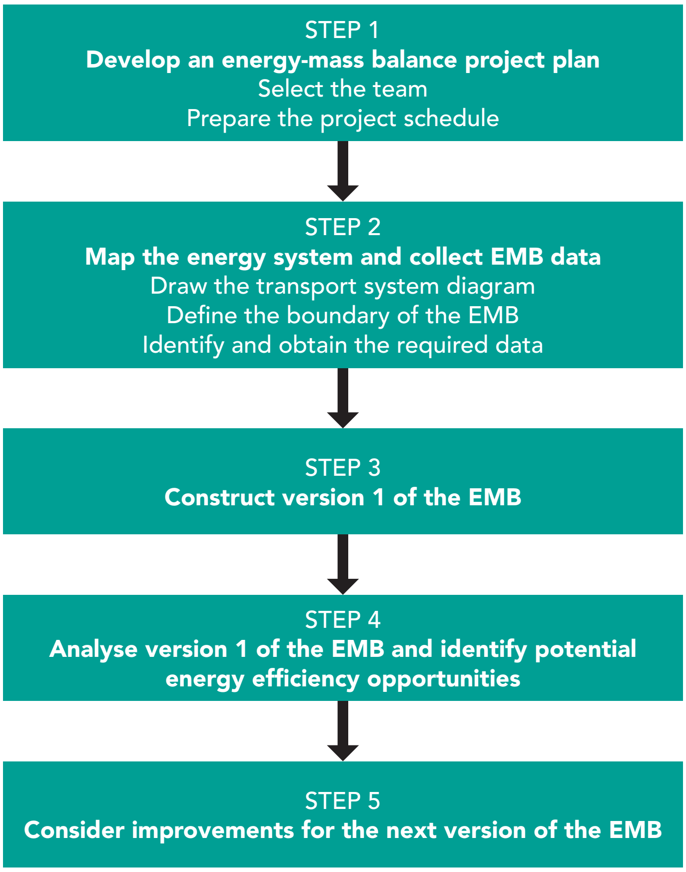
[6] Similarly, vehicle selection and substitution can also yield significant energy savings.
For example, allocating the smallest, lightest vehicle suitable for a given task can yield energy savings of between 30% and 40% for passenger vehicles.

[7] See, for example, B Isler, 'Transportation systems', in F Kreith, & D Yogi Goswami, *Handbook of energy efficiency and renewable energy*, Taylor & Francis Group, Boca Raton (FL), 2006.

1.8 STEPS INVOLVED IN DEVELOPING A TRANSPORT EMB

Figure 2 illustrates the basic steps involved in developing an EMB for a transport fleet, beginning with project planning and team selection.

Figure 2: Basic steps to develop a transport sector EMB



These tasks will be explained in sections 2 to 8 using the hypothetical case study of Terrific Transport, a diversified freight company. Summaries of the outcomes and benefits from completing each step are provided before the case example moves to the next step. While figures and error margins provided in the case example should not be regarded as accurate benchmarks, they are broadly indicative of actual figures.

1.9 ABOUT THE CASE EXAMPLE COMPANY

Terrific Transport (TT), a theoretical company, is used to demonstrate the process and practical issues associated with creating an EMB for transport operations, focusing on developing a vehicle energy model. TT is a vertically integrated transport company which collects freight from customer premises and delivers it to destinations in Australia and to international freight forwarders at airports. The freight is diverse, ranging from envelopes to pallets and trailers loaded by others.

The company currently pays for fuel use and has operational control[8] over:

- 65 prime movers (used with the company's 180 trailers)
- 260 rigid trucks
- 364 vans
- 73 cars.

While the examples in this document use trucks, organisations which operate other transport modes and vehicle types may find analogous applications of the principles in their organisations.

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[8] Details of the operational control model may be found in the *National Greenhouse and Energy Reporting Guidelines*, available from the Department of Climate Change and Energy Efficiency website at http://www.climatechange.gov.au/reporting/guidelines/index.html.

2 STEP 1: DEVELOPING AN EMB PROJECT PLAN

In order to develop an EMB project plan, you need to:

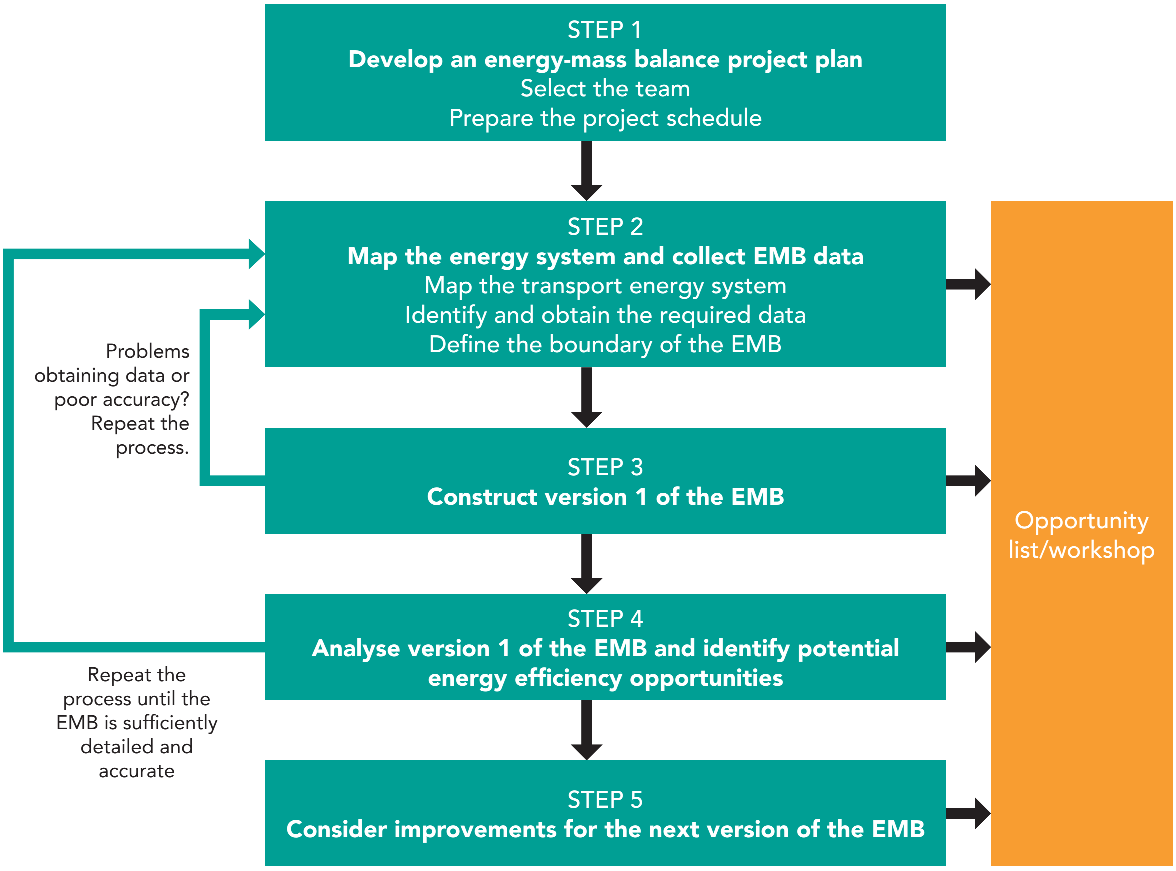
1. Identify and pull together a team of personnel with a range of knowledge and expertise. The kinds of people and skills you will need for the EMB team are:

- fleet/logistics managers, who have an understanding of the transport task and all the factors that affect the transport operation
- fleet engineering managers, with responsibilities such as vehicle and options specification, vehicle disposal decisions, and maintenance schedules
- accounts managers to supply and interpret fuel use data and communicate potential savings from opportunities
- operators and operations managers (e.g. drivers and their managers)
- mechanical engineers with qualifications, experience and expertise relevant to energy analysis. Specifically, they require a strong knowledge of vehicle dynamics and the factors affecting vehicle energy use.
- people with 'fresh eyes' who can bring perspectives from other industries, organisations and transport operations, and question assumptions and prevailing paradigms. These people may be from inside the organisation (e.g. from another operation, fleet or region) and may include consultants with expertise in preparing EMBs.
- project managers, to ensure that the EMB process is efficiently resourced, meets project timelines, maintains engagement of people resources and meets EEO requirements.

2. Develop a project schedule that will delegate key tasks, responsibilities and timelines which will assist with project implementation and monitoring of progress.

The time required to produce an EMB is directly related to the quality of data available. Producing an EMB is an iterative process which is most likely to require repetition of some steps as data is improved. Figure 3 presents a schematic of this iterative process.

Figure 3: Plan for developing the EMB



2.1 STEP 1: EMB PROJECT PLAN—TERRIFIC TRANSPORT

TT considered the skills, roles and information required to undertake its EMB, and put together a small team, as shown in Table 1.

Table 1: Roles, skills and knowledge of EMB team

Position	Role	EEO/EMB skills and knowledge
National fleet Manager	EEO project manager	• Vehicle selection and disposal policy • Vehicle modification, maintenance and trials • Program requirements and reporting • Liaison with suppliers
National accounts manager	Fuel economy reporting	• Fuel and trip data records • Database management • Knowledge of customer requirements and contractual arrangements
Fleet logistics manager	Operations liaison	• Vehicle tasking, liaison with drivers and customers • Real-time monitoring

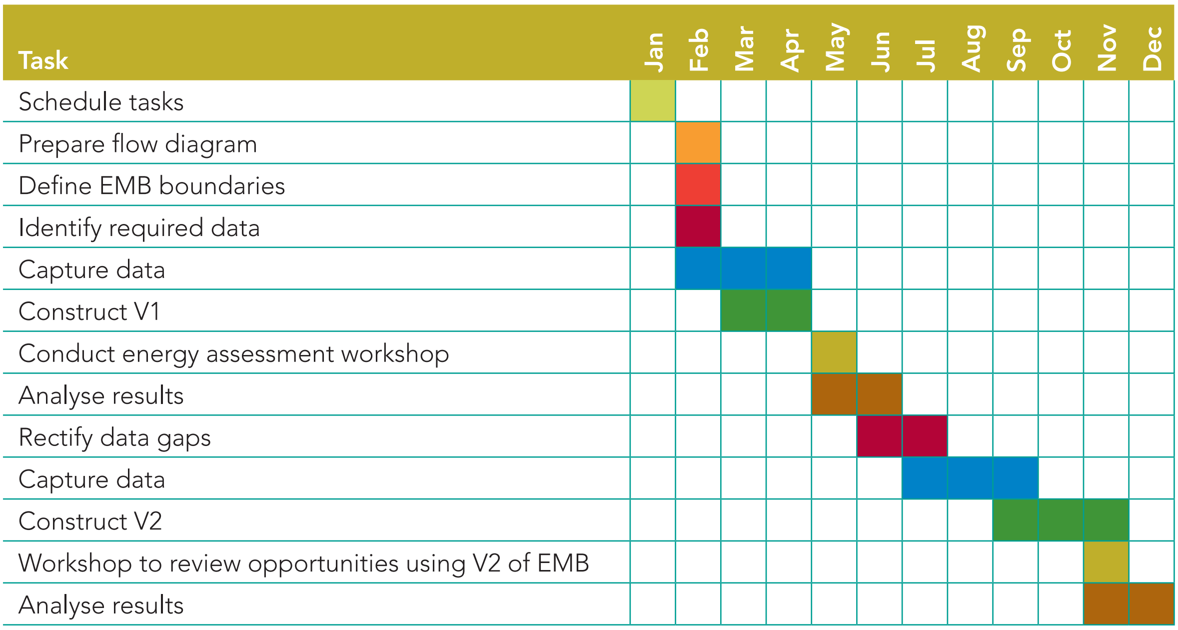
While this in-house team provided most of the skills and capability required for the EMB, TT recognised that it needed additional resources and skills to develop its EMB. In particular, it needed people with:

- the ability to carry out sophisticated analysis of energy data, and calculate energy requirements and energy savings from first principles
- 'fresh eyes' to challenge current procedures and assumptions, and suggest additional innovations
- the ability to work across different responsibility lines in the organisation
- time to complete some of the additional tasks and analyses within the allowed time.

It was decided that these capabilities would best be provided by an engineering contractor from outside the company, preferably one with transport experience and qualifications. A person with appropriate skills was engaged on a contract running over six months.

The national fleet manager, with the assistance of the EMB team, developed a schedule identifying the main steps and timing they would follow to develop the EMB, as presented in Figure 4. The team recognised that there were issues with the quantity and quality of data, such as incomplete data on the proportion of trips made with partial loads. Addressing these issues would require following an iterative process, using data from additional data recording systems as they were implemented (see Step 2). The first key deadline was the delivery of a preliminary EMB for the fleet's assessment workshop, which would be staged within four months.

Figure 4: Terrific Transport's EMB project schedule



Task	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Schedule tasks	🟩											
Prepare flow diagram		🟧										
Define EMB boundaries		🟥										
Identify required data		🟥										
Capture data		🟦	🟦	🟦								
Construct V1			🟩	🟩								
Conduct energy assessment workshop					🟨							
Analyse results					🟫	🟫						
Rectify data gaps						🟥	🟥					
Capture data							🟦	🟦	🟦			
Construct V2									🟩	🟩	🟩	
Workshop to review opportunities using V2 of EMB											🟨	
Analyse results											🟫	🟫

3 STEP 2(A): MAP THE ENERGY USING SYSTEM

3.1 WHAT IS THE TRANSPORT ENERGY SYSTEM?

Transport systems require large amounts of energy to transport payloads. The aim of the EMB is to improve understanding of the energy system and to provide insights into potential energy efficiency opportunities. The first step is to investigate the various factors that influence transport system energy use and to map out these influences.

To map the system, start by considering:

- whether the organisation's total vehicle fleet will be mapped as a system, or whether the fleet and service provided falls naturally into logical segments
- the transport services provided, including the factors that define quality of service (these might be described in key performance indicators (KPIs) used by the organisation)
- the factors that influence overall energy efficiency.

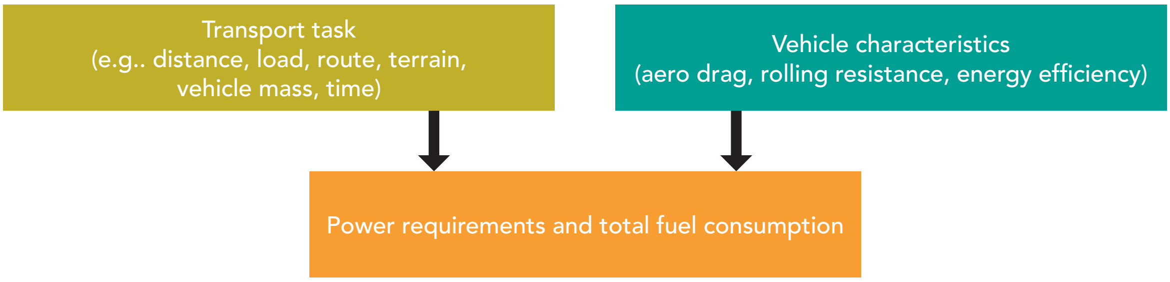
Brainstorming the factors that influence transport system energy use and their interactions helps to determine the appropriate way to break down the company EMB. Process mapping is illustrated in Section 3.2.

3.2 ENERGY SYSTEM MAP: TERRIFIC TRANSPORT

3.2.1 Major factors affecting transport system energy use

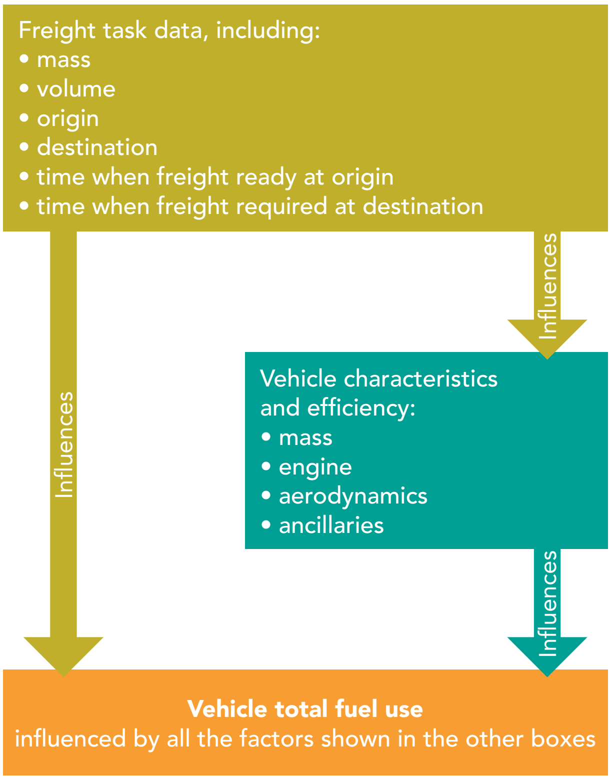
The TT team noted that they needed to consider the 'transport task' as well as the vehicle's efficiency in performing that task, in order to understand the vehicle's energy use. Their first block-diagram map of the transport energy system is shown in Figure 5.

Figure 5: First map of transport energy system



The team considered that this first-pass map of the transport energy system did not correctly show the relationships, as the transport task is a major factor in limiting the choice of vehicle. This influence on vehicle selection is shown in Figure 6.

Figure 6: Map of transport energy system with freight task's influence on vehicle characteristics



This map of the transport energy system prompted further discussion. The general manager attended part of the team meeting and commented that the system should include the driver, because studies indicated that the driver could influence fuel economy by as much as 30%.[9] The fleet manager had thought that the vehicles and engine management systems were configured so that the drivers had a limited affect on fuel economy. In the absence of specific data, it was decided that the influence of driver behaviour should be included in the energy system map. Quantifying the affect of operator behaviour on energy use was therefore scheduled as an EMB task, as shown in Figure 7.

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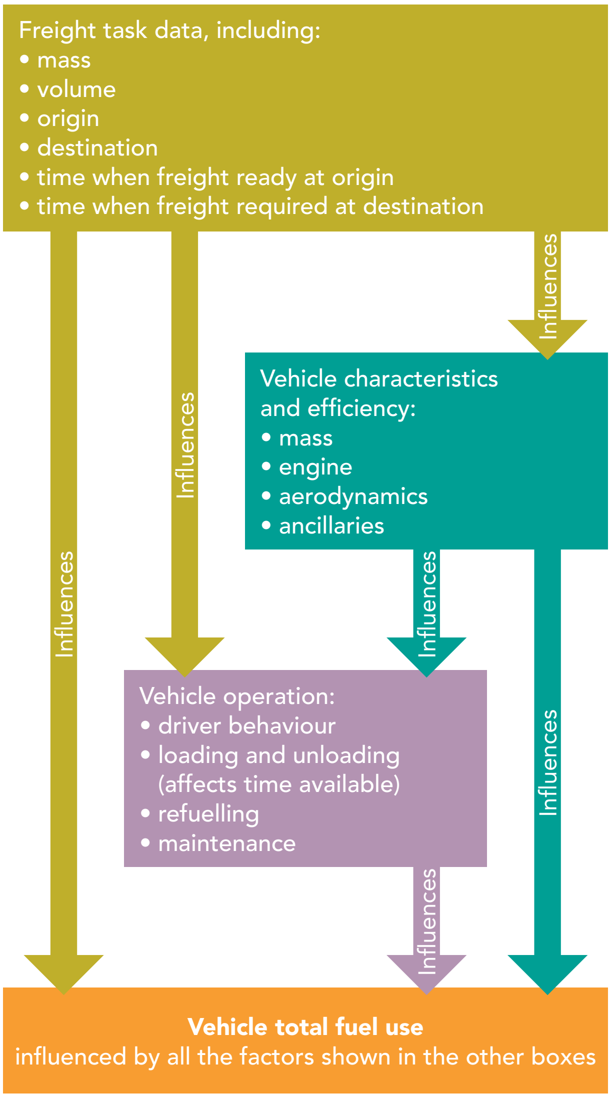
[9] See, for example, B Isler, 'Transportation systems', in F Kreith & D Yogi Goswami, *Handbook of energy efficiency and renewable energy*, Taylor & Francis Group, 2006.

Figure 7: Map of transport energy system with operator influence included

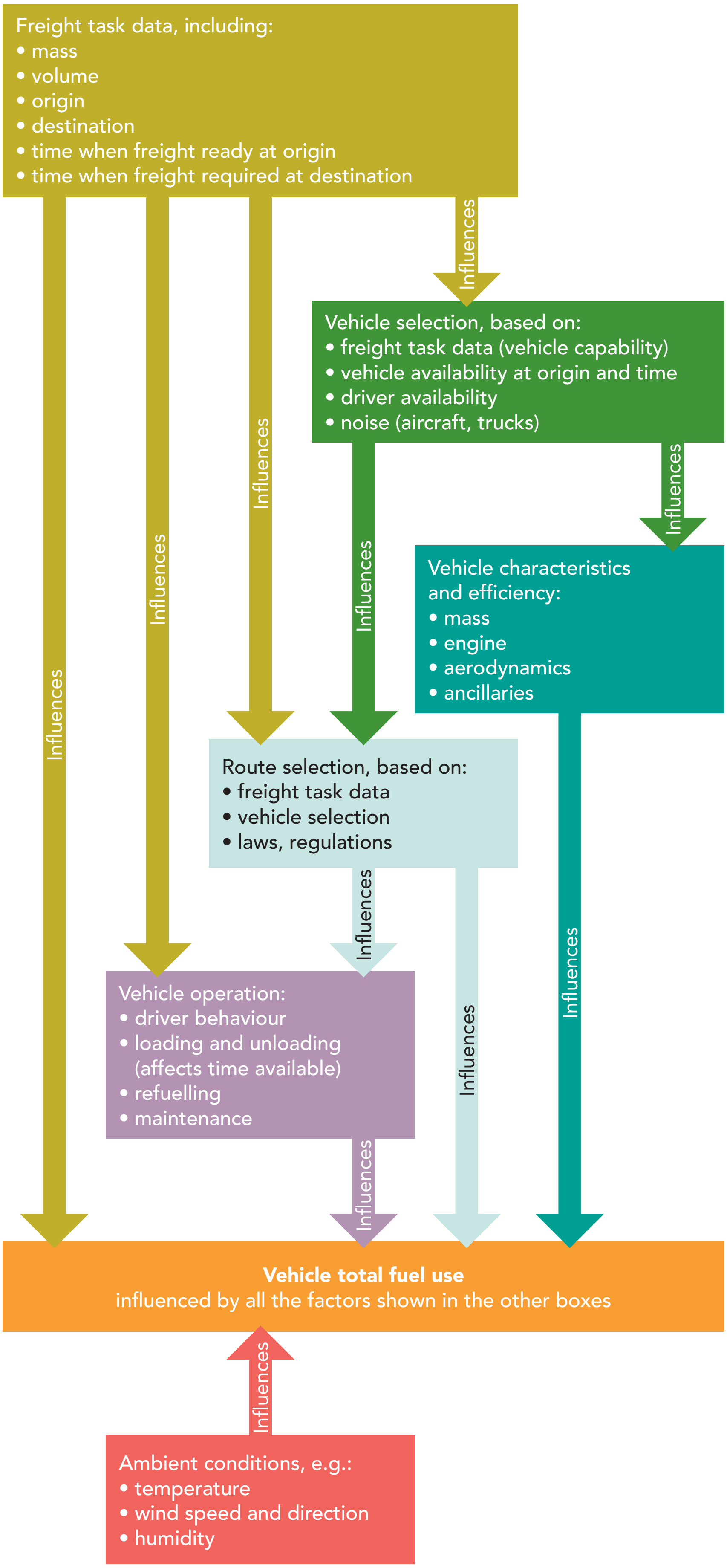


The revised map of the energy system prompted discussion on how the factors affecting energy use could be varied in order to reduce fuel consumption and broadened the discussion, which had previously focused on vehicle specification and modifications. The EMB team noted that this broader scope increased the range of potential opportunities. Discussions also raised many other factors influencing energy use, including:

- *Vehicle/transport mode selection*. There is usually more than one possible vehicle or transport mode which can satisfy a given vehicle task. Vehicle selection is partly governed by
  - freight mass
  - freight volume
  - vehicle availability at the time and location required
  - any restrictions as a result of collection or destination locations and so roads (or airports) that must be used (such restrictions can be either operational or regulatory)
  - driver availability and licensing (e.g. dangerous goods licences)
  - noise (e.g. airport curfews, residential street restrictions).
- *Route*. This clearly depends on the freight origin and destination, but there are many choices of route, particularly when there are multiple collections and deliveries. The route is also influenced by
  - the freight (road weight limits)
  - the vehicle (road dimensional limits and vehicle type limits)
  - congestion and traffic management systems (e.g. traffic lights)
  - the freight task timing (noise restrictions on trucks in some areas, and curfews for some combinations of aircraft and airport).
- *Ambient conditions*. Ambient conditions to consider include
  - air temperature (affects engine performance, road 'stickiness')
  - wind speed and direction (affects aerodynamic drag on road vehicles, aircraft and marine craft)
  - relative humidity (affects engine performance)
  - barometric air pressure (affects drag, engine performance, and aircraft lift).

These three categories of factors influencing energy use and efficiency were incorporated into the transport energy system map for version 1 of the EMB, as shown in Figure 8.

Figure 8: Map of transport energy system, version 4



Freight task data, including:
- mass
- volume
- origin
- destination
- time when freight ready at origin
- time when freight required at destination

Vehicle selection, based on:
- freight task data (vehicle capability)
- vehicle availability at origin and time
- driver availability
- noise (aircraft, trucks)

Vehicle characteristics and efficiency:
- mass
- engine
- aerodynamics
- ancillaries

Route selection, based on:
- freight task data
- vehicle selection
- laws, regulations

Vehicle operation:
- driver behaviour
- loading and unloading (affects time available)
- refuelling
- maintenance

Vehicle total fuel use
influenced by all the factors shown in the other boxes

Ambient conditions, e.g.:
- temperature
- wind speed and direction
- humidity

3.3 ANALYSE THE TRANSPORT ENERGY MAP

The aim of constructing and analysing the map of the transport energy system is to guide development of the EMB and create a list of preliminary efficiency ideas or opportunities that can be investigated.

Because the map is a 'whole-of-system' approach the analysis normally identifies whole-of-business issues and benefits in addition to energy efficiency. For example, some energy efficiency measures may impact positively or negatively on customer expectations and satisfaction, or on utilisation of vehicles and staff.

Constructing and considering the map of the transport energy system will lead to the identification of potential opportunities, even before energy flows and influences on energy use are quantified.

Some possible questions suggested by analysis of the mapping are shown in Table 2.

Table 2: Questions raised by the energy mapping

Energy mapping	• Does the map of the overall transport energy system make sense? Is there anything missing? • Should the sales function be shown on the system map? • Which of the factors affecting energy consumption can we change? • Which of the factors affecting energy consumption can we measure?
Customer needs	• What is the role of sales staff in setting customer expectations?
Scheduling	• Could sales staff improve fleet fuel efficiency (e.g. by organising weekly pickups in each area on the same day of the week)? • What is the reason for the customer's stated schedule? Can the schedule be varied? • Do all consignments and freight types carried for Customer X have the same priority? • Could the bulkier/heavier/lower priority items be shifted to a different transport mode or moved to the next trip to rather than triggering a trip with a less than full load?
Route/vehicle selection	• How are routes selected? Are routes always optimal, or are they designed once for a transport task which changes daily or weekly? • Is selection of the vehicle for each task optimal? Is the optimal vehicle different according to the day of the week (because of differing freight volumes), especially for aircraft? • Could a change in vehicle selection allow more flexible routing? • What is the current vehicle purchasing and specification policy based on (e.g. fuel price)? • Is the vehicle life and disposal policy optimal? • Does fleet management and policy influence transport system energy consumption?
Vehicle and driver influences	• How much of the gross vehicle mass is the tare (empty vehicle) mass? • What is the affect of mass on fuel consumption? • How much influence does the driver have on fuel efficiency, and what can be done to promote better driving practices? • How do scheduling and route selection influence driving practices?

It is likely that some of the opportunities that arise from analysing the system map will fall into the 'just do it' category, while others—those that involve significant capital or effort—will require further data and evaluation. Having developed the system map and considered interactions, the EMB team is now ready to break down the business into appropriate categories for further analysis.

4 STEP 2(B): COLLECT EMB DATA AND DEFINE EMB BOUNDARIES

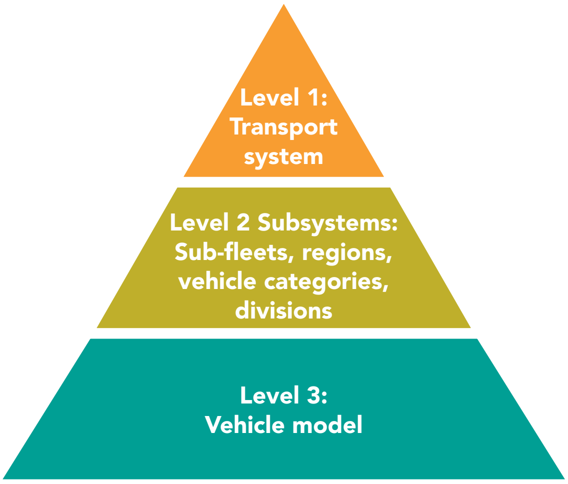
Having mapped out the factors that influence transport system energy use, the next step is to establish appropriate EMB system and subsystem boundaries. System boundaries should include all areas likely to contain significant opportunities. Section 4.1 outlines one possible approach to breaking down the transport system into suitable subsystems for detailed analysis. TT's system breakdown and data collection processes are discussed in sections 4.2 and 4.3.

4.1 BREAK DOWN OF THE TRANSPORT SYSTEM

To effectively develop a transport system EMB, it is useful to break the system down into appropriate subsystems. One possible approach is to analyse the transport system at three broad levels, all of which interact to form a complete transport system:

- *Level 1.* At the top level, there is the basic mapping of the structure of the whole transport system into appropriate major subsystems. This breaks down the fleet system into subsystems such as vehicle types or categories, business divisions or transport modes. These subsystems will be examined in detail at Level 2. For instance, a multimodal freight company may break down the fleet into different vehicle types (rail freight, trucking, vans), different types of freight (such as bulk, express or minerals), or by geographic zone, based on business considerations. At Level 1, energy use for each subsystem is quantified against high-level business performance indicators. This high-level breakdown helps to identify priorities for further analysis, clarifies which parts of the fleet should be included in the EMB, and indicates appropriate subsystem boundaries—such as different freight or vehicle categories—for further investigation at Level 2.
- *Level 2.* The next level analyses each secondary subsystem identified by the Level 1 analysis (such as vehicle categories, geographic or business divisions). This reveals, for example, major transport routes by vehicle type and freight loads and fuel use by vehicle type. This level of analysis reveals usage and loading patterns, but not how these patterns combine with vehicle characteristics to determine energy use. For example, analysis of a trucking operation may show that vehicles are making many trips with low loads, but may not provide an indication of the change in fuel use with loading—which requires a vehicle energy model.
- *Level 3.* At the lowest level of the EMB, there is the energy model at the vehicle level, which investigates the factors that contribute to the energy used by a single vehicle, such as aerodynamic drag. Vehicle models allow the affects of different scheduling or loading rates to be investigated and compared. For example, a vehicle model enables the benefits of improved aerodynamics to be estimated based on typical vehicle speeds and route characteristics. Vehicle models can also be used to evaluate the energy savings and business benefits available from changes in transport mode for particular load types or routes. For example, diversion of loads from trucking to rail may be appropriate for routes with high average road gradients. Figure 9 illustrates the three broad levels of analysis involved in a transport system EMB.

Figure 9: Three levels of analysis of a transport system



Level 1: High-level data analysis for the business, and determination of subsystems to include in the EMB, e.g.:
- (Trucking, rail, vans), or (minerals, bulk freight, express packages, passengers)
- Determination of company-wide energy KPIs, e.g. GJ/t, GJ/1000kmLevel

Level 2: For each subsystem (e.g. rail freight), examination of:
- Major transport routes, loading rates and load scheduling
- Specific KPIs to compare energy use to output
- Downtime, maintenance and reliability

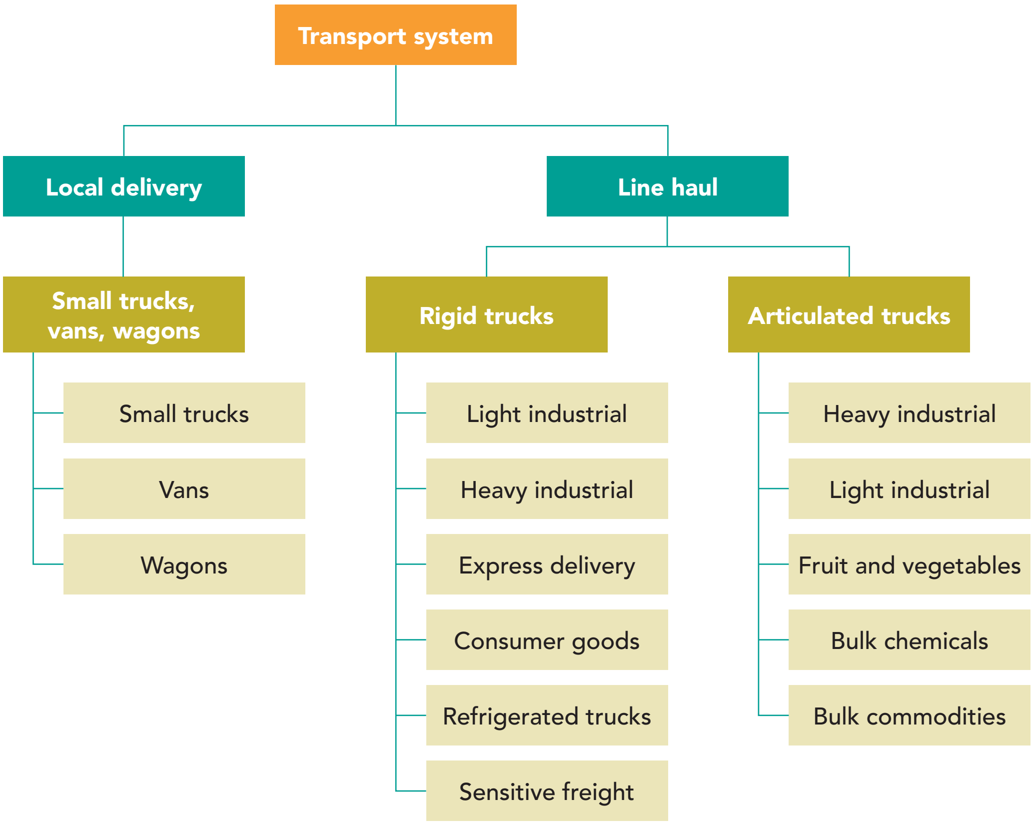
Level 3: Development of a vehicle energy model:
- Examination of physical factors affecting energy use (such as gradients, routes, loading, vehicle design, wind and rolling resistance) for vehicle types and models
- Optimisation of loading rates for energy use
- Allocation of load types to appropriate vehicles

EMB project managers can allocate the examination of Level 2 and Level 3 subsystems to staff or external experts with specific skills, knowledge and experience, which can shorten assessment timelines.

4.2 LEVEL 1: FLEET ENERGY USE BREAKDOWN AND BUSINESS CONTEXT FOR TERRIFIC TRANSPORT

To facilitate Level 1 data collection and analysis, the TT team first broke down the transport system into suitable subsystems to examine in detail at Level 2, and obtained the top-level data for these subsystems. The resulting EMB system breakdown diagram reflected vehicle types, but was also compatible with the organisation structure that was based on product and customer types, as shown in Figure 10.

Figure 10: Terrific transport EMB breakdown diagram



4.2.1 Fleet energy data

The energy consumption of each vehicle type was extracted from the company's fuel database, and billing records, as shown in Table 3.

Table 3: Energy costs by vehicle type, Terrific Transport

Vehicle type	Number	Fuel used (litres per year)	Fuel type	Price ($/L)	Cost ($/year)	MJ/L	Energy (PJ/year)	Energy (% of total)
Prime movers	65	13,650,400	Diesel	1.25	17,063,000	38.6	0.5269	58.7
Rigid trucks	260	8,190,240	Diesel	1.25	10,237,800	38.6	0.3161	35.2
Vans	279	948,600	Diesel	1.25	1,185,750	38.6	0.0366	4.1
	85	312,120	Petrol	1.15	358,938	34.2	0.0107	1.2
Cars	62	83,700	Petrol	1.15	96,255	34.2	0.0029	0.3
	11	16,500	LPG	0.53	8,745	26.2	0.0004	0.0
Stationary energy	1	–	Electricity	–	–	–	0.0046	0.5
Total					**28,950,488**		**0.8982**	**100**

$/L = dollars per litre; MJ/L = megajoules per litre; PJ = petajoules

Based on the fleet energy use breakdown:

- The two highest priorities for the EMB analysis were the articulated and rigid trucks, which together constituted 94% of energy use.
- Cars and stationary energy (both under 0.01 PJ) did not need to be included in the EMB.

Although the car fleet would not be directly included in the EMB, the TT team noted that many of the opportunities and approaches from the trucking fleets could potentially be transferred to smaller vehicles.

The EMB team further examined the fuel database to identify other potential EMB subsystems, such as types of goods, routes or the speed of delivery required. At the same time, the team acquired data and information on maintenance schedules, vehicle fleet age and the specifications of the vehicles making up the fleet, for analysis at levels 2 and 3.

4.2.2 Business contextual data

To ensure that the EMB led to realistic opportunities, the EMB team also considered other business information affecting the EMB approach, including:

- TT had just won a large tender with a major manufacturer, which was expected to lead to a need to increase the size of the rigid truck fleet by 40%. Developing a vehicle model could therefore help to optimise vehicle selection to significantly reduce vehicle energy intensity over time.
- The TT Board wanted to examine fleet safety (particularly articulated trucks), following several high-profile accidents in other freight companies.
- TT was having difficulty recruiting truck drivers, potentially forcing the company to accelerate the move from single trailer to B-double trucks, and to increase the capacity of rigid trucks.
- A few customers had asked for information on the carbon dioxide emissions associated with TT's freight service, in order to quantify their total emissions with a view to going 'carbon neutral', and a competitor was offering a 'green' freight service.
- The fleet renewal policy was based on vehicle age and distance triggers, but there was no evidence that this was developed based on analysis of the cost of turning vehicles over more quickly or more slowly, or using alternative triggers such as vehicle condition, maintenance costs, or predicted

salvage and changeover costs. The vehicle energy model and Level 2 analysis could help to investigate these questions.[10]

Based on the Level 1 energy and business data, the company decided to develop an EMB for line-haul services, first for articulated trucks and then for rigid trucks. This approach was designed to maximise the value of any early opportunities identified.

4.3 LEVEL 2: SUB-FLEETS, REGIONS, VEHICLE CATEGORIES, DIVISIONS, ETC.

Level 2 Subsystems: Sub-fleets, regions, vehicle categories, divisions

Analysis at Level 1 involved the organisation segmenting its overall transport system based on organisational structure, similarity of transport roles, vehicle types, and how energy and transport task data were collected and managed.

Analysis at Level 2 will examine the factors that affect energy use for each chosen subcategory. For example, analysis of the light truck division would examine vehicle types, loading and route scheduling for each subsystem. This analysis can yield data indicating whether particular models are more appropriate for specific routes, or whether loading or scheduling improvements are potentially available. This data can be used in conjunction with the Level 3 vehicle model to investigate opportunities.

The order in which these secondary level groupings of the transport system are analysed will probably be influenced by:

- energy data—how much energy is used by each secondary level group
- business contextual data—are there factors other than energy consumption and cost which increase the priority of assessing energy in a transport group?

These principles are illustrated in Section 4.3.1 using the TT example.

4.3.1 EMB considerations: Terrific Transport

The TT Level 2 analysis investigated energy efficiency opportunities in the line-haul divisions. The EMB team realised that all previous energy efficiency efforts had focused on reducing vehicle fuel consumption per kilometre travelled, but that this was just one category of energy saving opportunities.

At Level 2, the EMB team set out to analyse the factors affecting energy use for each subcategory identified in the EMB system diagram developed at Level 1. In doing so, the team noted that many opportunities that emerged from one subcategory could be applied to others. The team decided to focus initial EMB efforts on the bulk fruit division, which had been experiencing problems with reliability and product quality.

The bulk fruit division delivered produce over long distances nationwide, and was made up of articulated trucks of various makes and models, some of which were approaching the end of their lifecycle. The team examined data available for the bulk fruit division, noting that:

- There was variation in load types at different times of year for the same regional fruit wholesalers.
- Product condition in transit can be affected by temperature, humidity, and road surfaces or potholes.
- Data was available on fuel use, but not for specific fuel use by route, load and destination.

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[10] While it is generally believed that vehicles should be disposed of before their maintenance costs escalate with age, TT had never tested this by retaining a few vehicles beyond the usual disposal triggers. Retaining a vehicle longer may justify a higher initial investment in a higher specification and more energy-efficient vehicle. On the other hand, if there are vehicles now on the market that are significantly more efficient than those in the TT fleet, it may be worth trading in the existing fleet sooner than planned. Improving real-time monitoring and preventive maintenance may reduce the risk of unexpected failures in older vehicles.

- There was not sufficient data available to understand the proportion of distance travelled with partial loads.
- Fruits and vegetables have various packing densities, so load composition would affect loaded vehicle mass, energy use and vehicle stability (safety).
- Packaging requirements vary with load composition, which should be taken into account via product-specific KPIs.
- Seasonal variation should be tracked, as it affects load distributions.
- On average, the bulk fruit fleet experienced 1.1 vehicle breakdowns per 1,000 hours of travel time, equivalent to a breakdown every 2.2 months on average for the 12 trucks in the division. This suggested that maintenance KPIs should be examined as part of the EMB.

In addition to the energy efficiency opportunities at the fleet and vehicle level, TT's Level 2 investigation of line-haul opportunities identified several broad categories of opportunities, as outlined in Table 4.

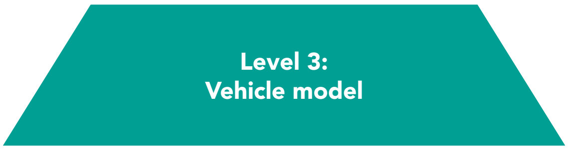
Table 4: Categories of energy efficiency opportunity at Level 2

Opportunity category	Examples of opportunities
Reduce distance travelled *(fewer kilometres)*	• route planning • task planning (sales and operations staff to try to arrange all pickups and deliveries in an area on the same day of the week)
Improve vehicle utilisation	• greater load per vehicle • reduce waiting time
Reduce fuel use per kilometre *(fewer litres per 100 km)*	• vehicle specification and purchasing • vehicle selection for task (task most efficient and appropriate vehicle available) • maintenance • operator behaviour

Analysis of the bulk fruit fleet showed that the EMB team would need to collect manufacturers' data on the different vehicle models in the fleet. Where possible, the availability of data on fuel consumption, reliability and load schedules for individual vehicles was collated to identify specific opportunities and to inform the Level 3 vehicle model development.

TT considered collating data to quantify variation in energy use for different drivers. However, to avoid possible morale problems, the EMB team decided to consult with driver representatives before undertaking such analysis. Pending consultation, evidence in the literature was deemed sufficient to identify opportunities relating to driver behaviour, such as driver training, in the first iteration of the EMB.

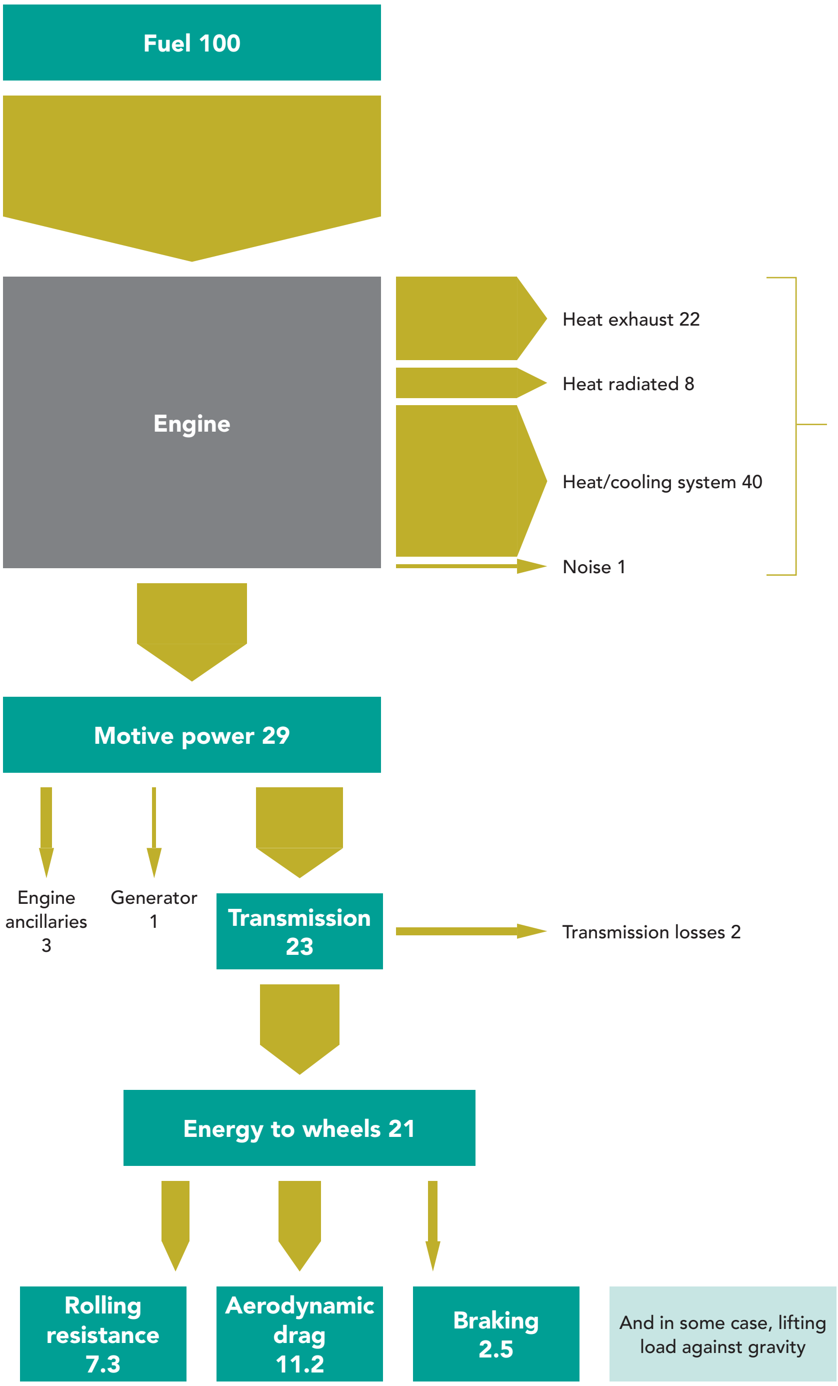
4.4 LEVEL 3: VEHICLE ENERGY MODEL



The third level of mapping the energy system is the vehicle energy model. Most transport operators record the amount of fuel supplied during each refuelling and record the distance travelled. This allows tracking overall fuel economy of each vehicle and the fleet as a whole, but it does not reveal the components of energy use in the vehicle. For example, while Level 2 data analysis may indicate suboptimal loading rates, the vehicle model will allow estimation of the energy use of each vehicle type at different loading rates. Some energy is used to overcome aerodynamic drag and rolling resistance, in running ancillary equipment, in the conversion of fuel energy to motive energy, and in the transmission of motive energy, etc.

These energy flows in a vehicle are represented in the Sankey diagram[11] in Figure 11. **Note that the figures shown are for illustration purposes only, and the actual figures will vary from vehicle to vehicle, task to task, and minute by minute, so these percentages are not generally applicable.** Methods for quantifying these energy flows are presented in Section 5.2.[12]

Figure 11: Example map of energy flows in a vehicle



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[11] In a Sankey diagram, the quantity of (energy) flow is proportional to the size of the arrow showing that flow.

[12] Some vehicle manufacturers are enabling vehicle engine management system data to be utilised for energy efficiency analysis. For example, Fiat has developed the 'Ecodrive' system, which allows car drivers to load real-time vehicle performance data onto a USB drive. This data can then be analysed and compared to data from other drivers of the same vehicle. The software suggests improved driving techniques and allows performance to be tracked over time. Future versions will include maintenance scheduling capabilities, and fleet management software is also being developed ('Emissioni Zero', Attachment to *Quattroruote*, 643, Editoriale Domus, May 2009, p. 50).

It is important to know how much energy is used by each of these components in order to estimate the potential energy savings in each of these areas. For example, the amount of energy being consumed by engine ancillaries represents an upper limit on the potential energy savings available from changes to components such as the cooling fan or water pump.

The vehicle energy model is also needed in order to calculate the affect of implemented opportunities on energy consumption and during trials and experiments. Vehicle models can be used to adjust for the affects of changing conditions in which a vehicle operates. These conditions and influences vary from task to task, and from minute to minute.

Note that vehicle design is just one factor that influences energy consumption and overall energy efficiency. In fact, some of the largest opportunities lie outside the vehicle in the overall 'transport system'.[13] However, the scope for vehicle modifications such as aerodynamic improvements or weight reductions should be considered. Section 5.2 outlines the development of a vehicle energy model in more detail.

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[13] Building energy efficiency into vehicle purchasing policies can ensure that many of the energy efficiency benefits of new vehicles can be obtained. Vehicle modelling as part of the EMB will enable rigorous comparison of new vehicle options. An indicative summary of the benefits of specific internal combustion engine design features is provided in S Kobayashi, S Plotkin & S Kahn Ribeiro, 'Energy efficiency technologies for road vehicles', *Energy Efficiency*, vol. 2, pp. 125–137, 2009.

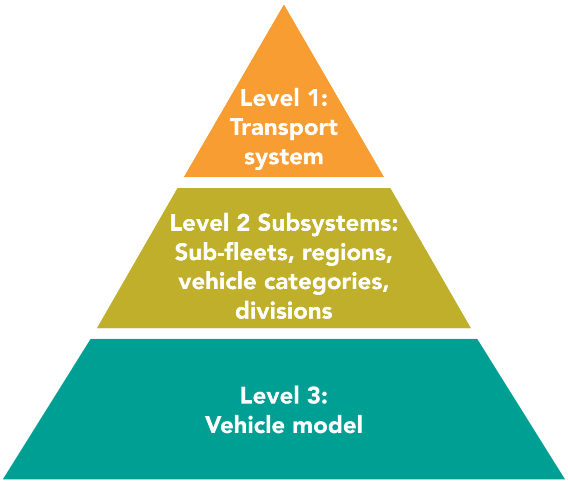
5 STEP 3: CONSTRUCT VERSION 1 OF THE EMB AND ENERGY MODEL

5.1 MODEL LEVELS AND MODELLING TOOLS

5.1.1 Transport energy model levels

As discussed in Section 4.1, the transport EMB can be constructed and considered at three levels:

- *Level 1: Overall transport system energy model*
  Analysis at this level is used to identify organisation-wide transport energy opportunities, and to prioritise the EMB of the Level 2 segments of the overall fleet. Completion of this process for version 1 of the EMB involves collating the top-level data for all of the main subcategories of the business, as discussed for TT in Section 4.2. At Level 1, the aggregated energy use, payloads, distances and other metrics are collated and examined for each subsystem.
- *Level 2: Subsystems—Sub-fleets, regions, vehicle categories, divisions, etc.*
  Analysis at this level examines energy usage and identifies and investigates factors specific to a particular subcategory, such as vehicle type or transport task. This requires analysing the data and information on routes, vehicle scheduling, loading rates and other factors affecting subcategory energy use. Analysis at Level 2 will typically reveal energy efficiency improvements that do not involve vehicle modifications. Maintenance schedules, reliability and customer data should be considered, as well as any requirement for further data capture. For TT, this process was presented in sections 4.3.1 to 4.3.3.



- *Level 3: Vehicle energy model*
  Analysis of the components of energy use at the vehicle level, and opportunities to reduce energy use by modifying vehicles or their operation. This enables detailed investigation of opportunities identified via the Level 2 data analysis. Vehicle modelling may use various methods, as discussed in Section 5.2. TT's modelling process is presented in Section 5.2.2.

5.1.2 Transport energy modelling methods

At each of these levels, a combination of tools, methods and resources is likely to be required in order to best understand how energy is used and the opportunities to improve efficiency. These include:

- literature and internet searches, to obtain benchmarking and vehicle performance information (noting that many opportunities may involve logistical and procedural changes as well as changes to equipment)
- talking to people inside and outside the organisation who understand factors affecting energy use
- analysis of energy records and transport task records (see Section 5.2.3)
- regression analysis (see the *ESMG* and the *Representative Assessment Guide* for guidance)
- standard vehicle formulae, engineering calculations (see Section 5.2.2)
- controlled experiments (see the *ESMG*)
- in-service trials (see Section 5.2.6).

The logical first step is to list the energy data and transport task information which is currently available and likely to be useful, and to identify where the data are stored. Construction of the first version of the model can then proceed with this information. This first iteration provides an indication of which factors are important, which other factors should be included and what further data might be required.

5.2 LEVEL 3: VEHICLE ENERGY MODEL

5.2.1 Modelling tools and methods

A general model of the energy flows in a road vehicle was described in Section 4.4. This section describes how TT analysed the energy flows in the vehicle energy model, then progressively quantified the model and made the analysis more accurate and complete, using some of the tools and methods listed in Section 5.1.

The tools and methods described in this section are:

- standard vehicle formulae, engineering calculations
- analysis of energy records and transport task records
- regression analysis
- controlled experiments
- in-service trials.

All of these methods can be used to fill in data gaps in an EMB and to model interactions between opportunity areas.

5.2.2 Standard vehicle formulae: Terrific Transport

The TT team started with a standard mathematical model of road vehicle energy use sourced from a textbook (see Figure 12). This formula might look complicated, but it is a simplification, because:

- it represents only a ‘snapshot’ or an average of the vehicle’s energy usage, which varies continually
- a driver can reduce fuel use by allowing a vehicle to slow down under the affect of rolling resistance and aerodynamic drag, rather than deliberately incurring additional energy losses by braking. It is difficult to incorporate such a subtlety in version 1 of the vehicle energy model. Nevertheless, the results will at least indicate the level of significance of each factor, to guide further analysis.

Figure 12: Vehicle energy model

A vehicle energy model could be written as:

$$E = E_{idling} + 1/\eta_{u} \left(E_{aero} + E_{roll} + E_{accel} + E_{climb} + E_{brake} + E_{ancill} \right)$$

Equation 1: Vehicle energy model

where

E = total energy used by the vehicle
E_{idling} = energy used by idling
η_{u} = energy efficiency of the engine and transmission
E_{aero} = aerodynamic resistance
E_{roll} = rolling resistance
E_{accel} = energy required for acceleration (overcoming inertia)
E_{climb} = energy required for climbing
E_{brake} = energy dissipated in braking
E_{ancill} = energy consumed by ancillaries (e.g. alternator, air compressor).

At the start of the EMB process, the company did not have the data needed to evaluate all the energy use components in the model, such as the range of vehicle speeds or the extent of hill climbing. In order to perform a first-pass desktop analysis of these opportunities, the team agreed that the following simplifying assumptions were reasonable for the articulated vehicles, which are used exclusively for long-distance line-haul operations:

- Ignore energy used by braking, acceleration, and hill climbing, all of which are route specific; idling, which should be negligible in highway driving; and ancillaries.[14]
- Assume prime movers travel at 100 km/h for 95% of total distance driven (based on a sample of engine management system records).
- Assume a constant value for engine and transmission efficiency.

The simplified energy model is shown in Figure 13. It will be refined later to include the influence of additional factors, in order to assess other identified opportunities in which these factors are more significant. For example, evaluating hybrid vehicles or those with regenerative braking requires incorporating braking and acceleration in the vehicle energy model.

Figure 13: Simplified vehicle energy model

The simplifying assumptions described above result in the following equation

$$E = 1/\eta_u \left(E_{aero} + E_{roll} \right)$$

Equation 2: Simplified vehicle energy model

The relationship between energy and power is:

$$E = \text{power} \times \text{time}$$

and so the energy required, using the simplified vehicle energy model is

$$E = 1/\eta_u \left(P_{aero} + P_{roll} \right) \times \text{time}$$

where the components of power required (at a given speed) are:

P_{aero} = the instantaneous power required to overcome aerodynamic drag
P_{roll} = the instantaneous power required to overcome rolling resistance

The power to overcome aerodynamic drag is dependent on the frontal area, the drag coefficient, the air density and the speed of vehicle through the air:

$$P_{aero} = A_{frontal} \cdot C_d \cdot v^3 \cdot \rho_{air} / 2$$

where

$A_{frontal}$ = vehicle frontal area (m^2)
C_d = coefficient of drag (dimensionless)
v = vehicle speed (m/s)
ρ_{air} = air density (kg/m^3)

The rolling resistance for a vehicle is:

$$P_{roll} \text{ (watts)} = M_{GrVeh} \cdot g \cdot R_{roll} \cdot v$$

where

M_{GrVeh} = gross vehicle mass (kg)
g = gravitational constant (9.81 $m.s^{-2}$)
R_{roll} = coefficient of rolling resistance (dimensionless)

Note that although power to overcome rolling resistance is proportional to vehicle speed, the energy used in overcoming rolling resistance is not affected by vehicle speed because energy = power × time and the time for a trip is inversely proportional to average speed. By contrast, the **power** to overcome aerodynamic resistance is proportional to the **cube** of velocity, so it is highly affected by vehicle velocity, while the **energy** consumed by aerodynamic drag is proportional to the square of the vehicle speed.

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[14] In principle, what makes transport system modelling complex is the absence of data on acceleration and braking patterns and frequencies, and road gradients. If a trial is undertaken to obtain measured data of sufficiently high frequency, it is not difficult to build an effective energy use model. The accuracy of the model can be easily verified from fuel consumption data at the completion of the trial.

Further literature searches categorised the main factors affecting rolling resistance and aerodynamic drag, as listed in Table 5. This table formed part of the documentation of the EMB model to enable further development even if the EMB team changed.

Table 5: Factors affecting rolling resistance and aerodynamic drag

Factor	Description	Influenced by	Comment
Rolling resistance	Energy required to overcome the resistance to movement from internal friction in tyres and bearings, and friction/slip between road and tyres	Total vehicle mass (directly proportional)	Mass of the: • empty vehicle • the load, including packaging and pallets • fuel • oil, water, fuel additive • driver
		Road surface	Friction varies for different road types.
		Tyre tread condition	Newer tyres with deeper tread have higher rolling resistance.
Aerodynamic drag	Energy required to push the vehicle through the air	Vehicle speed	**The largest influence is vehicle speed, a parameter which is easily controlled. Power to overcome aerodynamic drag is proportional to the cube of the speed, and the energy is proportional to the square of the speed.**
		Wind speed relative to the vehicle track/ direction	Wind speed will not normally be known, and so is assumed to average zero (head and tail winds). The affect of wind on track tests will be compensated for by running complementary tests in opposite directions and/or by measuring wind with a portable anemometer. Wind from the side can adversely affect drag coefficient and the effectiveness of aerodynamic aids.
		Vehicle frontal area	Including trailers, accessories, and attachments.
		Air density	Tabulated based on temperature and pressure, equals 1.29 at 0°C.

5.2.3 Analysis of energy data and transport task records

Analysis of an organisation's existing energy records and transport tasks records may help to fill some of the gaps in the vehicle energy model, or to check and refine answers derived from other methods. Fuel use in transport is affected by many factors. Determining the effect on energy use of one particular factor is likely to require taking account of all other influences, using methods such as:

- regression analysis
- controlled experiments
- in-service trials.

Table 6 lists examples of data which may be available and useful in quantifying and refining the vehicle energy model. The vehicle fuel and operations data may be available from several sources, including:

- fuel supplier invoices and electronic data files
- paper records
- vehicle on-board management systems (engine management systems, downloaded in real time or when vehicle is at a depot)
- telematic devices (that transmit vehicle management system and GPS data in real time).

Table 6: Examples of relevant data for transport operations

Category		Quantifiable parameter	Units
Overall performance		Key performance indicators (KPIs) (What KPIs are already in use to monitor the effectiveness of providing the transport service?)	L/km L/t.km $/pass.km $ cost / $ revenue
Transport task	What?	Mass	kg, t
		Volume	m^3
		Other requirements (dangerous goods, special handling, lifting equipment, etc.) .	Y/N for each
	Where?	Origin	–
		Destination	–
		Route taken	–
		Total distance	km
	When?	Time consignment available	hh:mm
		Time delivery required at destination	hh:mm
		Total time available	hh:mm
		Total time for task	hh:mm
		Travel time	hh:mm
		Time for waiting, loading, uploading, queuing	hh:mm
Vehicle selection	Which vehicle?	Vehicle fleet identification number	Fleet ID Registration Tail number
	Configuration	Seating	Number of passengers (pax)
		Trailers	ID
Vehicle operation		Driver (paper records or electronic key data)	Driver ID
		Gross mass, from weighbridge, aircraft weight and balance calculations	tonnes
		Engine management system data. (e.g. engine speeds, idling time, gears, fuel use, distance, etc.)	various
Energy data	Refuelling records	Fuel consumed	L
		Tankering/refuelling practice	location
		Distance reading	km
External factors 'outside' the organisation	Weather	Wind speed, direction, altitude, barometric pressure	various
	Traffic	Congestion, waiting time. diversions, speed regulation, etc.	various

L = litre; L/km = litres per kilometre; L/t.km = litres per tonne-kilometre; pass.km = passenger-kilometre; t = tonne

5.2.4 Regression analysis

Regression analysis is a statistical tool or method used to analyse quantitative data, in order to develop an equation which will explain the way the *dependent variable* changes in response to changes in *independent variables*. Regression analysis can be used to help build and refine a vehicle energy model where there:

- is a large quantity of data
- is a large variation in the data (variation in both the factors influencing energy use and in energy consumption)
- are many variables influencing vehicle fuel use
- are comparable transport tasks or operations.

For example, a freight train operator has records for 1,500 trips on a single route, and starts with a premise that the factors affecting fuel use on a trip are:

- who is driving the train
- total train mass
- ambient temperature
- total idling time (due to loading, unloading and waiting at signals).

The data for these parameters and energy consumption for each of the 1,500 trips would be entered into a statistical analysis package (such as Microsoft Excel[15], Minitab[16] or Matlab[17]).

The analysis was able to produce an equation which explained 87% of the variation in fuel use between trips, and showed that after correcting for the other factors, the difference in fuel use between the most efficient driver and the least efficient was 36%. This data led to further investigation and driver training, which was funded by the energy savings.

For further information on regression analysis, see the *Energy Saving Management Guide*, the *Representative Assessment Guide* and Section 12 of the *Assessment Handbook*.

5.2.5 Controlled experiments

Controlled experiments aim to reduce the difficulty in analysing vehicle fuel efficiency and quantifying the influences on fuel use, by controlling or at least being able to accurately measure and record some variables. In contrast to regression analysis, controlled experiments aim to minimise variation in most variables.

Controlled experiments can have the following advantages:

- They can be designed to answer a specific question.
- They can result in quick answers (rather than waiting for data from vehicles in service).

A disadvantage of controlled experiments is the removal of vehicles and operators from service. An example of a controlled vehicle experiment is a ‘coast-down’ trial (see Box 3).

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[15] Requires installation of the statistical analysis ‘ToolPack’ add-in available on the MS Office installation CD.

[16] www.minitab.com/products/minitab, accessed 16 February 2010.

[17] www.mathworks.com/products/matlab, accessed 16 February 2010.

BOX 3. TESTING AERODYNAMIC DRAG AND ROLLING RESISTANCE

In a truck, most of the motive power from the engine is used to overcome aerodynamic drag and rolling resistance. This annex describes how a "coast down" test will enable you to quantify the aerodynamic drag and rolling resistance of a road vehicle.

Test Procedure

You will need:

- still conditions (negligible wind)
- a safe test track which will enable you to reach a speed of 80–100 km/h and then coast, in a straight line, on level ground, to a standstill
- a method of recording the time taken to slow to reach each intermediate speed (e.g. 90, 80, 70 km/h … 20, 10 km/h, stopped). This could be a passenger with a stop watch with a lap-time function, or a GPS with recording function or a vehicle monitoring system. If using the vehicle speedometer, you will need to adjust for speedometer error at each speed

Procedure:

- ensure that the test track and conditions are safe for this test
- from the top speed, shift to neutral (to eliminate engine braking) and allow the vehicle to decelerate to a standstill
- have a passenger or vehicle data-logger, or GPS data logger record the speed and time elapsed at speed intervals of say 10 km/hour (as a minimum, you will need the total time and the time to reach an intermediate speed – effectively giving two test results: the time to stop from the high speed and from the intermediate speed)
- repeat the procedure in the opposite direction, to check for any slight incline or wind. Average the readings for both directions to produce a single set of readings of speeds and times
- weigh the vehicle

Calculations:

- calculate the corrected speeds, if using the vehicle speedometer
- tabulate the corrected speeds and the time periods for each speed band
- each speed band reading other than the reading for the top speed gives a time difference and a speed change since the previous reading. Calculate the acceleration for each set of readings

  $$\textit{Deceleration } (m/s^2) = \frac{\textit{change in velocity } (m/s)}{\textit{change in time (seconds)}}$$

- at each speed, the deceleration will be proportional to the total decelerating forces (rolling resistance plus aerodynamic drag, where the aerodynamic drag is proportional to the square of the speed, while the rolling resistance is directly proportional to the speed)

  Using the equations for aerodynamic drag and rolling resistance (see Equation 2, the simplified energy model), solve for:

  - $\{ A_{frontal} . C_d \}$, and
  - $\{ M_{GrVeh} . g . R_{roll} \}$
- Calculate:
  - the drag coefficient: divide $\{ A_{frontal} . C_d \}$ by the measured frontal area
  - the rolling resistance coefficient: divide $\{ M_{GrVeh} . g . R_{roll} \}$ by mass, then by the acceleration due to gravity, g (9.81 $m.s^{-2}$)

5.2.6 In-service trials

When developing an EMB, in-service trials of changes to procedures and equipment have the advantage that they provide 'real world' data on the affects of those changes. These trials do not require translation of results from, for example, wind tunnel tests or computer simulations to fuel savings predictions for the real transport fleet.

For some low-cost improvements, calculating expected energy savings before implementation might be difficult or impossible with the data available, or may be viewed as unnecessary because there is no capital cost to justify. However, it is still important that the affect of these changes be determined, so that there is a basis for continuing the change, or extending the change to other regions or divisions. Where the cost and effort of trialling a change is cheaper and easier than predicting the energy savings, in-service trials provide a solution.

However, in-service trials have the weakness that energy use during regular transport operations will be influenced by many varying factors, not just those tested. Therefore, to determine the affect on energy use of the change being trialled requires that the affect of these other influences can be calculated. This, in turn, requires data collection and the application of techniques such as multiple regression analysis and development of an accurate vehicle energy model as part of the EMB process.

It is important that any experimental designs for the EMB be planned so that at the end of the experiment it will be possible to quantify the affect on fuel efficiency.[18]

Having a method of isolating the change in fuel use attributable to the change being trialled is particularly important in a transport EMB because:

- there are many variables affecting fuel use, they change frequently, and many are beyond the control of the transport operator
- often the change being trialled has a potential energy saving of less than 10%, which is much lower than the usual variation in fuel economy.

Ultimately, the aim of the in-service trial is to complement and refine other estimation techniques in the EMB.

5.2.7 Multiple small opportunities

Energy efficiency opportunity workshops and investigations typically identify 30–50 potential opportunities, of which two-thirds are low-cost, easy to implement operational changes. EMBs can be used to estimate and model savings from such changes. One suitable approach to estimating energy and cost savings from the changes is to:

- group all the changes into a single opportunity for the purpose of reporting to government (e.g. 'operations optimisation for the Queensland van fleet').
- establish energy efficiency KPIs (see Section 5.2.8) that are most relevant to your transport operation (e.g. litres of fuel per tonne-kilometre) and monitor these KPIs frequently (at least monthly and preferably weekly) so that the effect of implementing individual changes can be monitored.
- gradually implement the individual opportunities in the group of operational opportunities, recording the date when they were implemented and any experiences or lessons that could benefit other parts of the organisation.

Using this approach, the organisation can capture and maximise the benefits of the opportunities, despite possible difficulties in predicting the savings from first principles calculations. Non-energy outcomes that could provide financial benefits should also be documented for inclusion in the business case and for future EMB iterations.

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[18] For example, it is advisable to account for the impact of vehicle maintenance when conducting a trial, either by servicing vehicles before the trial or by collation and subsequent analysis of maintenance records.

5.2.8 Key performance indicators

KPIs can assist with benchmarking and efficiency evaluation, which are important components of the EMB process. Energy KPIs will be most useful if they compare energy use with the amount or value of the transport service being delivered. For example, a KPI of *litres of fuel per tonne-kilometre* or *litres of fuel per passenger-kilometre* more closely reflects the service being delivered than *litres of fuel per vehicle-kilometre* or *litres per hour* and is able to show the efficiency gained, for example, in moving from semitrailers to B-doubles or changing to aircraft with more seats.

Another KPI to consider is *litres of fuel per $1,000 revenue*, as this broadly indicates how big an influence fuel is likely to be on profit for a particular service, as well as taking account of the value that the customer places on the service, and makes comparisons between air freight, rail, line haul trucks and local delivery more valid. In practice, several indicators may be needed to fully reflect the significance of a factor for the EMB results.

5.3 ENERGY AND MASS FLOWS FROM VERSION 1 OF THE EMB

The first iteration of the EMB may use a combination of the methods outlined in sections 5.2.2 to 5.2.8. TT used the model from Figure 13 to estimate the EMB for prime movers in the bulk fruit division. These calculations are shown in Table 7. Some key assumptions were made in this first iteration, such as the load, air density and time at the chosen vehicle speed of 100 km/h. In addition, the fuel economy figure was based on aggregate data and did not account for different loading rates.

Table 7: Energy-mass balance for a bulk fruit transport division prime mover

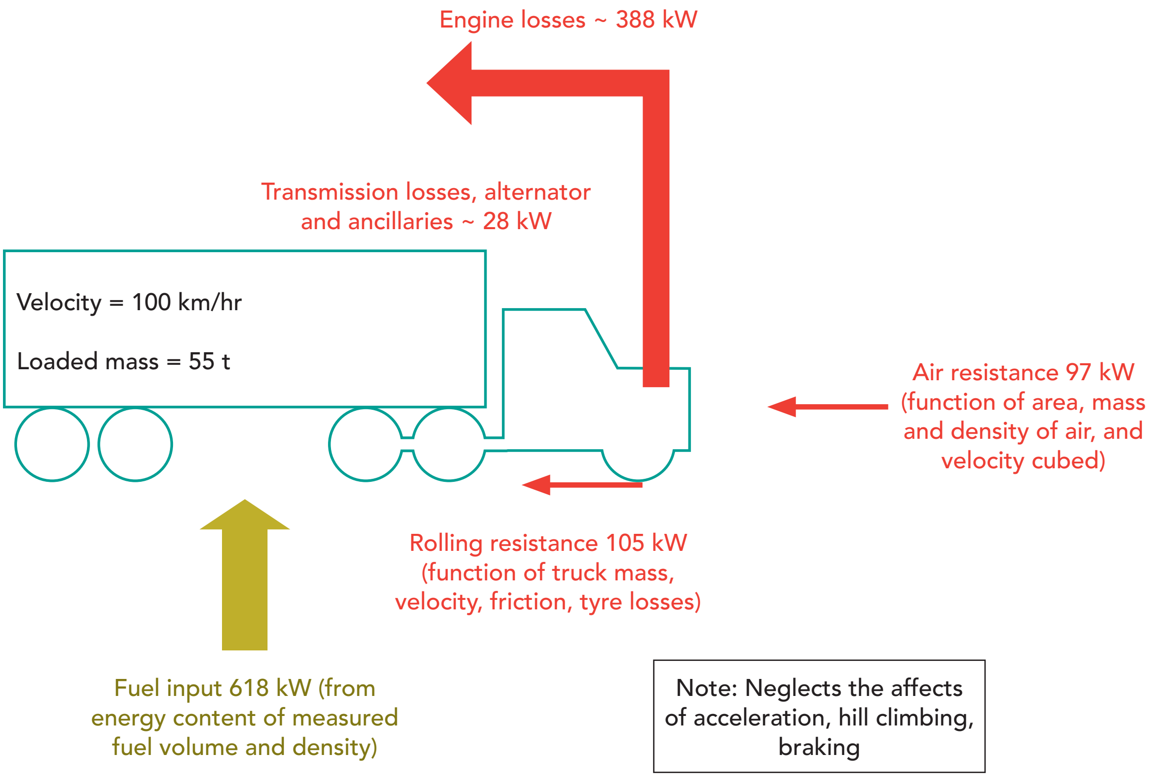
Parameter	Derivation	Calculation	Value	Units	Accuracy (standard error)[a] (±%)
Prime-mover fuel	Fleet measurement data	–	3,412,600	litres per year	1
Distance, fruit division fleet	Fleet measurement data	–	5,903,798	kilometres per year	2
Distance with 100 km/h operation, estimated	Assumption, based on broad route analysis	–	95%	of all distance driven	5
Fuel used during 100 km/h operation, conservative first guess	Assumed percentage	–	95%	of fuel for division	5
Drivers' pay including on-costs, average	From human resources	–	35	$/h	5
Truck total mass, including freight and fuel	From weigh records	–	55	tonnes, average	5
Truck frontal area	Measured	–	10.8	m^2	5
Truck coefficient of aerodynamic drag (C_d)	From manufacturer	–	0.65	–	5
Truck rolling resistance,	Initial figure from manufacturer	–	0.007	–	5
Fuel economy, fruit division fleet average, 2006–07 data	Fleet measurement data	–	0.578	L/km	5
Energy content of fuel, physical property	Engineering handbook	–	38,500	kJ/L	2

Parameter	Derivation	Calculation	Value	Units	Accuracy (standard error)[a] (±%)
Price of fuel after tax rebate, short term	Estimate	–	1.25	$/L	5
Density of air, physical property, assume standard conditions	Engineering handbook	–	1.29	kg/m^3	1
Vehicle speed	Assumption	–	100	km/h	–
Vehicle speed (m/s)	Unit conversion from km/h	100 × (1000/3600)	27.8	m/s	–
Fuel input power, average	v[km/h] × (1/3600)[h/s] × 0.578[L/km] × 38500[kJ/L]	100/3600 × (0.578) × 38500	618	kW	5
P_{aero} =	$A_{frontal} \times C_d \times v^3 \times (\rho_{air} / 2)$	$10.8\ m^2 \times 0.65 \times (27.8\ m.s^{-1})^3 \times 1.29\ kg/m^3 \times 0.5$	97.05	kW	8
P_{roll} (watts) =	$M_{GrVeh} \times g \times R_{roll} \times V$	$55 \times 1000\ kg \times 9.81\ m.s^{-2} \times 0.007 \times 27.8\ m.s^{-1}$	104.91	kW	7
$P_{aero} + P_{roll}$ =			201.96	kW	5
Implied drivetrain efficiency	$(P_{aero} + P_{roll})$ / fuel input power	(201.96 kW/618 kW) × 100	33%		9
Power to ancillaries (assumed 1.5% of fuel input power)		618 kW × 0.015	9.3	kW	5
Alternator (assumed 1% of fuel input power)		618 kW × 0.01	6.2	kW	5
Transmission losses (assumed 2% of fuel input power)		618 kW × 0.02	12.4	kW	5
Implied thermal engine losses	Fuel input power – (P_{aero} + P_{roll}) – ancillaries – alternator – transmission losses	618 kW – 201.96 kW – 9.3 kW – 6.2 kW – 12.4 kW	388.4	kW	9
Implied thermal efficiency of the engine	Implied thermal engine losses/ fuel input power	(618 kW – 388.4 kW)/(618 kW) × 100	37%		11

kJ/m^3 = kilojoules per cubic metre; kJ/L = kilojoules per litre; kW = kilowatts; m/s = metres per second;
(a) Accuracy ranges have been calculated using the methods outlined in the *ESMG*.

Table 7 estimates that of the estimated 618 kW of power from fuel, 63% is lost through thermal inefficiencies in the engine, which is in the normal range for diesel trucks. Of the remainder, the bulk (33% of power from fuel) is used to overcome rolling and aerodynamic resistance, while 4.5% of the total fuel power is assumed to be used for ancillaries. These figures are sensitive to the assumptions made, as discussed in Section 6.1.1. Note that since approximately two-thirds of energy from fuel is lost during combustion, each 1% efficiency gain further down the energy conversion chain will reduce fuel requirements by around 3%. Figure 14 illustrates the energy and mass flows from the simplified vehicle model.

Figure 14: Estimated energy and mass flows from the bulk fruit division vehicle energy model, at 100 km/h



6 ANALYSE VERSION 1 OF THE ENERGY MODEL

In order to analyse initial EMB results, you need to:

- validate the results to ensure that the analysis is representative of actual operation and all relevant energy flows and mass transport have been accounted for
- identify opportunities to reduce the energy flows quantified in the model
- use the model to calculate the expected savings from the opportunities identified.

6.1 CASE EXAMPLE: TERRIFIC TRANSPORT

TT used a questioning framework (see page 61 of the *Assessment Handbook*) to start analysing the EMB results. The framework provided a starting position to encourage staff to think openly about alternative options and opportunities to reduce existing energy use.

With the system maps and EMB results at the fleet, sub-fleet and vehicle level, the EMB team:

- asked 'does the model make sense?'
- asked 'what does the model show us?'
- invited views from other people, informally and at a workshop to identify opportunities
- used the model to calculate the energy savings it was capable of evaluating
- identified shortcomings in the model, and set a priority order for overcoming these based on the potential opportunities which the improved capability would help quantify
- identified and prioritised data gaps, and devised ways of filling these gaps.

Results of these questioning processes are discussed in Section 6.1.1.

Looking at the results shown in Table 7, the EMB team noted that the implied efficiency of the engine was in the right ballpark. However, the actual efficiency may have been lower in practice because truck weights had been measured after loading, but data on distances travelled unloaded or partially loaded were not available. Vehicle mass had been included in the model as a fixed variable, yet loading variation occurred in practice. The model may have therefore overestimated efficiency to the extent that trucks had travelled with part loads or unloaded, so TT decided to examine options to address this data gap for subsequent EMB iterations.

Another key assumption that needed revisiting was the assumption that vehicles were travelling at 100 km/h for 95% of travel time. This assumption also affects calculated efficiency because both aerodynamic and rolling resistance depend on velocity. After reviewing tabulated air density data, the EMB team decided to investigate refinement of the assumed air density, noting that 1.29 kg/m^3 corresponds to a temperature of 0°C. In addition, the team envisaged developing a program to calculate the EMB model frequently during road trials.

Addressing data gaps and the accuracy of assumptions would help to reveal potential recoverable losses, such as lower than expected engine efficiency that could be addressed through maintenance. TT noted that the model did not account for driver behaviours, which could potentially be investigated through controlled experiments and incorporated into future modelling if feasible.

6.1.1 Evaluate opportunities

Using the vehicle model from the first EMB iteration, TT initially quantified the savings and costs from four of the opportunities identified as a result of the first EMB iteration:

- reducing speed to 90 km/h (which reduces fuel used in overcoming aerodynamic drag, and incurs an additional labour cost due to extended driving time)
- reducing the mass of fruit bins, to reduce total vehicle mass and so reduce rolling resistance

- replacing steel wheels with aluminium alloy wheels, to reduce vehicle mass and rolling resistance (and in the case of liquids division trucks which operate at their mass limits, carry additional load and so increase revenue)
- improving aerodynamic efficiency.

The results of these savings calculations made using the simplified energy model from Figure 13 are shown in Table 8, with details being provided in the transport example in version 2 of the *ESMG*. Additional business costs and benefits were also included in the analysis, but are not shown here.

Table 8: Savings from reducing vehicle speed to 90 km/h

Parameter	Value	Units	Accuracy (±%)
Distance travelled at 100 km/h	5,608,608	km per year	2
Total vehicle operating hours at 100 km/h	56,086	hours per year	5
Total vehicle operating hours at 90 km/h	62,318	hours per year	5
At speed of 100 km/h:			
Power needed at wheels =	202	kW	5
Energy at wheels (power x time)	40.8	TJ/year	**7**
At speed of 90 km/h:			
Power needed at wheels =	165	kW	5
Energy at wheels (power x time)	37.1	TJ/year	**7**
Energy saving at wheels	3.7	TJ/year	**109**
Energy saving from fuel (saving at wheels divided by drivetrain efficiency from Table 7)	11.2	TJ/year	**109**
Percentage energy savings, (constant engine and transmission efficiency)	9.1%	of fuel	**109**

TJ = terajoules

The results from the model revealed that the predicted energy savings were smaller than the margin of error, with an accuracy of ±109%. This initial uncertainty margin indicated a need for further investigation. The EMB team noted that there was scope to improve the EMB in several areas:

- The energy use predictions at the two speeds were within ±7%, which was magnified for energy savings because the savings were small relative to the energy use figures.
- Since the vehicle model was based on sound physical principles, the team was certain that energy would be saved, though the precise magnitude of savings was uncertain.
- When other whole-of-business considerations were included, the lack of need for capital expenditure meant that this opportunity should bring an immediate estimated return of around $12,650 per month (or $152,000 annually). However, this is only feasible where customer delivery schedules can absorb extra trip time.
- Based on an assumed coefficient of variation of 0.5, a random trial of 20 trucks would give an accuracy of ±22% for energy use, while a sample of 45 would give ±14% accuracy.[19]

In developing its energy model, TT confirmed that reducing speed from 100 km/h to 90 km/h would reduce energy use, but was uncertain about the exact amount of the reduction. This suggested that the model would need to be revisited to improve the accuracy of predictions. Key assumptions in the model were the proportion of the trip spent at the chosen speed and the corresponding proportion of fuel use. Available data were not sufficient to permit significant improvements to the accuracy of assumptions in the model without further trials.

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[19] Sampling questions are discussed in the EEO *Representative Assessment Guide*.

However, the TT team expected that a trial of this opportunity would provide a better indication of accuracy and also help to refine the assumptions behind the model. To improve the accuracy of the estimates, TT decided to implement a random trial. To maximise the value of the trial, it decided to investigate collection (and possibly transmission) of vehicle management system and GPS data in real time. This would enable investigation of the affects of gradients and acceleration patterns on fuel consumption for inclusion in the model.

While the EMB modelling results were also used to evaluate the salary costs of this opportunity, potential quality improvements for produce had not been estimated. The EMB team expected quality to improve due to reduced dynamic loads on the produce while in transit. Similarly, reduced speeds were expected to lower maintenance costs by reducing loads on the engine, suspensions, brakes and drivetrain. These non-energy benefits could be evaluated from trial results.

7 CONSOLIDATING THE EMB DATA

Preparing a consolidated EMB for a corporation's transport operations involves collating the energy use and loading data at levels 1, 2 and 3 in an appropriate report or tabulated format. Collation of this data is recommended to provide a consolidated summary of energy use throughout the transport system and enhance the understanding of how energy use contributes to business outcomes. This understanding is important because for some operations there may be interactions between the operations of different subsystems. For example, freight delivered by train or aircraft may be locally delivered by truck or van fleets. Accounting for these interactions in the EMB may identify energy savings from logistical improvements, such as improved local delivery vehicle selection or scheduling.

In consolidating and documenting results from the EMB process the development of key performance indicators (KPIs) for the various transport subsystems is strongly recommended. The development of KPIs will enable comparison of alternative transport modes, vehicles or routes. Vehicle models will feed into the energy use and loading data for each subsystem and, in turn, the transport system as a whole, enabling energy saving measures to be considered with reference to the whole transport system.

Section 4.2 discusses the sort of high-level data that might appear in a consolidated EMB, while Sections 5.2 and 5.3 discuss more detailed energy data requirements, key performance indicators and the types of data required for vehicle models.

7.1 WHEN IS IT GOOD ENOUGH?

The EMB is 'good enough' when:

- *The EMB accuracy requirement is met.* The EMB records (can explain) energy use to an accuracy of ±5%, with the required coverage.
- *Energy use is adequately covered.* The EMB covers at least 80% of the fleet's energy use, and all sub-fleets, transport services, routes or vehicles that use at least 0.1 PJ[20] of energy per year.
- *Opportunities can be accurately quantified.* The EMB (and other methods) allow detailed investigation of opportunity areas so that opportunities can be identified and costs and benefits can be calculated to within ±30%.

Specifically, an EMB or equivalent must be sufficient to satisfy the EEO requirements mentioned in Section 1.1.

7.2 HOW MUCH EFFORT AND TIME?

The time and effort required to build and improve the transport EMB will depend on the quality, extent and accessibility of existing energy data and transport task data, and any existing model of how the transport system operates.

As experience is gained with EEO activities, the time and effort required may decline for transport operations as lessons from one subcategory of the fleet may be directly transferable to another subcategory. Energy savings estimates will typically vary in accordance with fuel price fluctuations, so the payback periods from some opportunities may shorten over time.

It is worth noting that a thorough and comprehensive EMB will provide a map of the transport system that has value beyond the analysis of energy use and pursuit of opportunities. For example, investigating customer requirements to optimise energy use also reveals quality of service delivery. Similarly, revision of maintenance schedules would tend to improve service reliability and therefore customer satisfaction.

Building and improving the EMB is a progressive and iterative process. At each stage, effort and resources can be focused on the area with the highest apparent potential, consistent with keeping the whole-of-system opportunities and benefits in view.

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[20] 0.1 PJ is about 2.6 million litres of transport fuel.

8 WORK PLAN: IMPROVING THE EMB

Results from the first version of the EMB can highlight potential opportunities, but also reveal data gaps and assumptions or approximations that affect accuracy. Version 2 of the EMB will fill in the initial gaps in data identified in version 1. These gaps arise due to insufficient detail in fuel records and transport task data, or a lack of data on the factors influencing fuel use. Efforts should focus on areas where there are large energy flows and apparent opportunities.

Developing version 2 starts with preparing a list of improvement areas, capturing the insights gained through the development of the preliminary EMB and its initial analysis. Improvements should be prioritised based on the overall gain to the EMB process and the size of potential energy savings. For example, it is more reasonable to improve data capture in an area where it is believed that significant energy saving opportunities may exist than in an area where the energy savings are likely to be much smaller. Achieving an accuracy of ±5% for all fuel sources across at least 80% of the total energy use (and all transport tasks or vehicles not included in the 80% that consume 0.1 PJ or more per year) is especially important.

Questions which should be asked include:

- Where are the significant gaps in the data to explain energy flows? What is the estimated energy use for each of these gaps?
- How can these data gaps be cost effectively and accurately filled?
- What assumptions and estimates have been made that have contributed to any unaccounted losses?
- How accurate are these assumptions and what can be done to improve EMB accuracy?
- Are there any areas where potential opportunities might exist?
- What further data and analysis are needed to explore specific opportunity areas?

Once the EMB improvements are identified, the EMB team should prioritise the improvements and commence implementation. As improvements are made, further iterations of the EMB should be developed and further analysis undertaken.

8.1.1 Case example: Improvements for the next version of the TT EMB

The TT case example identified and explored a range of issues involved in producing an EMB and how to resolve them. TT needs to continue to refine its EMB to achieve the EEO accuracy requirements, and to refine the transport system map and the vehicle energy model. An EMB will also be required for the other fleets and services. To date, it has:

- quantified energy use by sections of the fleet
- systematically identified opportunities that go beyond the typical investigation boundary of the vehicle
- made simplifying assumptions in order to be able to model energy use with the existing data
- developed a preliminary map of energy and mass flows for prime movers in the fruit transport division
- resolved to obtain data to test the simplifying assumptions made
- quantified the potential savings from several opportunities.

Estimated energy savings from reducing speed from 100 km/h to 90 km/h were not within the required accuracy range of ±30%. TT therefore decided to run a trial with an appropriate sample size to deliver the requisite accuracy and refine the assumptions underlying the model. The EMB team expected that similar trials could produce accurate EMB models for the different driving patterns and vehicle characteristics applying to various parts of the fleet.

9 CONCLUSION

Developing an EMB is an iterative process that will provide a company with a deeper understanding of the energy and material flows through a site or process. The initial version of an EMB will typically help to identify areas for improvement in data collection and some low-cost, easily implemented opportunities, with subsequent improvements giving a better understanding of energy usage. The final, comprehensive EMB allows analysis of components within the system and the identification, detailed investigation and evaluation of specific opportunities.

This case example was developed to provide direct guidance on how to undertake an EMB for a transport fleet that will assist the company to undertake a comprehensive assessment to meet the requirements of the EEO program.

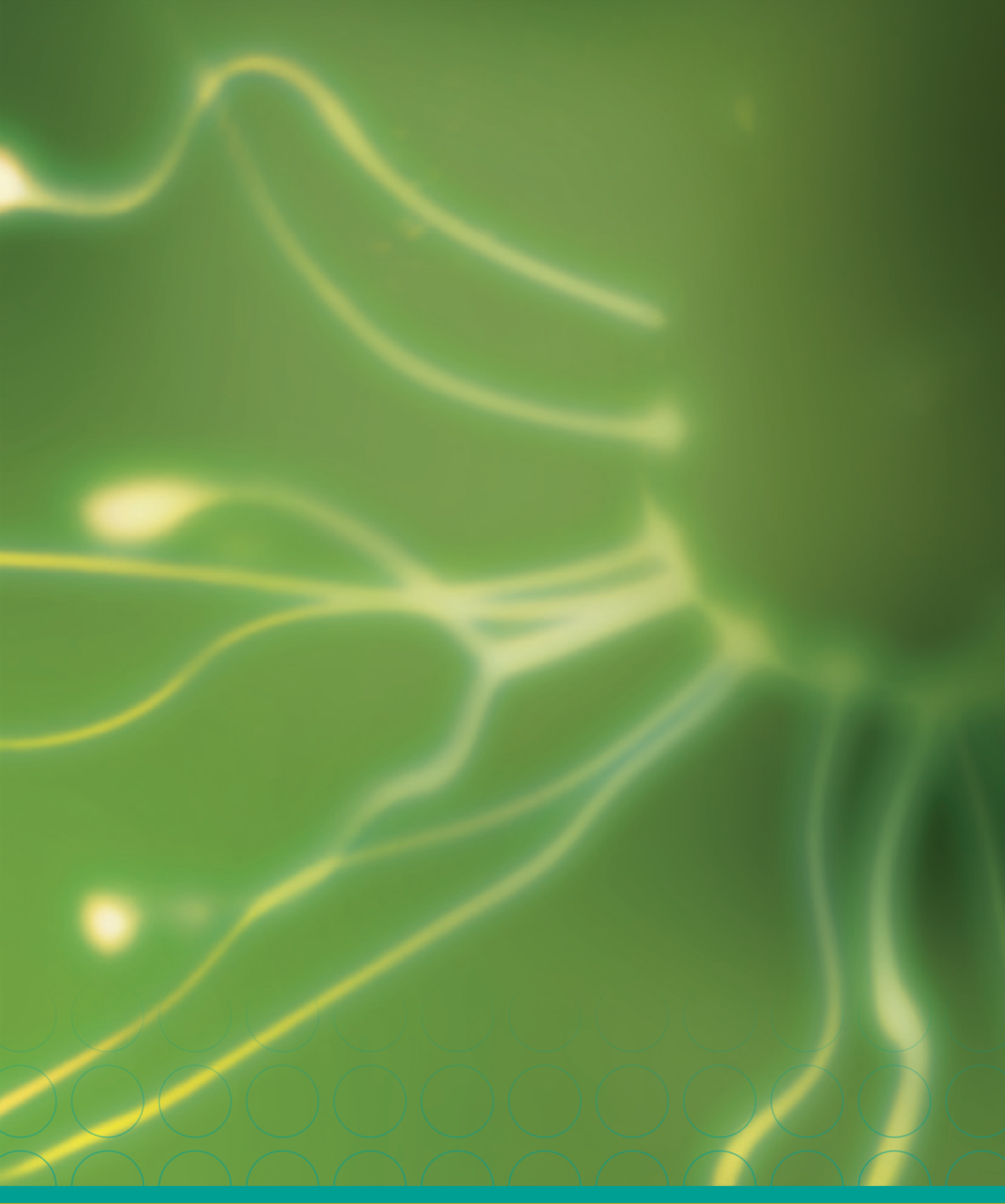
The example outlined how a hypothetical business, TT, undertook the EMB process for its total fleet, analysed its line-haul transport service and then developed a vehicle energy model. The example identified and explored a range of issues relevant to producing an EMB and highlighted approaches that could be undertaken to resolve them. Based on TT's progress to date, the company needs to continue to refine its bulk fruit division EMB to achieve the EEO accuracy requirements. The company plans to undertake in-service trials to refine its vehicle model with a view to applying the results to other parts of the fleet. TT also needs to develop an EMB for the other fleets and services and continue to refine the transport system map and the vehicle energy model.

SHORTENED FORMS

EEO	Energy Efficiency Opportunities program
EMB	energy-mass balance
ESMG	*Energy Savings Measurement Guide*
km/h	kilometres per hour
KPI	key performance indicator
TT	Terrific Transport (a theoretical company used to demonstrate the process and practical issues associated with creating an EMB for transport operations)

GLOSSARY

Term	Meaning, as used in this document
Air resistance	The energy required to push an object through the air.
Drag coefficient	A measure of the relative pressure and shear forces that are applied on an object in a moving fluid, based on factors including body shape, surface roughness and the speed of the flow.
Density (ρ)	The mass of a material per unit volume (e.g. approximately 1000 kg/m^3 for water, or 1.29 kg/m^3 for air at 0°C).
power (P)	Measured in watts, power is work (joules) per unit time (seconds). Energy required is the product of average power and the time taken.
rolling resistance	Energy required to overcome the resistance to movement from internal friction in tyres and bearings, and friction/ slip between road and tyres.



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