



The operational experience of an ultracapacitor e-bus - a fast-charging fully electric alternative for city transport

THE FUTURE OF URBAN TRANSPORTATION

No range limit. No pollution. No batteries



About the company



Chariot Motors together with **Aowei Technology** have developed the first ever electric bus, powered solely by an ultracapacitor (**Chariot e-bus**), to be used for commercial operation in Europe.



Chariot e-bus is purely ultracapacitor (UC)-based city e-bus that deploys the latest electric drive and world's most advanced ultracapacitor technology by Aowei. **Chariot e-bus** is assembled at a special high quality production line at one of the world's biggest bus factories by Higer Bus Company Limited, characterized with more than 17,000 electric and hybrid buses produced per year.



Chariot e-bus is a silent, low-cost vehicle with zero-emissions, which complies with the European homologation certifications, the strict market requirements in EU, including the ECE R100 standard for energy storage devices.

Chariot e-bus



SIEMENS



WABCO



E-bus set up and pantograph fast-charging



Charging station, 660V DC to 585V DC



Charging poles



Ultracapacitor



Pantograph during charging



Charging stations

150 kW DC/DC (Belgrade project)

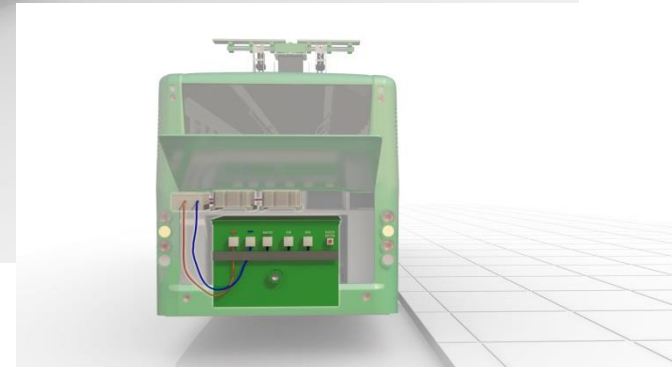
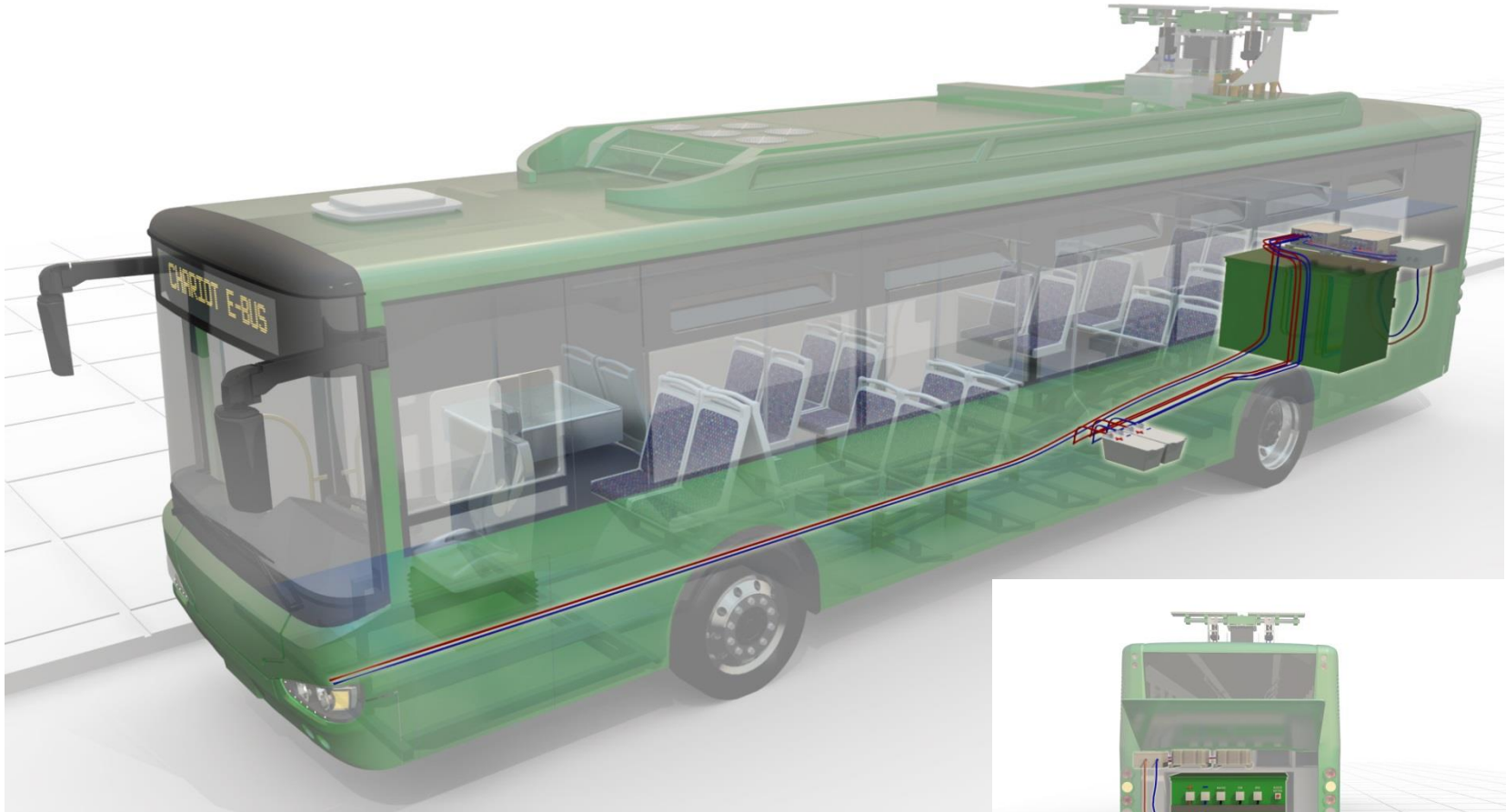


340 kW AC/DC (Graz project)



Ultracapacitor electric bus – general view

- Ultracapacitor location



Ultracapacitor technology – short summary



S672V66-K12 Ultra capacitor system specification (50 kWh) (9P168S)	
Project	Parameters
Type	S672V66-K12
Connection Type	9P168S
Nominal Capacity (F)	1680
Operating Voltage Window (V)	470~672
Surge Voltage (V)	706
Stored Energy (kWh)	54±5%
Standard Charge Current (A)	500
Standard Discharge Current (A)	500
Maximum Charge/Discharge Current (<20s) (A)	790 (20s)
Storage Temperature (°C)	-30~ +65
Protection level	IP67
Electric Property	Overvoltage, Overcurrent, Overheat, Overload, Short circuit, DC leakage protection, etc
Capacitor Management System	Automatic balance, Voltage monitor, Temperature monitor, DC leakage monitor, etc
Cooling Mode	Air-conditioner cooling
Communication Interface	CAN

Main features:

- ☐ Operating within a broad temperature range: - 30° C up to + 55° C;
- ☐ Explosion- and impact-protected containment tank;
- ☐ As per BELICON institute study the average recuperation is 32.2%, reaching up to a maximum of 39%;
- ☐ Very fast charging time (10C);
- ☐ Manufacturing warranty of 8 years, that could be extended to 10 years;
- ☐ No toxic and/or hazardous substances and simplified disposal process;
- ☐ Limited range with one charge;
- ☐ Fast-charging at terminals only, however still needs to be compliant with the driving schedule of the line;
- ☐ No overnight charging/balancing required.

Results from an independent validation by BELICON

Chariot e-bus performance

Date	08.10.14						
Status	Journey 1	Journey 2	Journey 3	Journey 4	Journey 5	6-8	Daily statement
Measuring Point	Measuring Point2: Ultra-Caps						
P _{max} discharging / kW	-140.6	-150.5	-149.7	-150.6	-147.7	...	-147.6
P _{max} charging / kW	103.6	109.5	110.0	108.0	111.8	...	107.0
E _{Supercap Output} / kWh	-15.51	-18.17	-15.58	-18.05	-13.54	...	-125.34
E _{Supercap Recording} / kWh	5.75	6.40	5.98	6.17	5.09	...	40.8
Δ Energie _{Supercap} / kWh	-9.76	-11.77	-9.60	-11.88	-8.45	...	-84.6
E _{Pantograph charging} / kWh	13.42	13.30	11.53	13.12	9.13	...	99.5
Time / min	41.0	45.0	38.0	47.7	36.3	...	5h 26min
Route length / km	10.8	11.8	10.8	11.8	10.9	...	88.7
Recuperation / %	37.1	35.2	38.4	34.2	37.6	...	32.2
Consumption / kWh/km	0.91	1.00	0.89	1.01	0.78	...	0.95
Consumption / kWh/min	0.24	0.26	0.25	0.25	0.23	...	0.26

Chariot e-buses on the map



5 UC **Chariot e-buses** in commercial operation by GSP Belgrade since 1st Sep 2016.



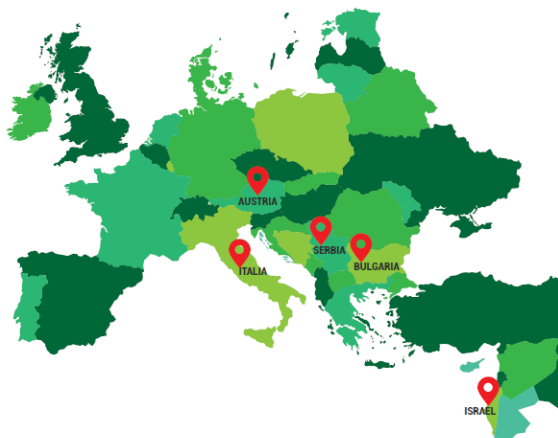
26 UC **Chariot e-buses** in operation by DAN, Tel Aviv as per the end of 2017 with another 100 UC buses agreed to be delivered in 2018 and 2019.



2 UC **Chariot e-buses** in operation by Holding Graz Linien, Austria since April 2017.



1 UC **Chariot e-bus** in operation in Italy since March 2018.

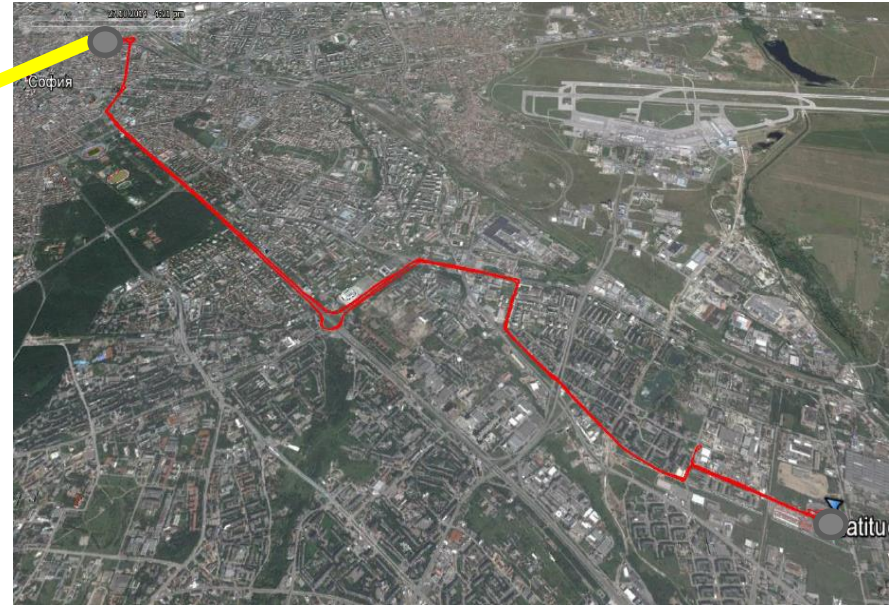


1 UC **Chariot e-bus** in operation in Macedonia as a pilot project since April 2018.

1 UC **Chariot e-bus** in operation in Bulgaria as a pilot project in 2014-2016.

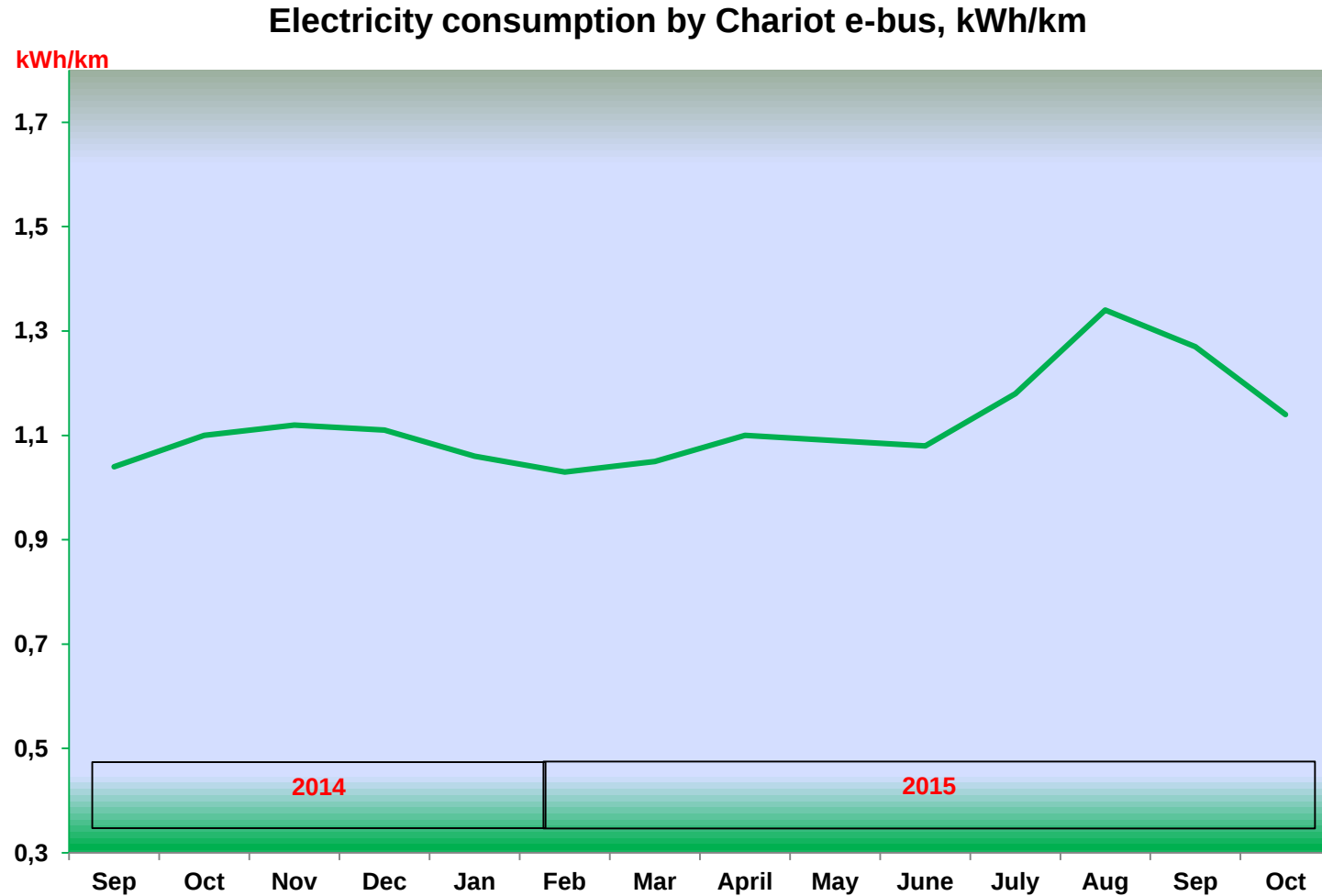
**Bulgaria,
various cities**

UC Chariot e-bus in Sofia example 2014-2015



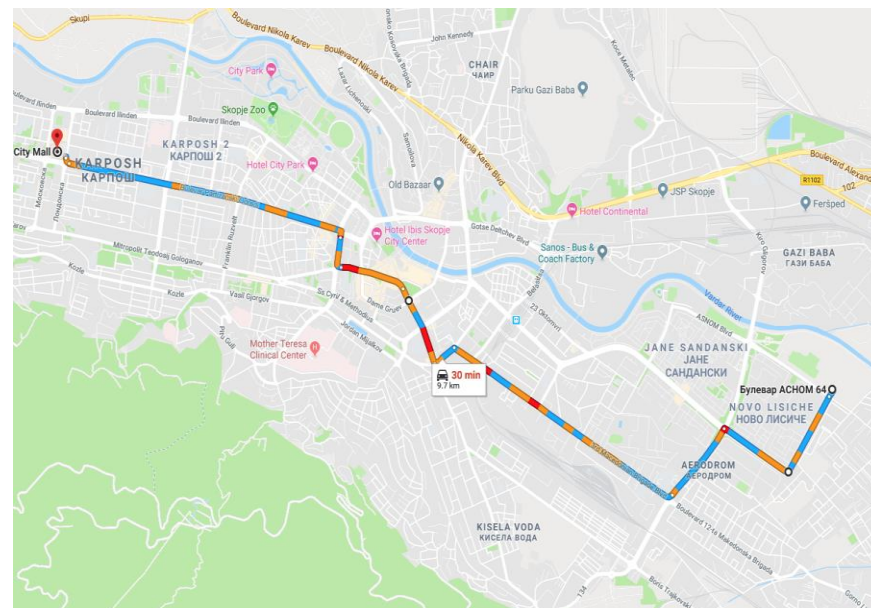
- Operated and maintained by the Stolichen Elektrotransport;
- Line № 11 (trolleybus line) -> flat profile, length of 11.2 km, crossing;
- DC/DC charging stations at terminals only, using trolleybus power supply;
- Average energy consumption, recorded by BELICON: 0.95 kWh/km (no auxiliary consummators);
- Recuperation rate: 32.2 %, highest 39%;
- Operating temperatures: -15°C to 40°C;
- Siemens electric motors, 2 x 67 kW.

Consumption in Sofia 2014-2015 (Non-electric heating)



- During the winter time a diesel heater was used for heating purposes, which is not reflected in the diagram above;

Skopje, Macedonia, pilot project from, May 2018 - Dec 2018



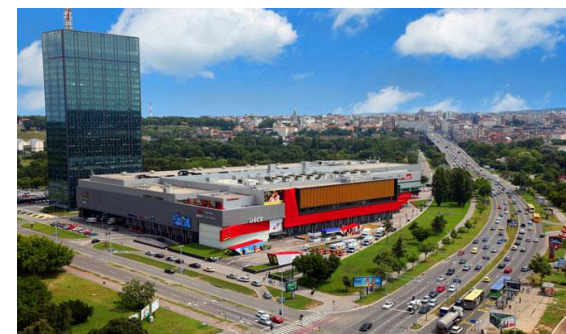
- Pilot project for 6 months, operated and maintained by the JSP Skopje;
- Line № 15, flat, high traffic (bus lane unavailable), length of 10 km;
- Charging stations at terminals only;
- Average energy consumption: varying between 1.2 -1.6 kWh/km (August 2018);
- 10.08.18: close to 1.9 kWh/km at 16:48; 1.11 kWh/km at 18:59;
- Operating temperatures: -5°C to 40°C.



The Belgrade Project



1 EKO line	5 E-buses in the operation						
Total length of route [km]	driving time [min]	charging time[min]	time of turnround [min]	interval [min]	Operational daily shift [hours]	offered capacity (places/hour)	Outside operational temperature
16,4	34	5-10	88	17-18	18.5	289	-14°C to 40°C



The Belgrade Project (Serbia)

- Delivery of 5 UC Chariot e-buses, 20kWh, and start of operation in September 2016;
- Around 1000 passengers per e-bus per one day are being transported;
- Operational schedule from 5:30 o'clock until 23:00 o'clock, 7days per week;
- Availability of the ultracapacitor electric bus line over the first calendar year of exploitation of 97.5%, improved to 99.2%.



Consumption during the four seasons



The average consumption of the " Chariot e-bus in different operating conditions is:

❑ Standard operating conditions, an average of 1.07 kWh / km:

Direction "A" 0,85-0,99 kWh / km;

Direction "B" 1,15-1,20 kWh / km.

❑ In summer conditions on 11.8.2017, with temperature of 38°C, with activated air conditioner*, an average of 1.48 kWh / km:

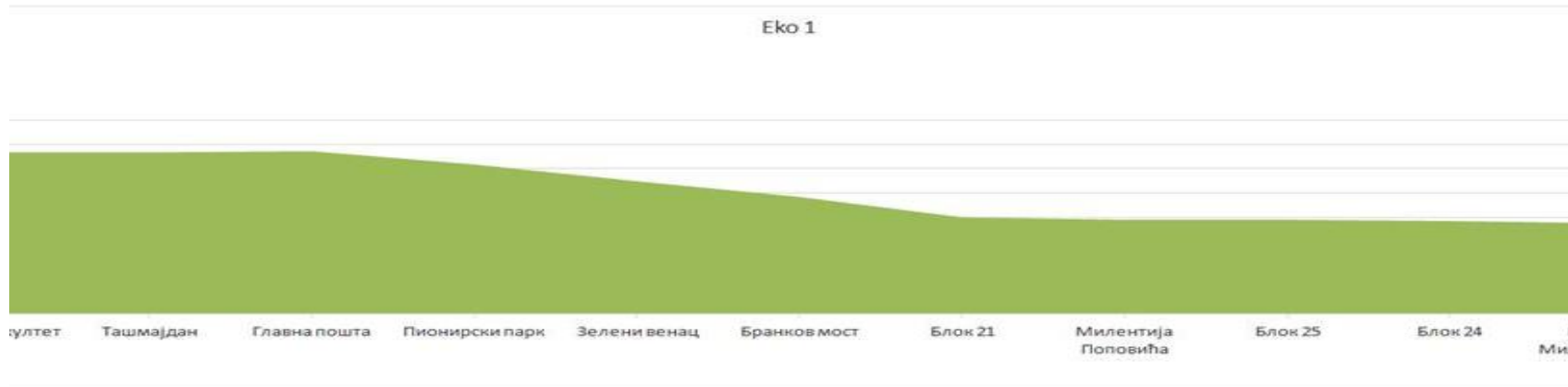
Direction "A" 1,24 kWh / km;

Direction "B" 1,72 kWh / km.

*The ambient temperature in the passenger compartment was between 22,6°C and 25,5°C.

❑ In winter conditions, when the heating system is activated, the average consumption is about 1,90 kWh / km.

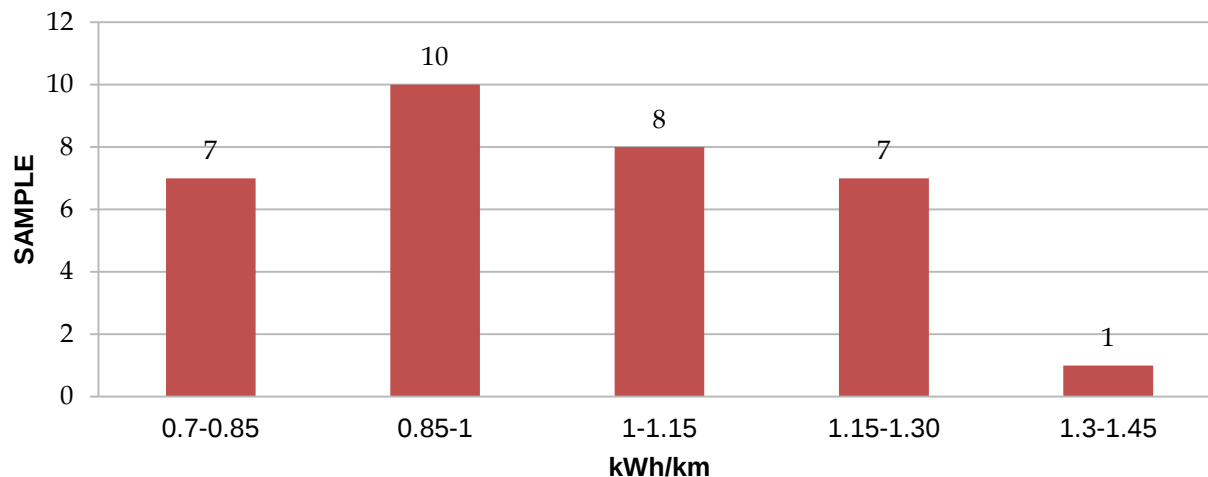
This data has been provided by the Operator – GSP Beograd.



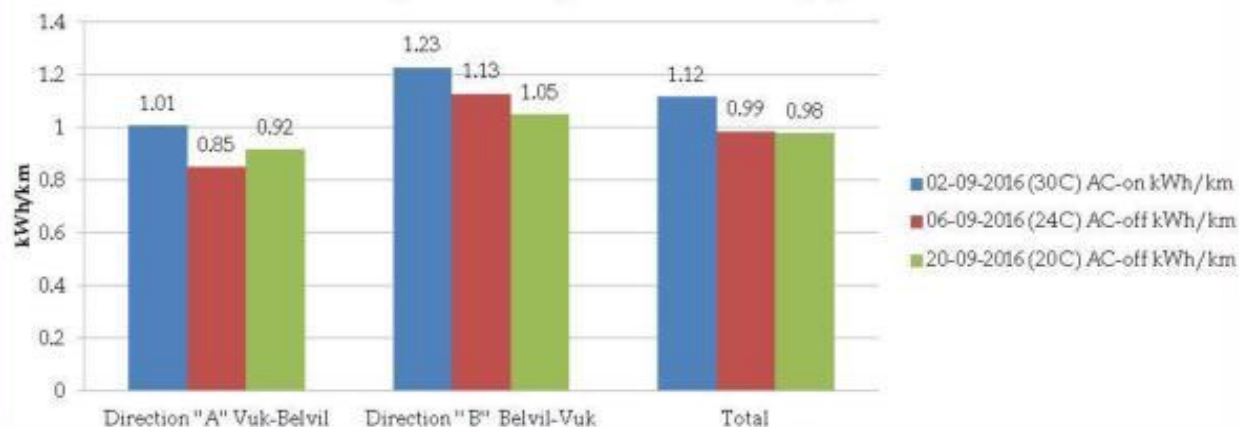
Consumption electricity per km on 2nd Sep 2016 (30 C°), AC-on



Distribution of consumption electricity per kilometer
Direction "A" Vukov spomenik- Belvil 2.9.2016



Average consumption electricity per km



Terminal	SOC %	Terminal	SOC %	kWh/km
Belvil	97	Vuk	56	0.95
Vuk	97	Belvil	67	0.77
Belvil	99	Vuk	52	1.09
Vuk	97	Belvil	65	0.82
Belvil	99	Vuk	51	1.12
Vuk	95	Belvil	62	0.85
Belvil	97	Vuk	36	1.42
Vuk	97	Belvil	50	1.21
Belvil	99	Vuk	43	1.30
Vuk	99	Belvil	52	1.21
Belvil	100	Vuk	41	1.37
Vuk	97	Belvil	50	1.21
Belvil	100	Vuk	40	1.40
Vuk	98	Belvil	50	1.23
Belvil	95	Vuk	41	1.26
Vuk	97	Belvil	56	1.05
Belvil	99	Vuk	46	1.23
Vuk	85	Belvil	51	0.87
Belvil	100	Vuk	43	1.33
Average				1.14

Tel Aviv Project (Israel)

- Start of operation on 15th Sep 2016 with 5 UC e-buses on a line with a total length of 15 kilometers and a total of 32 bus-stops subsequent purchase of another 21 e-buses, which are being released on various lines ranging from 6.5. to 9.5 km in length;
- The lines operate around 14 hours per day, average speed 13 km/h;
- E-SORT: 1.2 kWh/km (SORT 2 cycle); average annual consumption around 1.5-1.6 kWh/km (A/C only, no heater);
- Flat line, however high traffic and humidity, as well as high temperatures;
- The difference between the seasons is very mild and the A/C is being operated around the year. August is the hottest month and there is a slight difference in consumption from April (1.2 kWh/km). During winter time, the regular A/C system is operating for mild heating of the cabin.



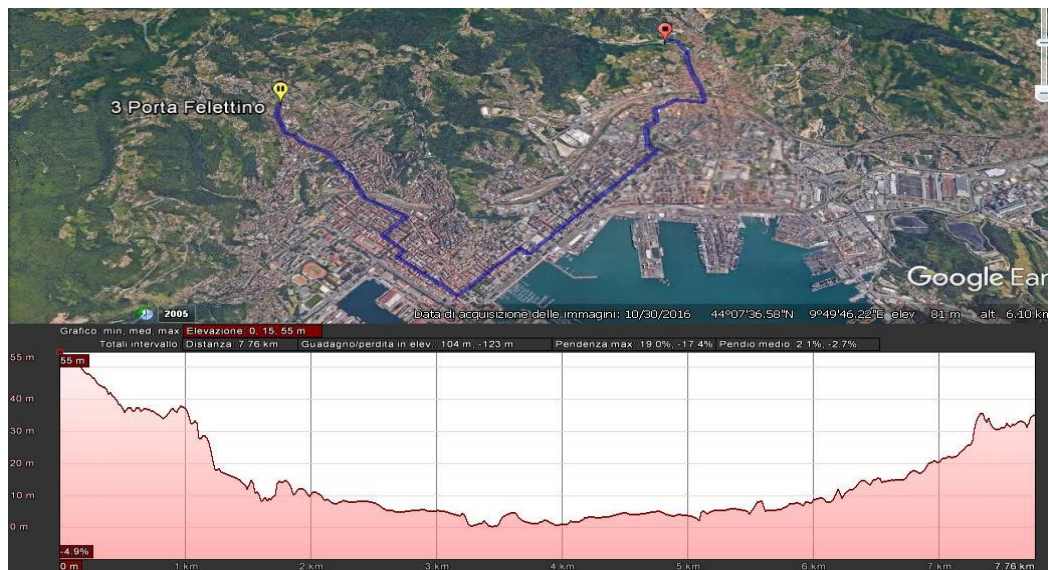
The Graz Project (Austria)

- Chariot e-bus was selected for 1-year trial due to the UC compliance with 2-3 minutes charging time criteria, trial was prolonged;
- Delivery of 2 UC Chariot e-buses, 32 kWh;
- Start of operation in mid-April 2017;
- 340 kW charging stations, one used more regularly, one used for top up only;
- 3-door city bus;
- ZF wheel hubs electromotors;
- Line 50 in Graz with length of 7 km.



La Spezia (Italy)

- One UC e-bus is being operated by the bus & trolleybus operator ATC in La Spezia;
- Start of operation on March 2018, average operational hours per day: 13h, 16 km bus line and 1 fast charging station of 340 kW;
- Challenging operational conditions: terrain, traffic, location of the charging station, climate and drivers' handling of the auxiliary consummators;
- When the SOC falls under 30%, limitation of the power of the A/C through software.



La Spezia (Italy)

Data by Politecnico di Milano and E-CO:

PERIOD	AVERAGE CONSUMPTION*	AVERAGE SPEED
SPRING	1,10 kWh/km	11,3 km/h
SUMMER	1,45 kWh/km	11,5 km/h
AUTUMN	1,15 kWh/km	11,0 km/h
WINTER (SIMULATION)	1, 61 kWh/km	10,6 km/h

- * average energy consumption, complete charging cycles and trips only.
- Average speed during tests without auxiliaries and with average speed of 16 Km/h (spring period), with 30 passengers, by a good driving style = 0,96 kWh/km.

Results from the Chariot e-buses operation: June 2018: La Spezia and Graz comparison



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Yellow Warning for Wind No Special Awareness Required BE AWARE, ...

→

← May 2018

View:

June

▼

2018

▼

July 2018 →

SUN 5/27

Actual Temp
30°/17°

Hist. Avg,
24°/14°

MON 5/28

Actual Temp
28°/18°

Hist. Avg,
24°/14°

TUE 5/29

Actual Temp
27°/17°

Hist. Avg,
25°/14°

WED 5/30

Actual Temp
28°/17°

Hist. Avg,
25°/14°

THU 5/31

Actual Temp
25°/16°

Hist. Avg,
25°/14°

FRI 6/1

Actual Temp
24°/15°

Hist. Avg,
25°/14°

SAT 6/2

Actual Temp
25°/14°

Hist. Avg,
25°/14°

SUN 6/3

Actual Temp
29°/13°

Hist. Avg,
25°/14°

MON 6/4

Actual Temp
25°/17°

Hist. Avg,
25°/14°

TUE 6/5

Actual Temp
25°/15°

Hist. Avg,
26°/15°

WED 6/6

Actual Temp
25°/16°

Hist. Avg,
26°/15°

THU 6/7

Actual Temp
27°/15°

Hist. Avg,
26°/15°

FRI 6/8

Actual Temp
25°/16°

Hist. Avg,
26°/15°

SAT 6/9

Actual Temp
25°/16°

Hist. Avg,
26°/15°

SUN 6/10

Actual Temp
26°/15°

Hist. Avg,
26°/15°

MON 6/11

Actual Temp
28°/15°

Hist. Avg,
26°/15°

TUE 6/12

Actual Temp
26°/17°

Hist. Avg,
26°/15°

WED 6/13

Actual Temp
24°/16°

Hist. Avg,
27°/15°

THU 6/14

Actual Temp
28°/16°

Hist. Avg,
27°/16°

FRI 6/15

Actual Temp
27°/16°

Hist. Avg,
27°/16°

SAT 6/16

Actual Temp
28°/14°

Hist. Avg,
27°/16°

La Spezia, June 2018: Highest consumption recorded - 1.829 kWh/km; average consumption – 1.54 kWh.

Results from the Chariot e-buses operation: June 2018: La Spezia and Graz comparison



06-06-18 12:36	06-06-18 12:40	27.4	1.671
06-06-18 14:54	06-06-18 14:55	27.6	1.683
08-06-18 09:55	08-06-18 10:00	18	1.098
08-06-18 13:47	08-06-18 13:50	26.9	1.64
08-06-18 16:28	08-06-18 16:30	27.9	1.701
29-06-18 09:53	29-06-18 09:55	24.4	1.488
29-06-18 11:21	29-06-18 11:25	26.9	1.64
29-06-18 13:22	29-06-18 13:25	30	1.829

La Spezia, June 2018: Highest consumption recorded - 1.829 kWh/km; average consumption – 1.54 kWh.

Results from the Chariot e-buses operation: June 2018: La Spezia and Graz comparison



← May 2018		View:  		June ▼	2018 ▼	July 2018 →
SUN 5/27 Actual Temp 26°/13° Hist. Avg. 21°/10°	MON 5/28 Actual Temp 26°/13° Hist. Avg. 21°/10°	TUE 5/29 Actual Temp 26°/16° Hist. Avg. 22°/10°	WED 5/30 Actual Temp 25°/14° Hist. Avg. 22°/10°	THU 5/31 Actual Temp 27°/15° Hist. Avg. 22°/10°	FRI 6/1 Actual Temp 27°/15° Hist. Avg. 22°/10°	SAT 6/2 Actual Temp 26°/14° Hist. Avg. 22°/11°
SUN 6/3 Actual Temp 27°/15° Hist. Avg. 22°/11°	MON 6/4 Actual Temp 27°/15° Hist. Avg. 22°/11°	TUE 6/5 Actual Temp 27°/14° Hist. Avg. 22°/11°	WED 6/6 Actual Temp 26°/15° Hist. Avg. 22°/11°	THU 6/7 Actual Temp 23°/16° Hist. Avg. 22°/11°	FRI 6/8 Actual Temp 27°/14° Hist. Avg. 22°/11°	SAT 6/9 Actual Temp 25°/16° Hist. Avg. 22°/11°
SUN 6/10 Actual Temp 28°/16° Hist. Avg. 23°/11°	MON 6/11 Actual Temp 29°/16° Hist. Avg. 23°/11°	TUE 6/12 Actual Temp 29°/15° Hist. Avg. 23°/12°	WED 6/13 Actual Temp 23°/13° Hist. Avg. 23°/12°	THU 6/14 Actual Temp 20°/16° Hist. Avg. 23°/12°	FRI 6/15 Actual Temp 22°/16° Hist. Avg. 23°/12°	SAT 6/16 Actual Temp 24°/14° Hist. Avg. 23°/12°

Graz, June 2018: Highest consumption recorded - 1.974 kWh/km; average consumption – 1.191 kWh.

Results from the Chariot e-buses operation: June 2018: La Spezia and Graz comparison



06-06-18 17:44	06-06-18 17:48	9	1.184
06-06-18 18:15	06-06-18 18:21	13	1.711
06-06-18 19:33	06-06-18 19:38	10	1.316
08-06-18 15:12	08-06-18 15:17	9	1.184
08-06-18 15:50	08-06-18 15:54	10	1.316
08-06-18 16:29	08-06-18 16:36	15	1.974

Graz, June 2018: Highest consumption recorded - 1.974 kWh/km; average consumption – 1.191 kWh.

Results from the Chariot e-buses operation: June 2018: La Spezia and Graz comparison



CONCLUSIONS:

- ❑ Average consumption does not always correspond to the actual conditions on the line;
- ❑ E-SORT is a good tool for general indication of the consumption, but it does not provide a full and accurate picture of what the operating conditions of a bus will be;
- ❑ The drivers' behavior and the road conditions may play as much a role in the consumption of the auxiliary equipment, such as A/C, as the outside temperatures and terrain, therefore a more “holistic” approach in the training of the drivers can be a plus;
- ❑ It is always necessary to ensure that the worst-case scenario on a line is has been considered and a conservative approach is advisable.



Thank you!

www.chariot-electricbus.com

Contact information:

■ E-mail: kalina@chariot-electricbus.com

■ Tel: +359 876990181