Comparative analysis of energy efficiency for electric cars "Unibus" and "Tesla Model S"

1. Summary

Comparative analysis shows that unibus is the most efficient and ecologically clean electric car for public use in the world. In all variants of its alternate design, the unibus is minimum 6.2 times more efficient than, for example, electric car Tesla. Considering its optimal design variant — its efficiency is 17.8 times higher. In addition, in order to accelerate the unibus with the weight of 5 tons to the speed of 113.8 km/h, it requires the drive with capacity of just 27.7 kW (or 0.99 kW/pass.). In comparison, in order to accelerate Tesla, which is almost twice lighter, with the weight of 2,590 kg, it requires a 4.36 times more powerful engine — 120.8 kW (or 24.15 kW/pass., i.e. 24.4 times more than that of the unibus). Moreover, the unibus does not require braking (it is braked by aerodynamics and when moving uphill in a regular operation mode). Meanwhile, in order to brake Tesla, it is required to have brakes with capacity equal to -53.8 kW (see Table 1).

If energy consumption at movement is transferred for diesel fuel (based on 1 kWh = 0.25 kg of diesel fuel at operation of internal combustion engine), then energy consumption at city cycle with stops in every kilometer will be as follows:

— 5-seat Tesla Model S: 8.25 kg/100 km,
— 28-seat unibus: 2.6 kg/100 km.

Electric transport (including electric cars) currently only worsens global ecology. It actually replaces burning of fuel directly at the place of energy consumption with burning of 2.5 times more fuel in a remote location. It happens due to losses for conversion and delivery of energy (fuel to the power plant, and electricity to the vehicle). In any case, allegedly great environmental friendliness of electric vehicles today is an ungrounded misconception. Considering that internal combustion engines produce about four times more energy on the planet than all power plants of the world, then it is just simple ignorance.

There is a need for new transport and infrastructure innovations, based on other principles of efficiency. For example, if all urban public transport of the world is replaced with unibuses and not Tesla electric cars, annual energy savings (based on diesel fuel) in this case will amount to 623 million tons of fuel to the value of nearly a trillion dollars.

2. Comparative analysis

2.1 Choice of analogue

In order to compare energy efficiency of urban unibus, there was chosen automobile Tesla Model S — one of the best electric cars in the world. Unibus is driven by electric motors; therefore it is also an electric car. So, its comparison with Tesla will be meaningful and most suitable for analysis.

Initial data:

Parameter	Designation	Unibus	Tesla Model S
Mass, kg	m_a	5,000	2,590
Coefficient of aerodynamic drag	c_x	0.08 (according to test results in wind tunnel)	0.24
Frontal area (mid-section), m²	$A_в$	5.36 (design data)	2.34 (25.2 sq. feet)
Coefficient of wheel rolling resistance	f	0.003 (according to test results at site in Ozyory)	$f_0=0.015$ (at the speed up to 50 km/h), or $f=f_0(1+(0.006V_a)^2)$ (at the speed over 50 km/h)
Transmission gear ratio	U	1	9.73
Transmission efficiency factor	η	1 (transmission not available)	0.96
Coefficient of rolling friction (coupling with track)	μ	0.2 (according to test results at site in Ozyory)	0.5
Wheel radius, m	r_k	0.185	0.352 (245/45R17)
Traffic diagram		Sagging track structure between points at the same height	Straight-line horizontal motion
Ratio of track structure deflection at span		1:20	0
Maximal angle of ascent / descent	α	5.71° (1:10)	0°
Travel distance, m	S	1,000	
Acceleration at speeding-up / slowing at braking, m/s²	α	1.0/—1.0	
Number of passengers, people		28	5

The data on electric car Tesla Model S are taken from the following web-sites:

http://www.teslamotors.com/support/model-s-specifications
http://www.teslamotors.com/sites/default/files/blog_attachments/the-slipperiest-car-on-the-road.pdf
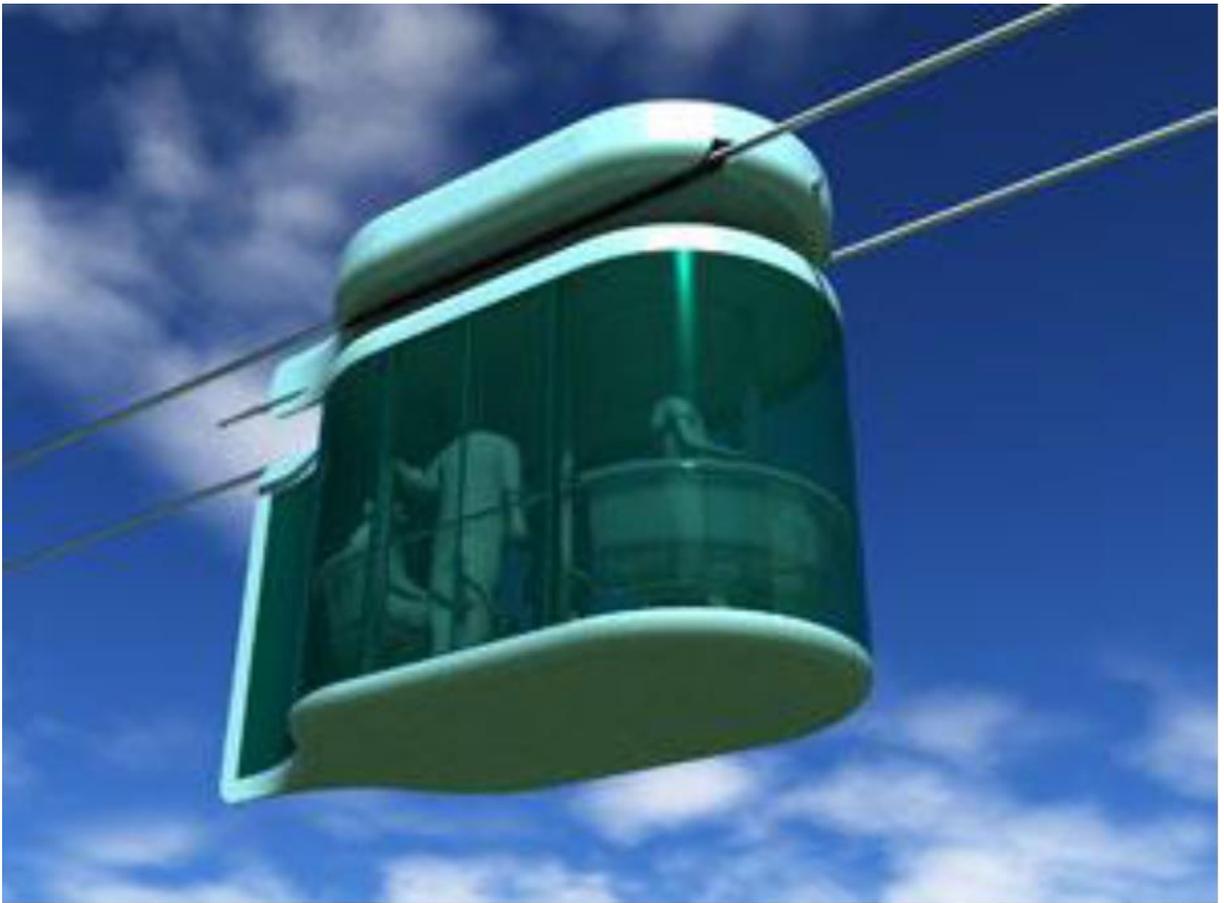http://catalog.drom.ru/tesla/model_s/80715

Fig. 1. Physical configuration of electric car "Unibus" (suspended variant)

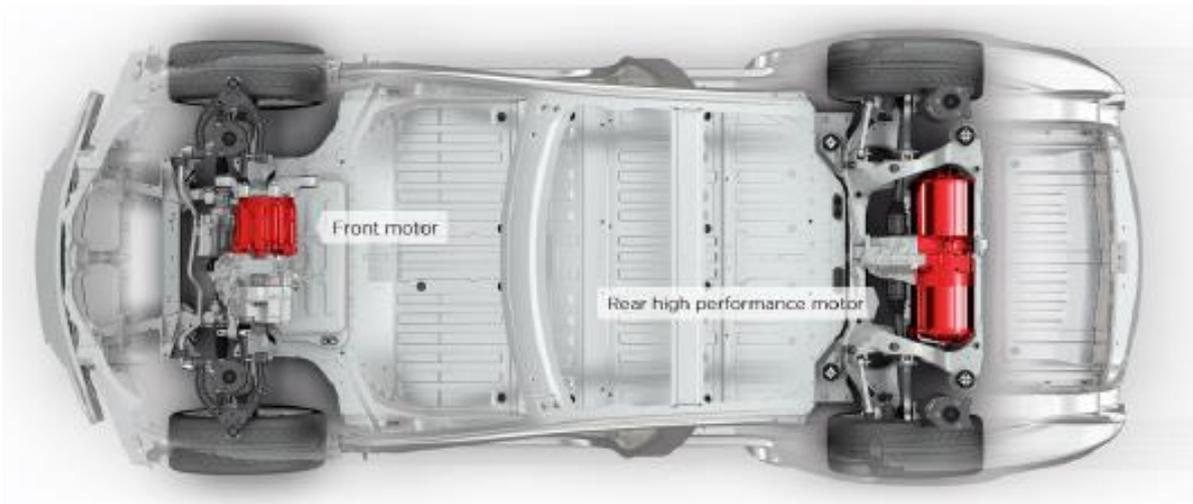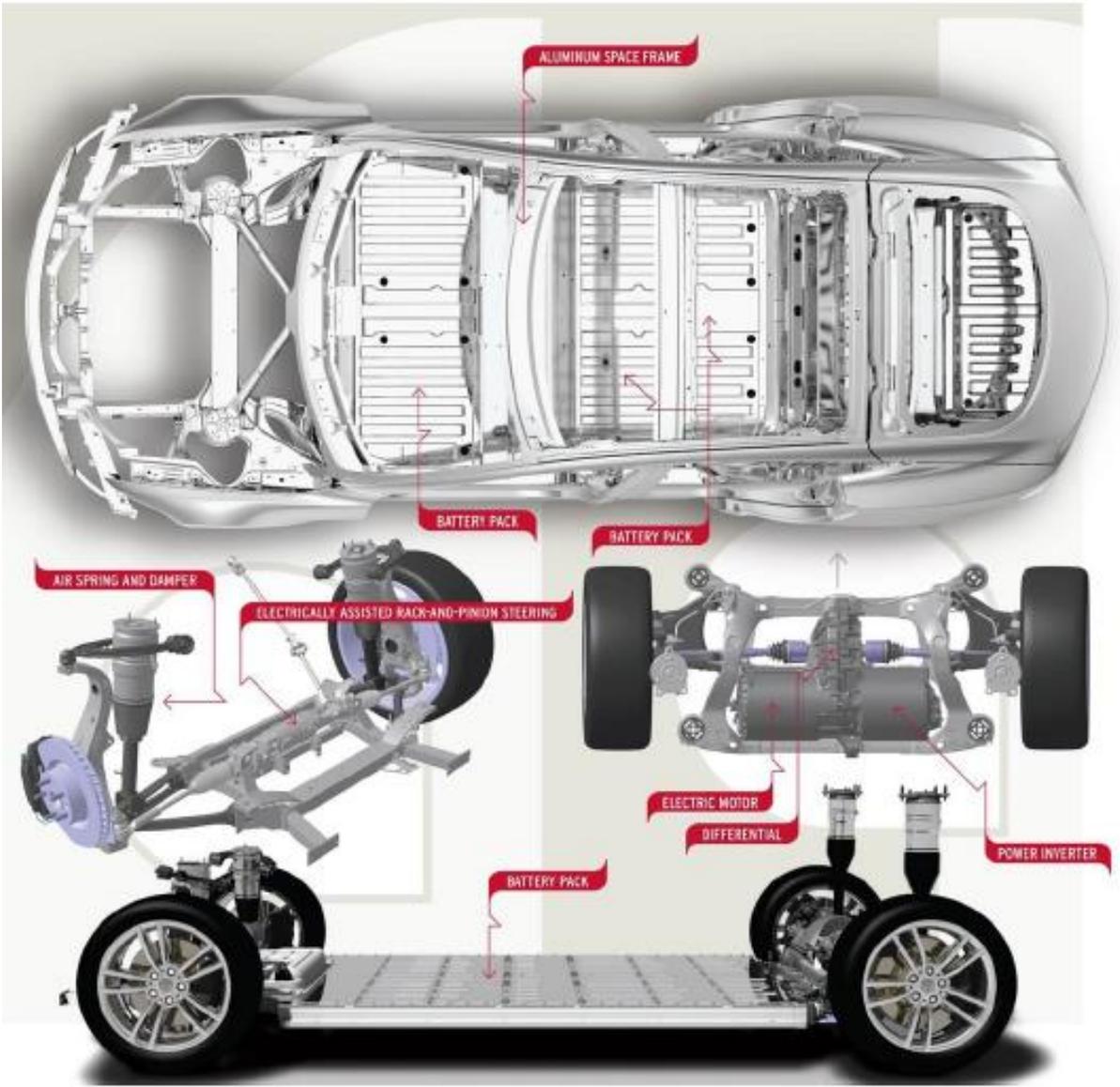Fig. 2. Urban station SkyWay combined with pedestrian crossing
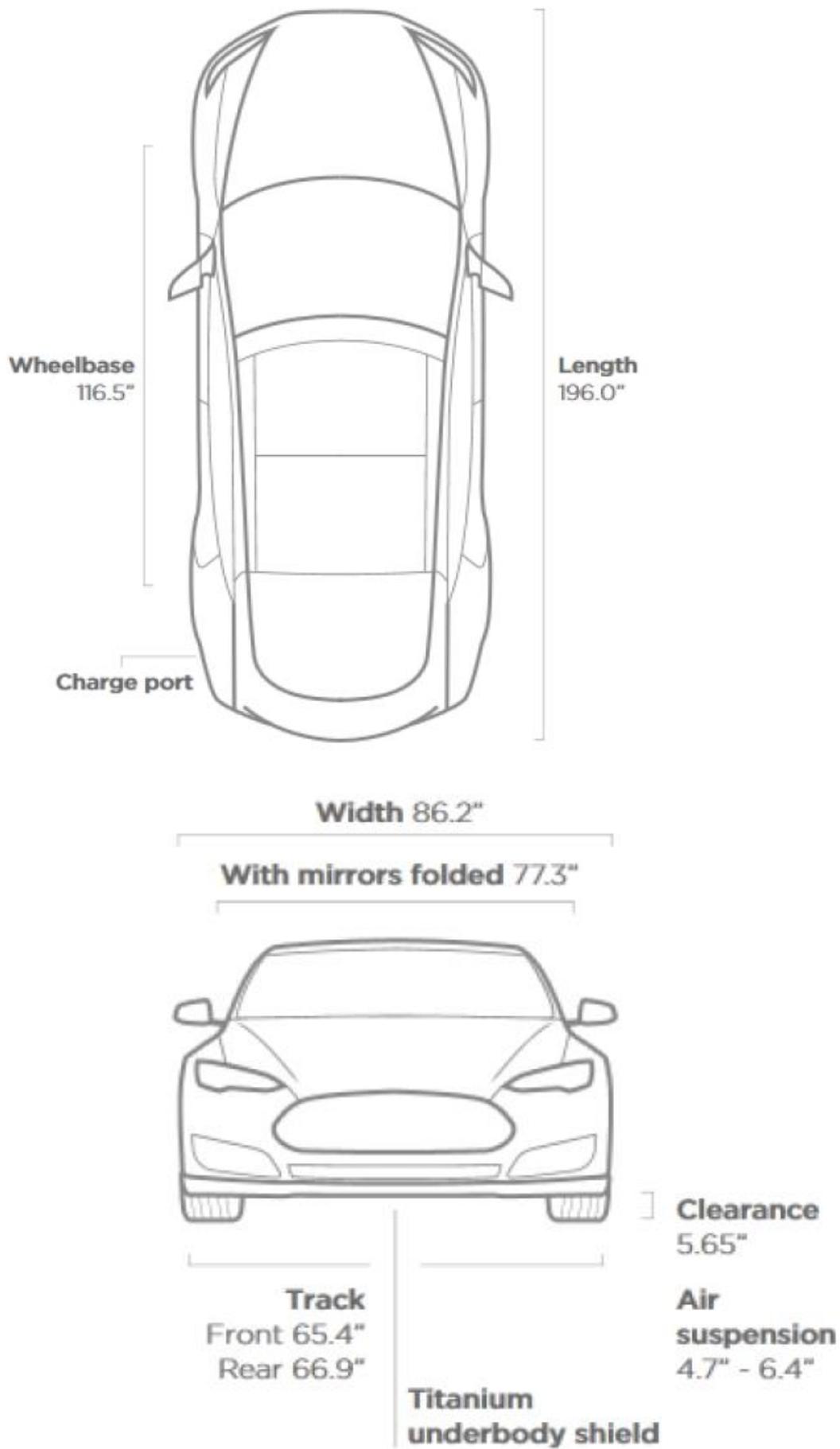
Fig. 3. Layout of electric car Tesla Model S

Fig. 4. General view of electric car Tesla Model S

2.2 Traction and dynamic analysis of electric cars

Traction balance

Traction balance formula is written as:

$$F_T = F_B + F_i + F_f + F_{aj},$$

Where F_T — traction force,
         F_B — air resistance force,
         F_i — grade resistance force,
         F_f — rolling resistance force,
         F_{aj} — resistance force to electric car acceleration.

Traction force (F_T)

Maximal force affecting the wheels depends on the weight falling on driving wheels and coupling coefficient between the wheel and rail (rail bed). The force is calculated on the following formula:

$$F_m = G_{сц} \cdot \mu,$$

Where $G_{сц}$ — electric car weight falling on all driving wheels (support reaction force);
         $G_{сц}$ — $m_{сц} \cdot g$; $m_{сц} = m_a \cdot g \cdot \cos\alpha$;
         m_α — electric car weight, kg;
         α — angle of ascent/descent, °; ρ
         g — free fall acceleration, equal to 9.81 m/s²;
         μ — coefficient of rolling friction.

The total turning torque on driving wheels is calculated on the following formula:

$$M_m = F_m \cdot r_k,$$

Where r_k — driving wheel radius, m.

Air resistance force (F_B)

Air resistance force significantly influences the traction and speed characteristics of electric car, especially at high motion speed. The main component of air resistance force is frontal resistance. Frontal resistance, basically, determines horsepower input at high speeds. Frontal resistance force is calculated as follows:

$$F_в = C_x \cdot \rho \cdot \frac{v^2}{2} \cdot A_в ,$$

Where C_x — frontal resistance coefficient (stream-lining coefficient);
         ρ — air density, equal to 1.2041 kg/m³ at temperature of 20°C;
         V — relative motion speed for air and electric car, m/s;
         $A_в$ — frontal area of the body (mid-section), m².

Grade resistance force (F_i)
Grade resistance force is calculated as follows:

$$F_i = G_a \cdot \sin\alpha ,$$

Where G_α — electric car weight, H, $G_\alpha = m_\alpha \, {}^*g$;

Rolling resistance force (F_f)
Wheel rolling resistance force is calculated on the following formula:

$$F_f = f \cdot G_a ,$$

Where f — rolling resistance coefficient.

Resistance force to acceleration (F_{aj})
Resistance force to forward acceleration of electric car is the force of its inertia

$$F_{aj} = \delta \cdot m_a \cdot \frac{dv}{dt},$$

Where δ — rotational inertia coefficient;
         $\delta = 1.07 — 1.11$, suppose $\delta = 1.07$.

2.3 Carrying out calculations

Traction force and air resistance force at the given motion speed depend on electric car design. The difference between traction force and air resistance force is free traction force, which can be used to overcome resistance forces of the road and automobile acceleration. At constant acceleration with speeding-up of 1.0 m/s^2 and constant braking with slowing of 1.0 m/s^2 at the track length of 1,000 m, the speeding-up path will make 500 m and the braking path will also make 500 m.

Maximal motion speed and speeding-up time can be determined based on the following formula:

$$V = a \cdot t, \ S = at^2 / 2.$$

The speeding-up time will make 31.6 s.

Maximal motion speed will make 31.6 m/s = 113.8 km/h.

Time for braking with slowing -1.0 m/s^2 will make 31.6 s.

When speeding up, it is necessary to select the turning torque required for electric car speeding-up with acceleration of 1.0 m/s^2. Similarly, when braking, it is necessary to select the torque for electric car slowing with acceleration of -1.0 m/s^2.

The results of traction and dynamic calculations, based on the basic comparison variant described above, are given in Table 1. The results of calculations for energy losses, based on the basic comparison variant, are given in Table 2.

The traffic diagram for the unibus along the sagging track structure is given in Fig. 1.

When calculating energy losses for automobile Tesla, it is necessary to take into consideration energy recuperation. The recuperated energy at braking makes 60% of the energy produced at electro-magnetic braking by electric motors.
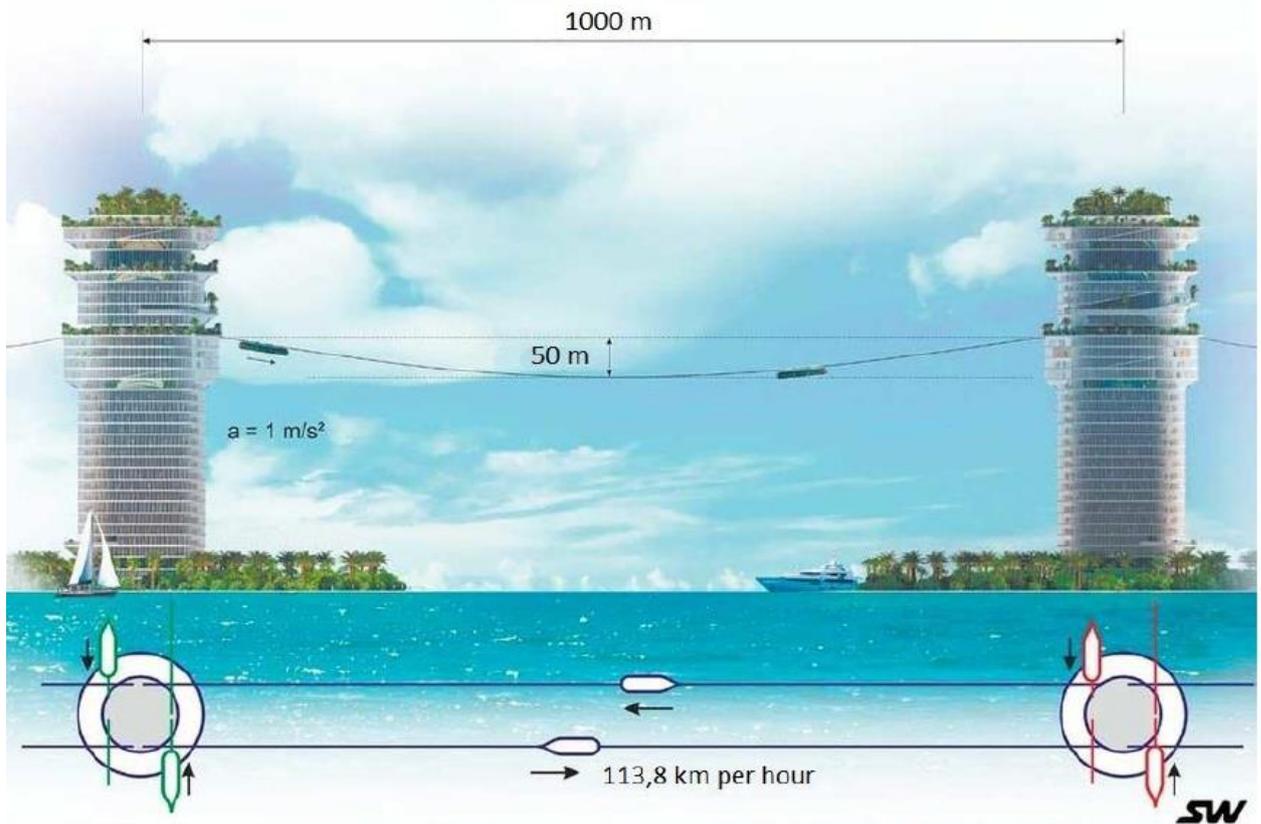
Fig. 5. Traffic diagram for suspended unibus along sagging track structure

For a more vivid analysis, we will also carry out a comparative calculation of the unibus and automobile Tesla Model S, having the same characteristics.

Variant 1 ("Unibus — as Tesla")

Unibus mass is equal to Tesla mass and makes 2,590 kg.
Unibus mid-section is equal to Tesla mid-section and makes 2.34 m^2.
The number of passengers is the same — 5 persons.
The calculations shall be carried out on the formulas specified above.
The results of traction and dynamic calculations are given in Table 3.
The results of calculations for energy losses are given in Table 4.

Variant 2 ("Tesla — as unibus")

Tesla mass is equal to unibus mass and makes 5,000 kg.
Tesla mid-section is equal to unibus mid-section and makes 5.36 m^2.
The number of passengers is the same — 28 persons.
The calculations shall be carried out on the formulas specified above.
The results of traction and dynamic calculations are given in Table 5.
The results of calculations for energy losses are given in Table 6.

Table 1

Data of comparative traction and dynamic calculation on basic variant

Parameter	Distance, m	Max speed, m/s (km/h)	Turning torque on wheels at acceleration, N•m	Turning torque on wheels at braking, N•m	Max power at acceleration, kW	Max power at braking, kW
Unibus (5 t, 28 pass.)	1,000	31.6 (113.8)	115—162	0	27.7	0
Tesla Model S (2.59 t, 5 pass.)			1,110—1,292	-624…-805	120.8	-53.8

Table 2

Energy losses on basic variant

Parameter	Distance, m	Travel time, s	Max speed, m/s (km/h)	Average speed, m/s (km/h)	Energy consumption at acceleration, kW•h	Energy consumption/ recovery at braking, kW•h	Energy consumption at movement, kW•h	Energy consumption at movement for 1 passenger, kW•h
Unibus (5 t, 28 pass.)	1,000	63.2	31.6 (113.8)	15.8 (56.9)	0.104	0	0.104	0.0037
Tesla Model S (2.59 t, 5 pass.)					0.493	0.163	0.33	0.066
Unibus energy efficiency compared to that of automobile Tesla Model S, times (%)					4.74 (474%)	—	3.17 (317%)	17.8 (1,780%)

Table 3
Data of traction and dynamic calculation on Variant 1 ("Unibus — as Tesla")

Parameter	Distance, m	Max speed, m/s (km/h)	Turning torque on wheels at acceleration, N•m	Turning torque on wheels at braking, N•m	Max power at acceleration, kW	Max power at braking, kW
Unibus (2.59 t, 5 pass.)	1,000	31.6 (113.8)	59—80	0	13.7	0
Tesla Model S (2.59 t, 5 pass.)			1,110—1,292	-624…-805	120.8	-53.8

Table 4

Energy losses on Variant 1 ("Unibus — as Tesla")

Parameter	Distance, m	Travel time, s	Max speed, m/s (km/h)	Average speed, m/s (km/h)	Energy consumption at acceleration, kW•h	Energy consumption/ recovery at braking, kW•h	Energy consumption at movement, kW•h	Energy consumption at movement for 1 passenger, kW•h
Unibus (2.59 t, 5 pass.)	1,000	63.2	31.6 (113.8)	15.8 (56.9)	0.053	0	0.053	0.0106
Tesla Model S (2.59 t, 5 pass.)					0.493	0.163	0.330	0.066
Unibus energy efficiency compared to that of automobile Tesla Model S, times (%)					9.3 (930%)	—	6.23 (623%)	6.23 (623%)

Table 5

Data of traction and dynamic calculation on Variant 2 ("Tesla — as unibus")

Parameter	Distance, m	Max speed, m/s (km/h)	Turning torque on wheels at acceleration, N•m	Turning torque on wheels at braking, N•m	Max power at acceleration, kW	Max power at braking, kW
Unibus (5 t, 28 pass.)	1,000	31.6 (113.8)	115—162	0	27.7	0
Tesla Model S (5 t, 28 pass.)			2,143—2,536	-1,161…-1,554	237.1	-100.1

Table 6

Energy losses on Variant 2 ("Tesla — as unibus")

Parameter	Distance, m	Travel time, s	Max speed, m/s (km/h)	Average speed, m/s (km/h)	Energy consumption at acceleration, kW•h	Energy consumption/ recovery at braking, kW•h	Energy consumption at movement, kW•h	Energy consumption at movement for 1 passenger, kW•h
Unibus (5 t, 28 pass.)	1,000	63.2	31.6 (113.8)	15.8 (56.9)	0.104	0	0.104	0.0037
Tesla Model S (5 t, 28 pass.)					0.960	0.308	0.652	0.0232
Unibus energy efficiency compared to that of automobile Tesla Model S, times (%)					9.23 (923%)	—	6.27 (627%)	6.27 627%)

2.4 Comparative analysis of electric cars

On the basis of the calculations above, it is clear that having identical dimension and weight parameters ("Unibus — as Tesla", or "Tesla — as unibus"), the unibus is 6.23—6.27 times more efficient than automobile Tesla Model S (see Tables 4, 6). The reason for this is the use of steel wheels with a lower rolling resistance coefficient, as well as a more aerodynamic shape of the unibus. Another reason is the application of physical laws — gravitation, or gravity drive — as energy recuperator. In fact, at the leg of the route between the stations with a sagging track structure (see Fig. 5), half of the way — when going downhill — the unibus is accelerated, apart from the drive, due to gravitation. When going uphill — it is braked, basically, due to gravitation. In this case, kinetic energy of movement is transformed into potential energy of ascent to the station with efficiency factor of 100%.

When considering a real automobile Tesla Model S and electric car "Unibus", the unibus efficiency compared to Tesla reaches 17.8 times (see Table 2). Such efficiency is explained, as mentioned above, by the use of steel wheels with a lower rolling resistance coefficient, a more aerodynamic shape of the unibus, application of physical laws (gravitation) as energy recuperator, as well as a more rational use of vehicle mass and its passenger capacity.

Apart from that, it shall be noted that for acceleration of the unibus with the weight of 5 tons to the speed of 113.8 km/h, it requires the drive with capacity of just 27.7 kW (or 0.99 kW/pass.). In comparison, for automobile Tesla, which is almost twice lighter, with the weight of 2,590 kg, it requires a 4.36 times more powerful engine — 120.8 kW (or 24.15 kW/pass., i.e. 24.4 times more than that of the unibus). Moreover, the unibus does not require braking (it is braked by aerodynamics and when moving uphill in a regular operation mode). Meanwhile, in order to brake Tesla, it is required to have brakes with capacity equal to -53.8 kW (see Table 1).

In addition, the required turning torque on unibus wheels at acceleration to the same speeds (with the weight twice heavier) is 8—9 times less than that of Tesla (115—162 N•m). It significantly simplifies the electric car drive and reduces its price. Further, the turning torque on unibus wheels at braking is equal to zero (which proves that it does not need brakes in a normal operation mode). In comparison, Tesla, which is almost twice lighter, needs powerful brakes, which create the turning torque equal to -624…-805 N•m (see Table 1).

Thus, it is possible to state that unibus is the most cost-efficient electric car for public use in the world. In all variants of its alternate design, the unibus is minimum 6.2 times more efficient than, for example, electric car Tesla. Considering its optimal design variant — its efficiency is 17.8 times higher.

If energy consumption at movement is transferred for diesel fuel (based on 1 kWh = 0.25 kg of diesel fuel at operation of internal combustion engine), then energy consumption at city cycle with stops in every kilometer will be as follows:

— 5-seat Tesla Model S: 0.33 kWh x 100 km x 0.25 kg/kWh = 8.25 kg/100 km,

— 28-seat unibus: 0.104 kWh/km x 100 km x 0.25 kg/kWh = 2.6 kg/100 km.

Urban passenger vehicle fleet can be replaced with either automobiles Tesla, or unibuses. At equal volume of passenger transportation, environmental impact with the second variant will be (8.25 kg/2.6 kg) x (28 pass./5 pass.) = 17.8 times lower. This proves immense advantages of unibuses over best world analogues once again.

3. Large-scale factor for implementation of most efficient electric car — unibus

According to the data of International Energy Agency, at present passenger flow in public transport of the world has a level of 40 trillion passenger-kilometer, with the average travel distance of about 10 km. In other words, about 4 trillion passenger trips on public urban transport take place annually. (see https://www.iea.org/media/workshops/2013/egrdmobility/DULAC_23052013.pdf).

If all public transport of the world is replaced with unibuses and not Tesla electric cars, energy savings (based on diesel fuel) in this case will amount to:
(0.066 – 0.0037) kWh/km x 0.25 kg/kWh x 40,000,000,000,000 km/year = 623,000,000,000 kg/year = 623 mln tons of fuel annually.

4. All truth about electrified transport

At the very beginning of electrified transport energy chain there is a heat power station, which converts heat energy of fossil fuel — coal, black oil fuel, gas, peat, nuclear fuel, etc. — into electricity. Conversion takes place with the efficiency factor, which reaches only 40% — due to the same thermodynamic reasons as in internal combustion engine (since the temperatures of fuel burning are the same, as well as refrigerant temperatures).

However, until electric energy reaches the wheel, which actually sets the vehicle into motion, in chain order: "step-up substation — high-voltage power line for thousands of kilometers — step-down high-voltage substation — electric power line — traction substation — contact system — on-board converters and electrical network — electric motor coils — reducing gear — wheel", passing through numerous switching devices and converters on its way, not more than 40% of it is left for useful mechanical work, just about as much as in a heat power station itself. Then, total efficiency factor (in relation to fuel) of electric transport will be as follows: 0.4 x 0.4 = 0.16, or 16% — as a modern locomotive has.

Electric transport without contact system looks not much better. It has energy storage units, being in fact on-board accumulator batteries. They have to be taken on board, although they are not effective load. In addition, a charging station with a rectifier will take its "tax", and efficiency factor cannot boast of its great value with accumulators being charged. A situation with energy recuperation at electric car braking in urban

conditions is similar — not more than 60% of energy will return to mechanical work again.

 A usual bus (automobile) has a different, much shorter energy chain. It is an internal combustion engine, which directly converts heat energy of fossil fuel — petrol, diesel fuel, gas, etc. — into mechanical energy of the vehicle directly on its board during motion.

Thus, at the end of both chains is mechanical energy of vehicle motion, and at the beginning — energy of fossil fuel. In this connection, "useful effect" is final mechanical energy of transport service (transfer of passengers and cargo). By the way, polluting emissions and ecological problems are directly proportional to the mass of burnt fossil fuel. Therefore, electrified transport is approximately 2.5 times more dangerous for the environment than a traditional automobile. Obviously, by environment we mean global ecology and not local interests of city dwellers.

In other words, currently electric transport only worsens the global environment. In fact, it replaces burning of fuel directly at the place of energy consumption with burning of fuel in a remote location, which only increases losses for delivery of energy (fuel to the power plant, and electricity to the vehicle). In any case, an allegedly greater environmental friendliness of electric vehicles today is an unfounded misconception. Given the fact that internal combustion engines produce about four times more energy on the planet than all power plants of the world, taken together, it is also mere ignorance.

It means that the mother of all questions is simple: "What is more reasonable — burning of fossil fuel directly in internal combustion engine on vehicle board or a 2.5 times bigger amount of fuel, burnt at the distant heat power plant thousands of kilometers away to get the same mechanical energy — transport service — at the output?"

Therefore, there is no point in setting high hopes on a production electric car or an automobile, whose operation would be based on the use of this or that kind of energy storage unit — whether it is an electrochemical battery, condenser or super-flywheel — since no revolution in energy industry is able to provide the amount of energy that is now generated in internal combustion engines of automobiles. It means that automobiles with self-contained engines will continue to serve us for a long time. In case automobiles become hybrid, it does not make any sense in replacing them with electric cars using accumulator batteries — the former are more efficient and ecologically friendlier than the latter.

The situation can change only in case if there will be discovered a large-scale way for ecologically clean production of electric energy, able to completely meet the requirements of humanity. Another way is passing to a fundamentally different kind of transport, which consumes by times less energy. That is — SkyWay.

5. What shall be done?

Based on the analysis above, it follows that transfer of transport to electrical drive not only fails to solve global problems of humanity, but just increases them. New transport and infrastructure innovations, based on different efficiency principles, are necessary.

According to thermodynamics laws, any mechanical work changes into heat in the end. Any ground transport on the planet moves practically horizontally — stations of departure and destination are at the same height. As passenger flow in any closed transport network is the same in both directions, useful transport operation in these conditions is equal to zero. The reason is that energy component of cargo (passengers) does not change with time — the height of useful load allocation above the sea level does not change (consequently, potential energy is unchanged, either). Their speed in relation to ground surface at stations of departure and destination does not change and is equal to zero (it means that kinetic energy is also unchanged). Therefore, any ground transport does not make useful transport operation — it is always equal to zero. All energy for movement, all burnt fuel in internal combustion engines and in furnaces of heat power stations goes to fight with the environment and destroy it, as the Nature resists this movement. More specifically, as follows:

1) A bigger part of energy goes to heat and pollute the environment even before mechanical energy is received, as efficiency factor for conversion of heat energy into mechanical one in transport is less than 50%. In addition, energy losses for heating in traditional automobile transport make 100% - 40% = 60%, and in electrified transport (considering the whole energy chain): 100% - 16% = 84%.

2) Transport efficiency can be improved only by means of decreasing resistance to motion, as well as reducing all losses — that is, in fact, environmental improvement. In the first place, it is necessary to improve vehicle aerodynamics (for example, at high-speed motion of a wheeled vehicle, over 90% of consumed energy goes to aerodynamics). Secondly, it is necessary to improve rolling of a steel wheel (wheel with contact "steel — steel" has efficiency factor of 99.8%, which is significantly more efficient than magnetic levitation and pneumatic wheel).

Thus, optimization of any transport system (and SkyWay is not an exception here) shall include the following:

1) improvement of high-speed aerodynamics and elimination of all protruding elements on the body — a vehicle shall be carried out in the form of a "wingless plane";
2) elimination of shield under the vehicle bottom, which improves aerodynamics twofold;
3) use of propelling device in the form of pair "steel wheel — steel rail", which is by times more efficient than pairs "pneumatic tire — asphalt" and "magnetic cushion — linear electric motor";

4) improvement of steel wheel support onto rail compared to traditional railway, particularly, elimination of a wheel pair and wheel taper;
5) elimination of reducing gear and application of motorized wheel;
6) obligatory recuperation of motion energy at braking;
7) use of gravity engine at acceleration and gravity brake at vehicle braking;
8) reduction in parasitic weight of the vehicle up to 150—200 kg/pass.

SkyWay technologies are developing exactly on this way of rolling stock perfection. Meanwhile, transfer of transport to electric traction, as many analysts and futurists view it, will not only fail to solve local and global problems of humanity, but just aggravate them.

Only SkyWay technologies can solve both energetic and ecological transport and infrastructure challenges, which humanity faces nowadays, in the most efficient way.