Life cycle analysis of the energy consumption of a rail vehicle

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Enhancing the environmental performance of rail transport – challenges, good examples, further tasks

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Energy efficiency for rail vehicles depends on …

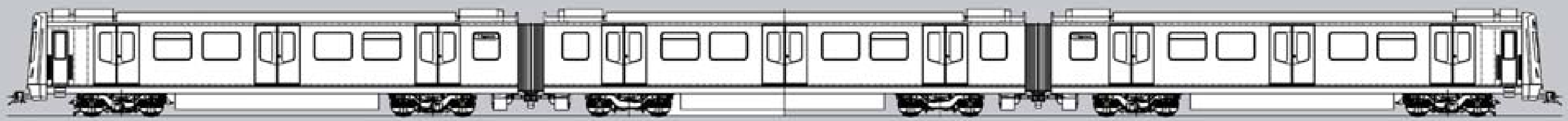
- Vehicle design (electrical and mechanical equipment)
- Materials / raw materials
- Manufacturing
- Delivery to the customer
- Energy losses e.g. train resistance, traction system
- Maintenance
- Disassembling and recycling

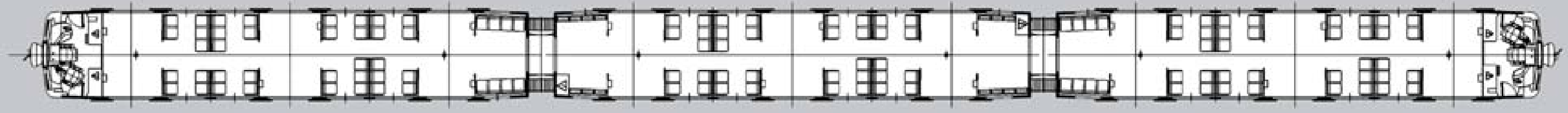
.... considering the whole life cycle of a metro train.

Vehicle example: 3-car train MX for the Metro Oslo

Train configuration: MC1 + M + MC2
Car body material: aluminium
Tara weight: approx. 100 t

Max. axle load: 12.5 t
Length over couplers: 54.14 m
Width of car: 3.16 m
Number of seats: 122
Train capacity (6 pers. / m^2): 678 passengers





Energy consumption of a metro train.
Description of the life cycle stages

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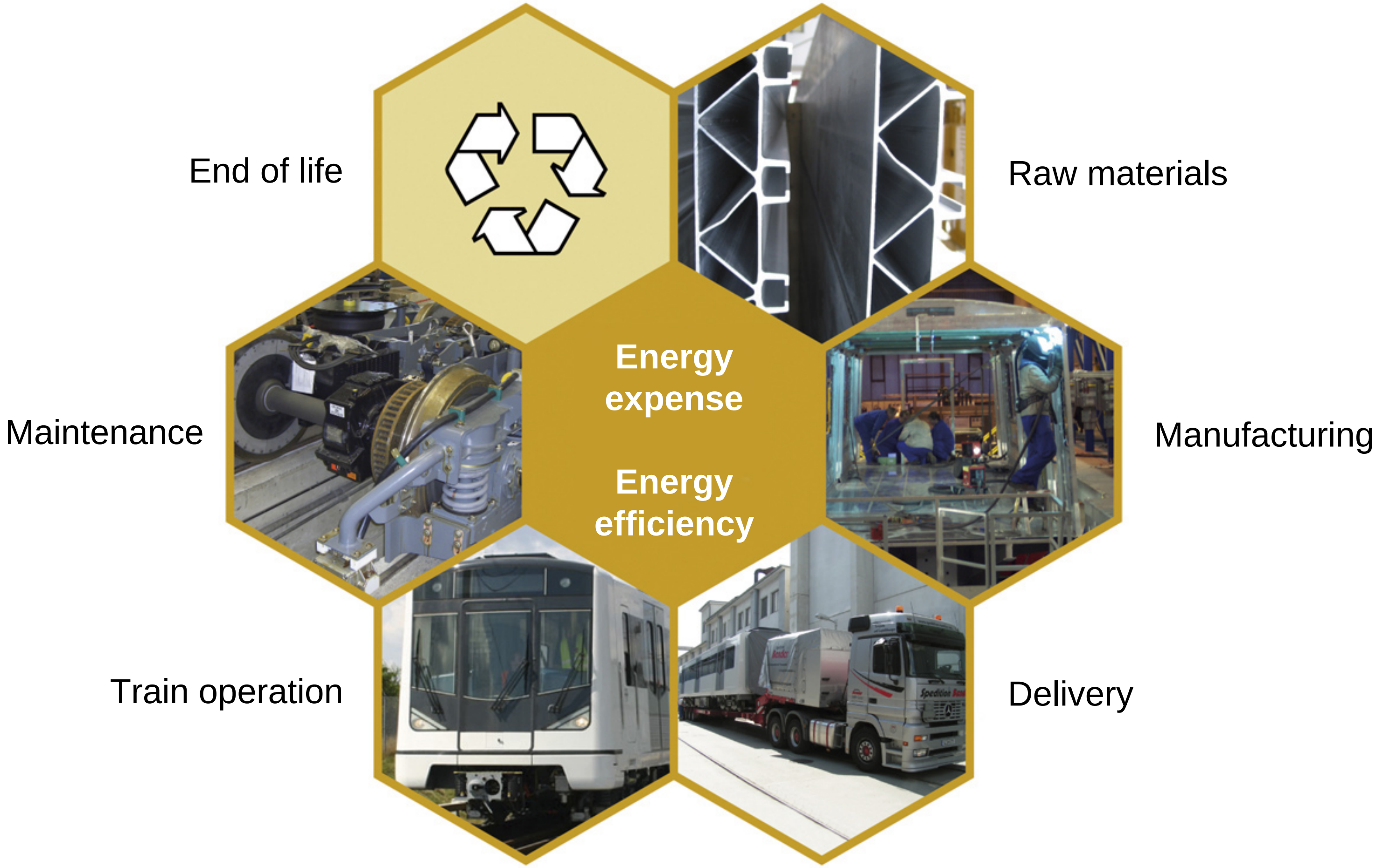

Energy consumption of the metro train MX for the overall life cycle and 30 years of operation

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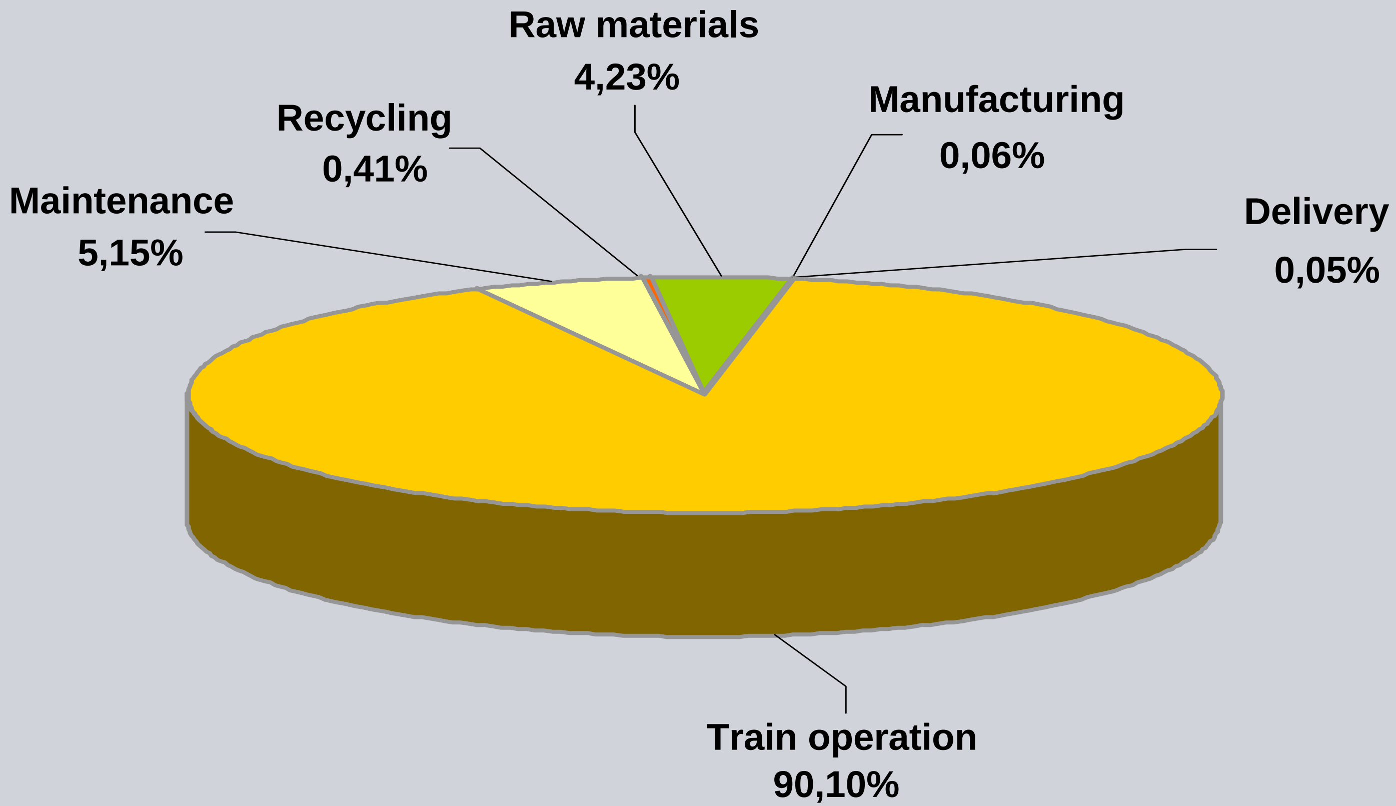

Raw materials and their energy consumption

In this table the energy consumption for the production of the raw materials of the metro train MX (approximately 100 t of train weight) has been considered.

Raw material	Energy consumption per kg raw material[1] [MJ/kg]	Percentage of vehicle mass	Energy consumption [MJ]
Steel (low alloyed)	45	14 %	630 000
Steel (high alloyed)	70	37 %	2 590 000
Aluminium (50 % secondary)	96	31 %	2 976 000
Plastics (average)	90	7 %	630 000
Composite materials	100	3 %	300 000
Chemicals (average)	90	1 %	90 000
Glass	13	2 %	26 000
Copper	80	3 %	240 000
Wood	22	2 %	44 000
Total	-	100 %	7 526 000 (2. 09 Mio. kWh)

[1] Energy values from the *Department of Manufacturing Engineering, Technical University of Denmark, Lyngby, Denmark, 2000*
The material percentage of the vehicle mass is derived from one car

Distribution of the raw materials for the metro vehicle MX

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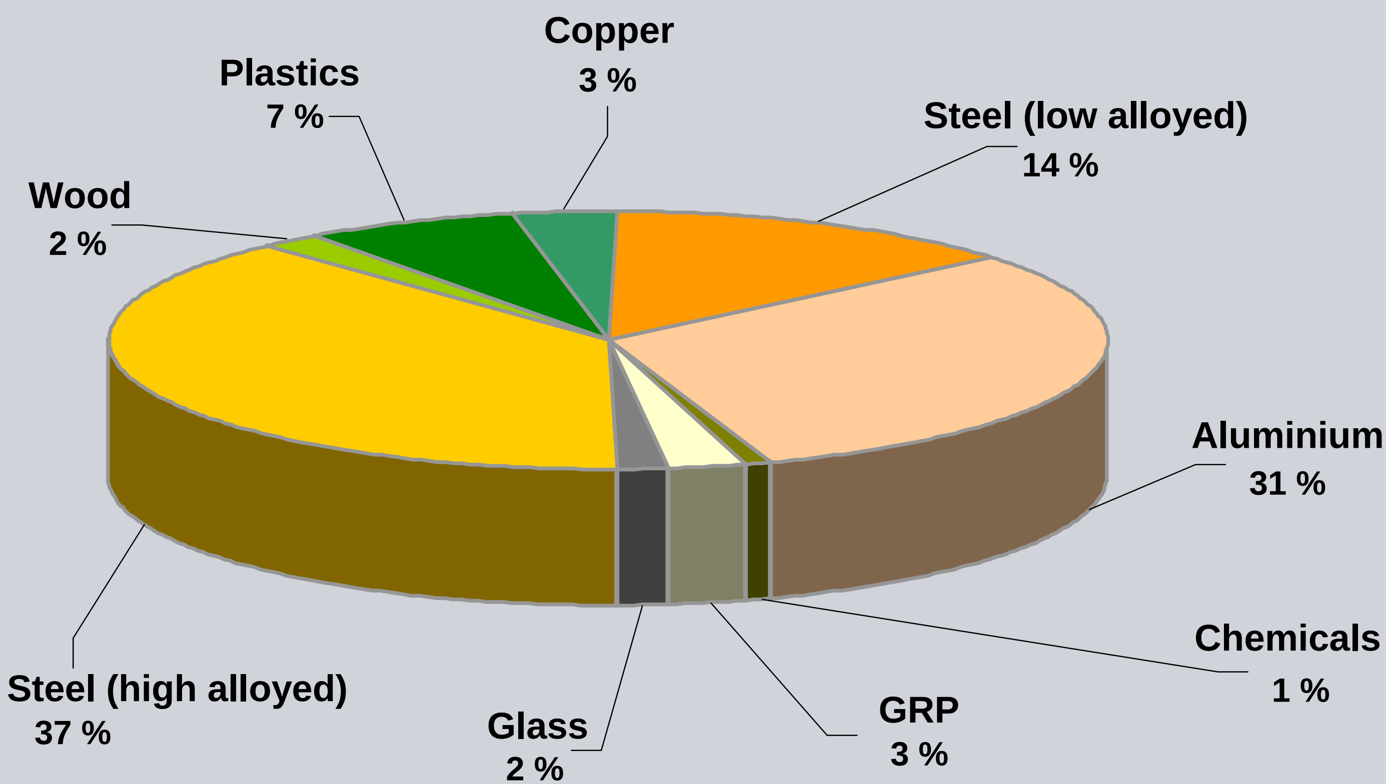

Energy consumption and percentage of mass for the raw materials

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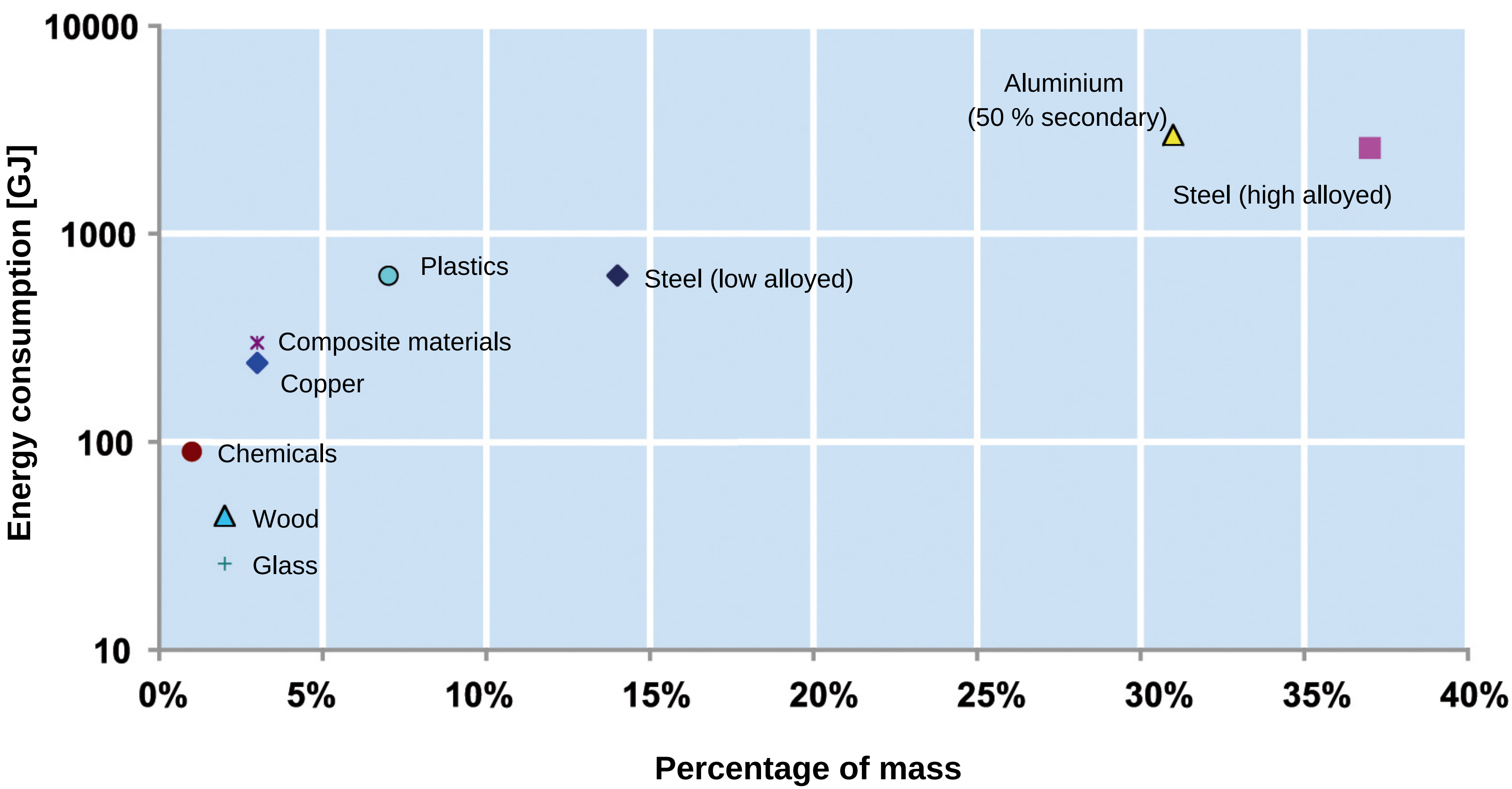

Manufacturing

Energy consumption for manufacturing the metro train at the factory site in Vienna:

About 100 000 MJ per metro train

- Estimation per 3-car train
- Incl. utilities
- Heating
- Electricity
- Supplies

References:
Jahresbericht im Betrieblichen Umweltschutz, 2004/05, Siemens Transportation Systems, Vienna
Energy values from the Department of Manufacturing Engineering, Technical University of Denmark, Lyngby, Denmark, 2000

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Delivery of the train to the customer

Energy consumption for transportation:

Per truck [1] : 0.5 MJ/t-km
Per train (diesel) [1]: 0.8 MJ/t-km
Per train (electrical) [2]: 0.51 MJ/t-km
Per ship [1] : 0.35 MJ/t-km
Example:
Distance Vienna – Oslo: 1800 km
3-car train per truck
= 90 000 MJ

[1] Energy values from the *Department of Manufacturing Engineering, Technical University of Denmark, Lyngby, Denmark, 2000*

[2] DB AG Umweltbericht 2002

Energy balance for the electrical equipment of the metro train MX

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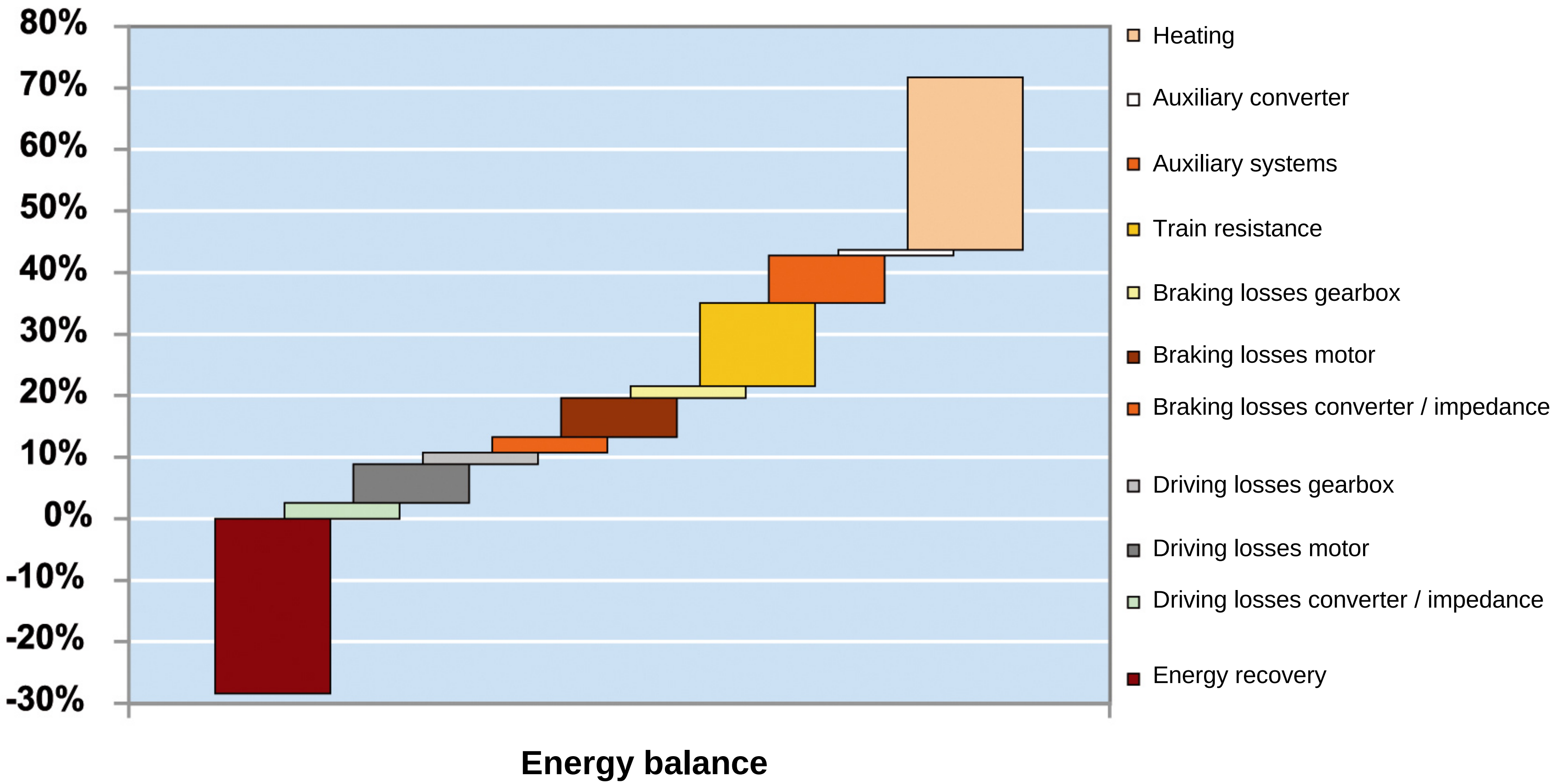


Use of the metro train MX in Oslo

Energy values according to the *Final Train Performance Metro Oslo MX (Simulation)*[1]

- **Energy consumption per kilometre: 44.5 MJ**
- **Energy consumption per year (120 000 km): 5 340 000 MJ**
- **Energy consumption for the life-time period of 30 years: 160 200 000 MJ**

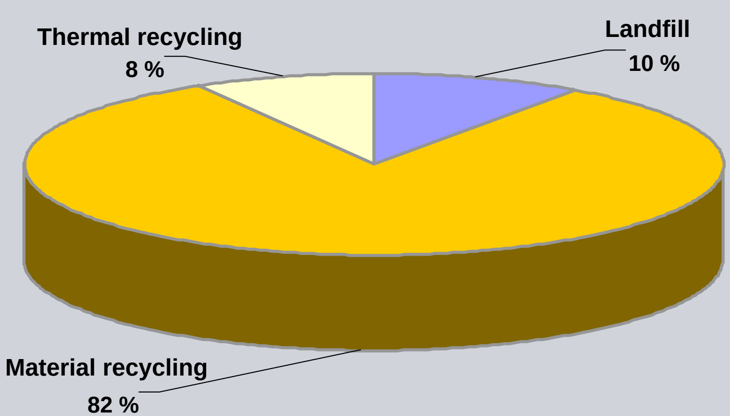
[1] Train weight with AW2 load =135 t; average value of summer and winter operation

Recycling behaviour of the metro train MX

Raw material	Energy consumption for recycling (MJ/kg)	Total energy consumption for material recycling (MJ)
Steel (low alloyed)	12 material[1]	168 000
Steel (high alloyed)	12 material[1]	444 000
Aluminium (50 % secondary)	2.5 material (Hamburger-Aluminium Werk GmbH)	77 500
Glass	9 material (Swiss Recycling) / 50 % thermal recycling	9 000
Copper	12 material[1]	36 000
Total		734 500

[1] Energy values from the *Department of Manufacturing Engineering, Technical University of Denmark, Lyngby, Denmark, 2000.*
The material percentage of the vehicle mass is derived from one car

The material use has been reduced to 82 % due to losses which are related to the material recycling technology.



Recycling rate = recyclable train mass / total train mass

Recycling rate = approx. 90 %

Ref.: Diploma Thesis, A. Kampenhuber, TU Vienna, 2006

Potentials for the optimisation of the system design. Energy-optimised speed profiles

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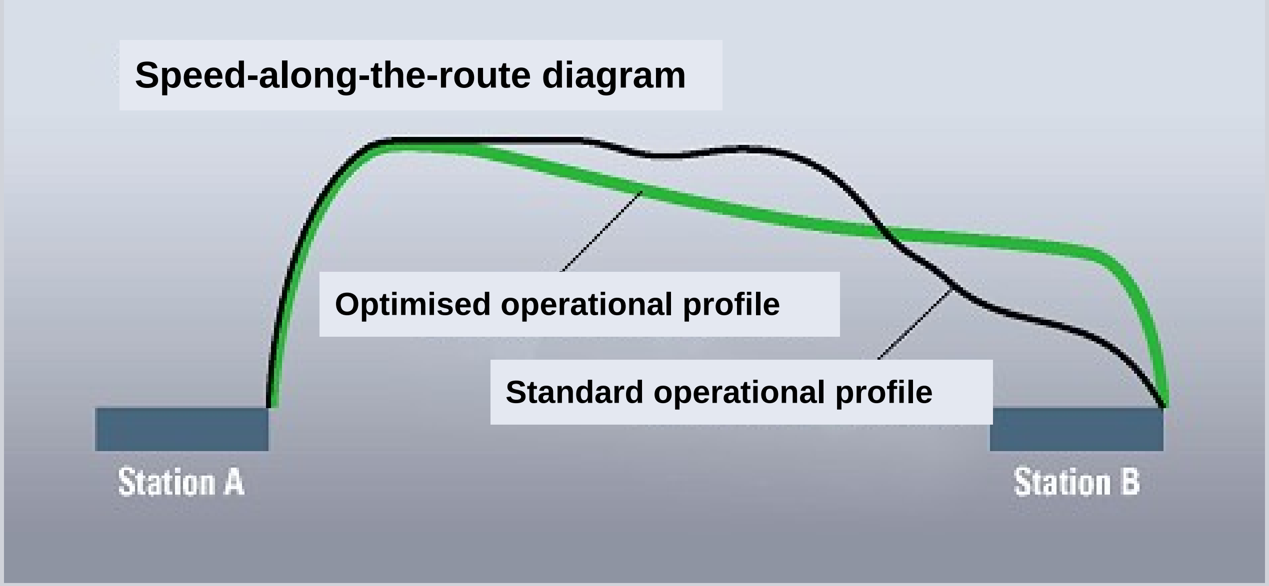

Example: distance = 490 m, travelling time = 53 s, stopping time = 15 s

	Travelling time	Stopping time	Energy consumption
Standard	48 s	20 s	6.0 MJ
Optimised	53 s	15 s	4.3 MJ

With this optimised speed profile an energy saving of up to 25 % would result.

Potentials for the optimisation of the system design. Automatic train operation

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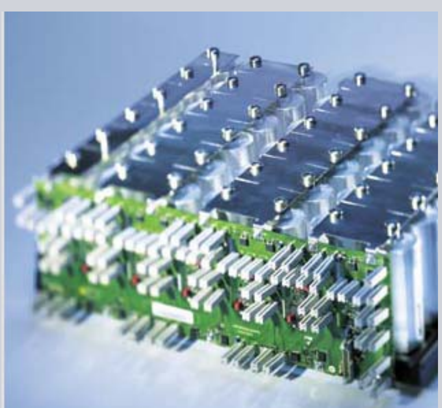
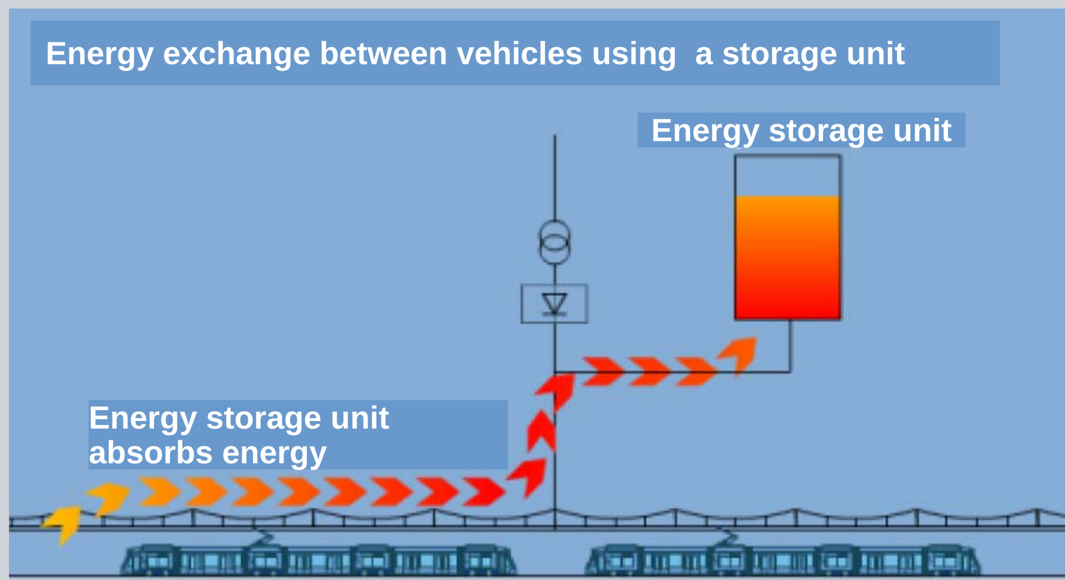
Benefits from an operational concept of an automated metro can be:

- Implementation of an optimised speed profile.
- Flexible adaptation of the transport capacity on demand.
- Higher line capacity due to shorter distances between trains.

Potentials for the optimisation of the system design. Energy storage with Sitras SES

- Optimised recovery of the braking energy of the vehicles
- Well balanced power consumption
- Stabilisation of traction voltage
- Reduction of power peaks
- References in Germany, Spain and in the United States





Potentials for the optimisation of the vehicle design.
Vehicle example: 3-car train for the Metro Kaohsiung

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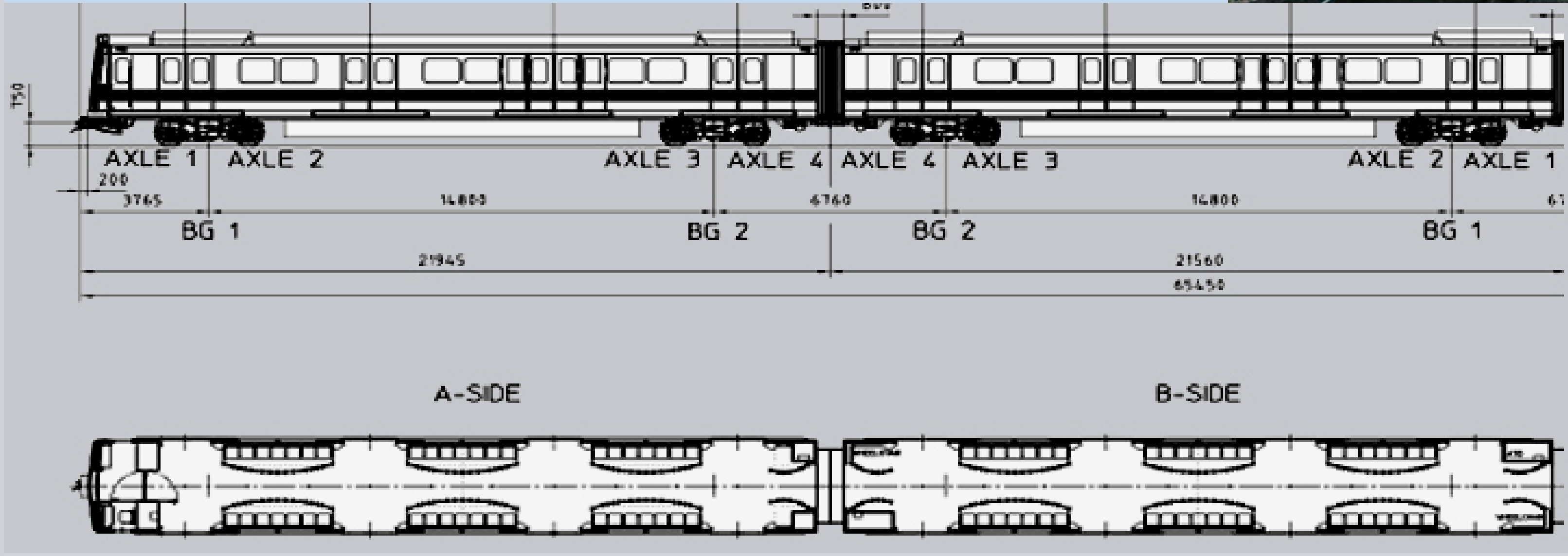
Train configuration: DM + T + DM
Car body material: stainless steel
Tara weight: 117.3 t

Max. axle load: 16.1 t
Length over couplers: 65.45 m
Width of car: 3.15 m
Number of seats: 126
Train capacity (6 pers. / m^2): 771 passengers



Potentials for the optimisation of the vehicle design. Comparison of vehicles in use (3-car trains)

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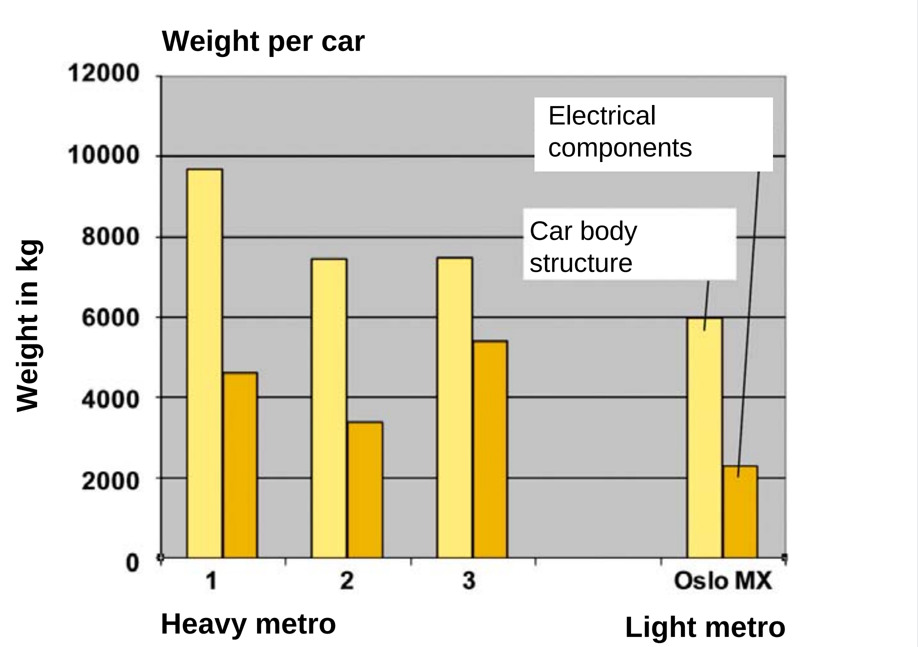
	1	2	3		Oslo
Car body material	Stainless steel	Aluminium profile, open	Aluminium profile, closed		Aluminium profile, closed
Tara weight [t]	117	107	109		100
Maximum speed [km/h]	80	90	120		70
Distance between bogies [m]	14.8	15.8	12.6		11.0

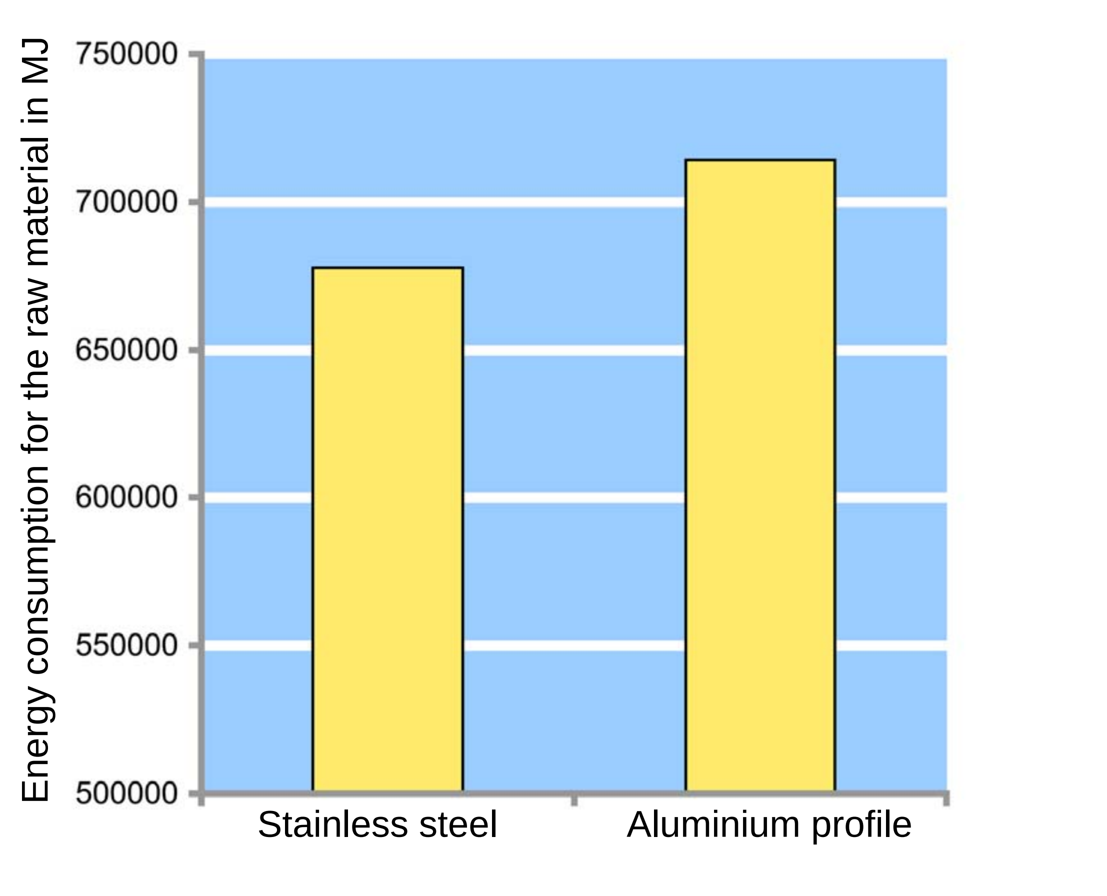


For the comparison of vehicles also the different requirements have to be considered (e.g. crashworthiness).

However, in general it can be stated that the material aluminium enables lighter car body structures.

In recent years GTO technology has been followed by IGBT converters for traction application. For the metro vehicle MX the use of IGBT technology leads to a remarkable weight reduction.

Potentials for the optimisation of the vehicle design. Examples of the energy consumption of raw materials



For the vehicles compared it can be stated:

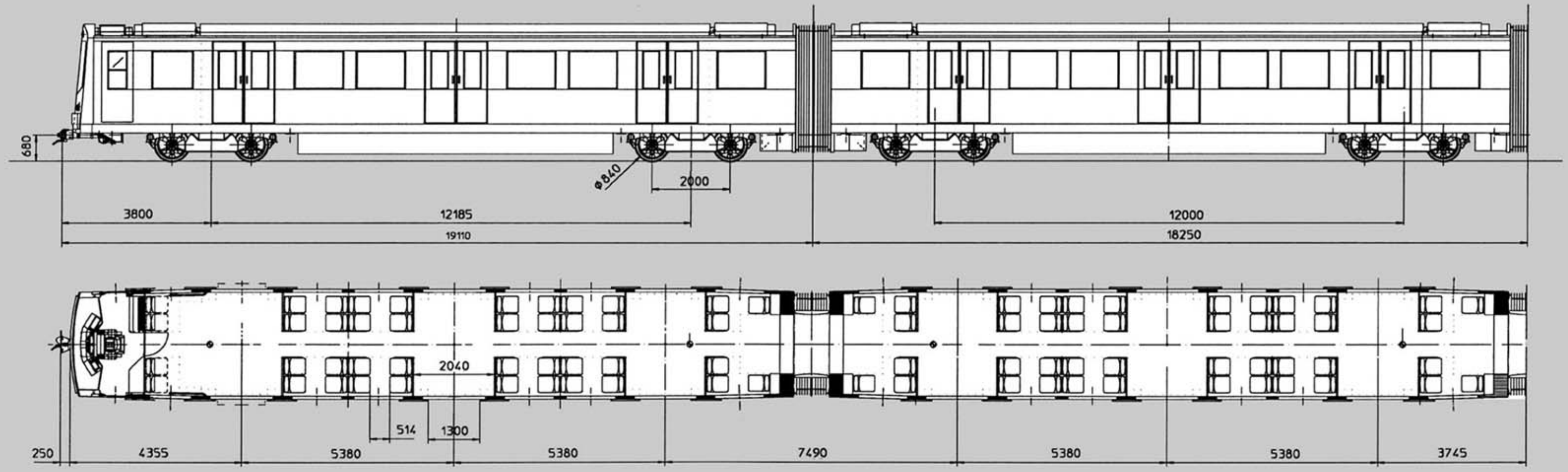
The raw material for car body structures made out of stainless steel is about 54 % more energy efficient compared to aluminium.

If secondary aluminium with a content of 50 % primary aluminium is used for the car body structure, this advantage of stainless steel is reduced to 5 % difference in energy consumption of raw materials.

Potentials for the optimisation of the vehicle design.
Vehicle example: 4-car train for the Vienna Underground

Train configuration: TR + MC + MC + TR
Car body material: aluminium
Tara weight: 109.2 t

Max. axle load: 11.5 t
Length over couplers: 74.72 m
Width of car: 2.85 m
Number of seats: 172
Train capacity (6 pers. / m^2): 782 passengers



Potentials for the optimisation of the vehicle design. Vehicle thermal insulation (1)

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Metro vehicles (stainless steel structure): calculated k-values

Metro vehicle	Heat transition coefficient [W/(m²K)]
Stainless steel, typical values	1.9 – 2.2
Kaohsiung	approx. 2

Potentials for the optimisation of the vehicle design. Vehicle thermal insulation (2)

Metro vehicles (aluminium structure): measured k-values (climatic wind tunnel)

Metro vehicle	Heat transition coefficient [W/(m²K)]
Aluminium, typical values	2.4 – 3.25
Oslo MX, measured	2.95

General statements:

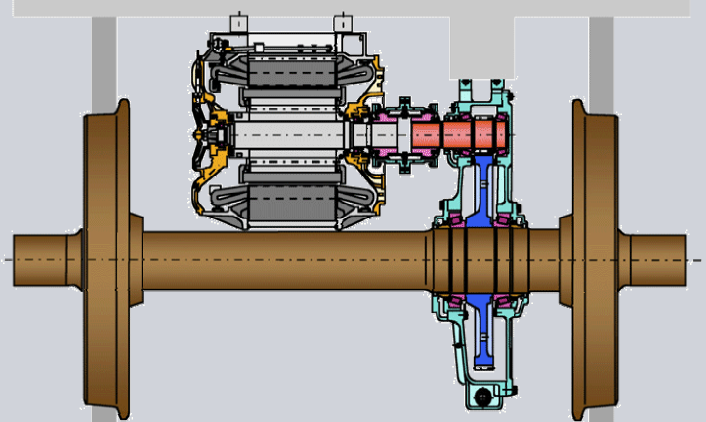
- The k-value of aluminium vehicles is higher than the k-value for vehicles made of stainless steel.
- Critical components: doors, windows, gangways between cars

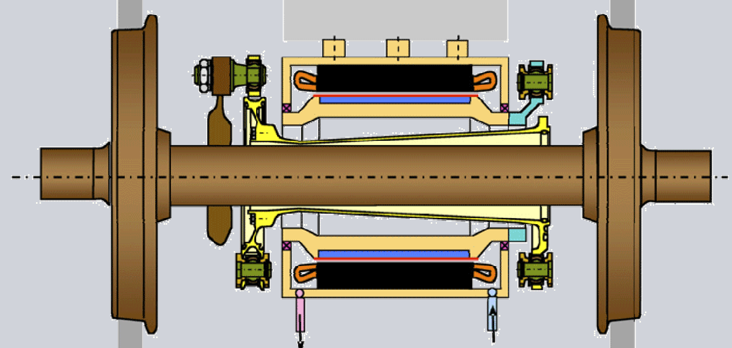
Source: Oslo Sporveier

Potentials for the optimisation of the vehicle design.
Direct motor

State-of-the-art
Asynchronous motor with gearbox

Innovation
Gearless permanent magnet motor





Efficiency factor	93 %
Mass	100 %
Noise	105 dB(A)
Gearbox	lubricated

Efficiency factor	96 %	
Mass	- 30 %	
	Motor	-10 %
	Gear / coupling	-20 %
Noise	90 dB(A)	
Gearbox	not necessary	

Conclusions

- Siemens products and solutions are distinguished by high energy efficiency, helping to protect both environment and health.

- We have set ourselves the target of designing, developing, manufacturing and operating our trains so as to protect the environment and human health to the highest possible extent.

- The stages of the energy life cycle and their share of the overall consumption have been given for the new metro vehicle MX for Oslo as an example. Environmental performance indicators for the metro train and its operation have been presented.

- Future potentials for the optimisation of the vehicle design and operational concept have been discussed.