INTERNATIONAL UNION
OF RAILWAYS

Welcome to the best practice workshop

BATTERY TRAINS

Proposed by
the UIC Energy efficiency and CO_2 Emissions Sector

Organised by the Sector's Chairpersons:

Bart Van der Spiegel, Infrabel,
Gerald Olde Monnikhof, ProRail.
Philippe Stefanos, UIC

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BATTERY TRAINS

- The meeting will be recorded.
- Please remain on **mute** while the speaker is active.
- Please keep your **camera off** while the speaker is active.

Workshop timeline

10 h **First part**

• Arup	**Robert Davies**	
• Transport and Mobility Leuven	**Christophe Heyndrickx**	
• TUC Rail	**Paul Tobback**	

11 h **Second part**

• SNCF	**François Degardin** **Bogdan Vulturescu**	**Matthieu Renault** **Benoît Gachet**
• Siemens	**Katrin Seeger**	
• Eaton	**Akos Labady**	

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ARUP
ROLLING STOCK

Battery Train Procurement

Robert DAVIES
Global Rolling Stock Leader - Arup

Rolling Stock

Battery train procurement
Operations concept
Solution
Route options
Capacity
Lifecycle
Future proofing
Entry into service
Conclusions

Welcome to Arup

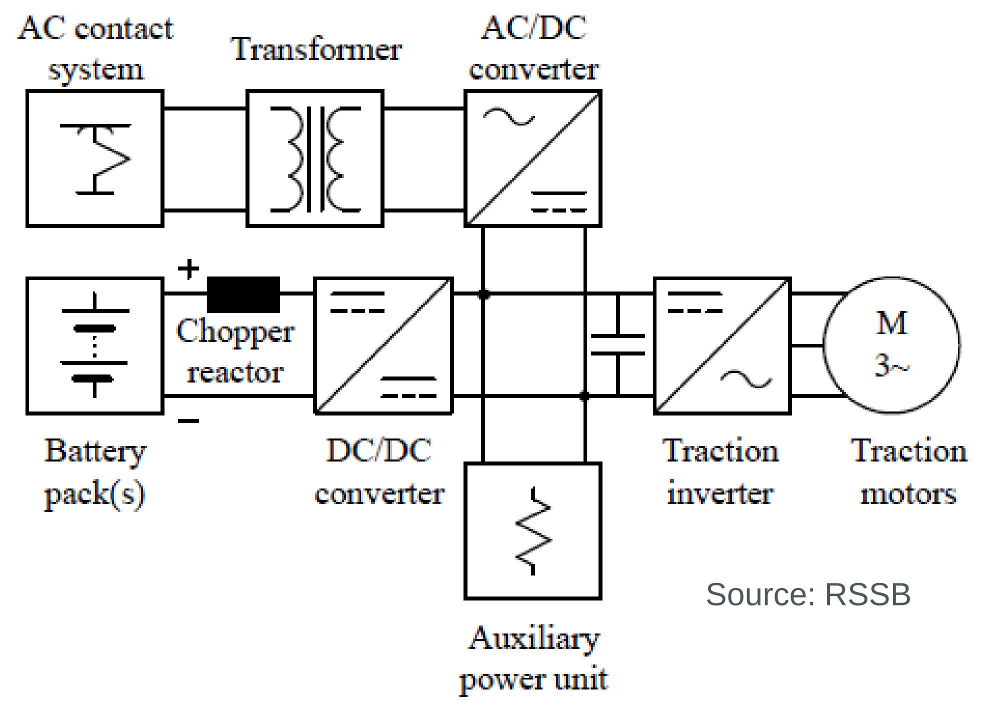
Arup is an independent firm of designers, planners, engineers, consultants and technical specialists, working across every aspect of the built environment.

Together we help our clients solve their most complex challenges – turning exciting ideas into tangible reality as we strive to find a better way and shape a better world.

We

- Design quality infrastructure and experiences for people and communities
- Deliver major programmes and develop high performing organisations
- Integrate complex new technologies and systems
- Unlock financial value for investors, asset owners and operators
- Optimise performance and value from existing and new assets

Traction battery – operations concept



Source: RSSB

Example modes

Independent Battery Powered

Independent Battery Powered with hydrogen fuel cell

Bi-mode with AC external pantograph

Bi-mode with DC external pantograph or power rail

Bi-mode with with diesel engine

Rail systems

Light Rail

Metro

Regional and Suburban

High speed and Intercity

Freight

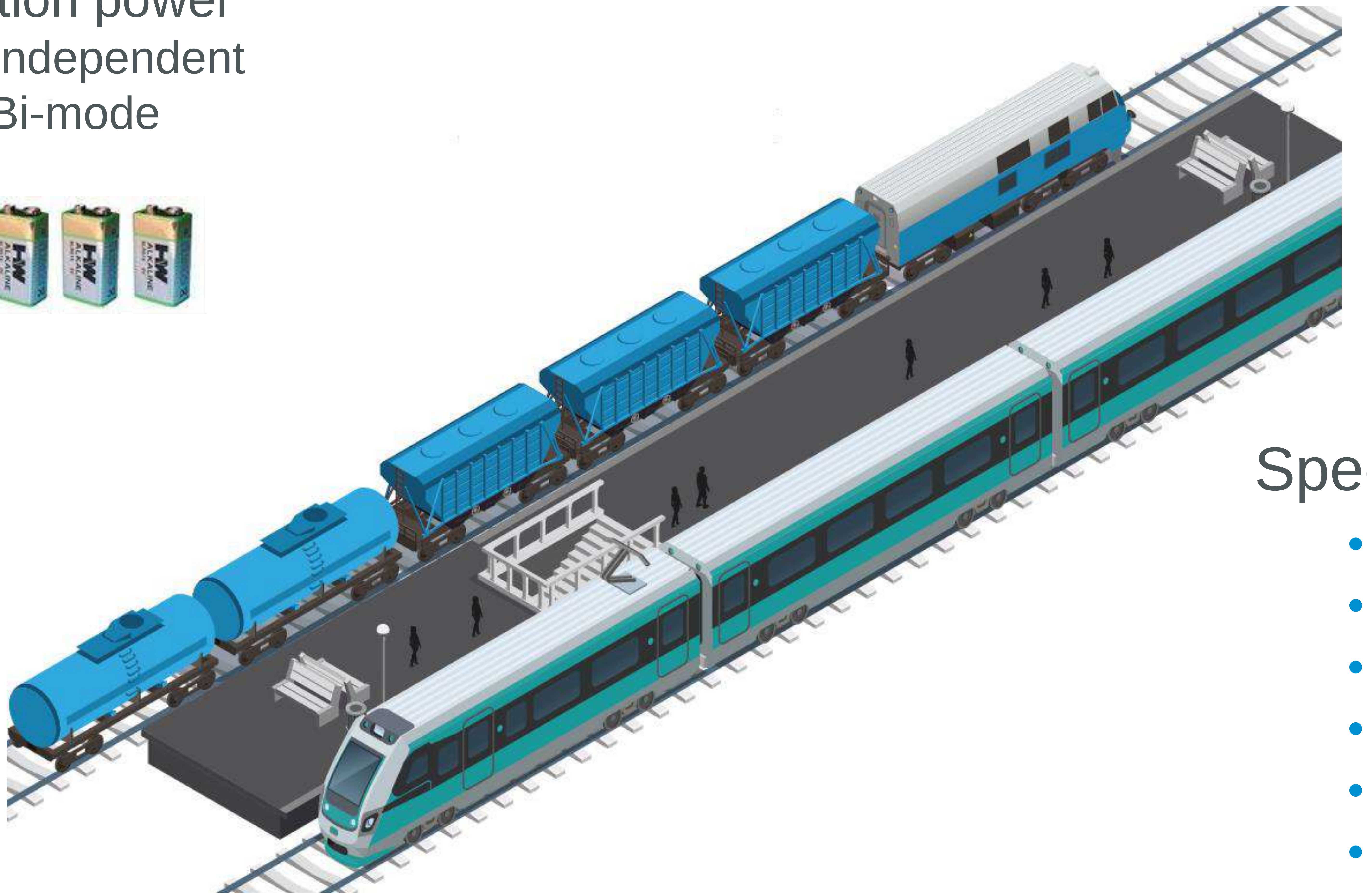
Track Plant and Engineering Trains

Rolling Stock – Battery Solution

Battery power

- Auxiliary equipment
- Traction power
  - Independent
  - Bi-mode

New Build
or
Retrofit ?



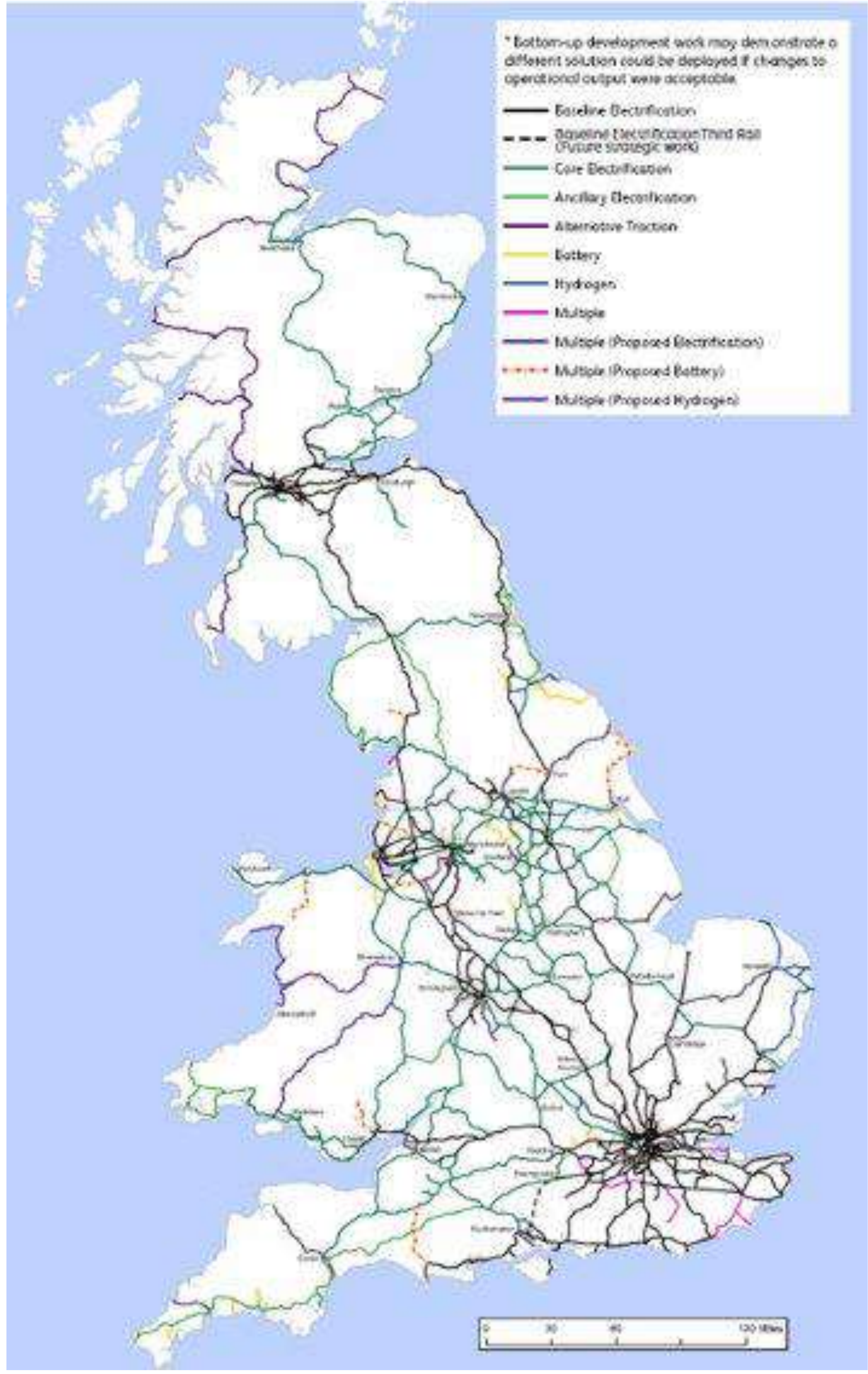
Why battery

- Sustainable
- Emission neutral
- Autonomous power
- (Go anywhere)
- Market driven

Specification

- Performance
- Range
- Capacity
- Charger
- Service life
- Whole life cost

Route options



Informed by

Policy

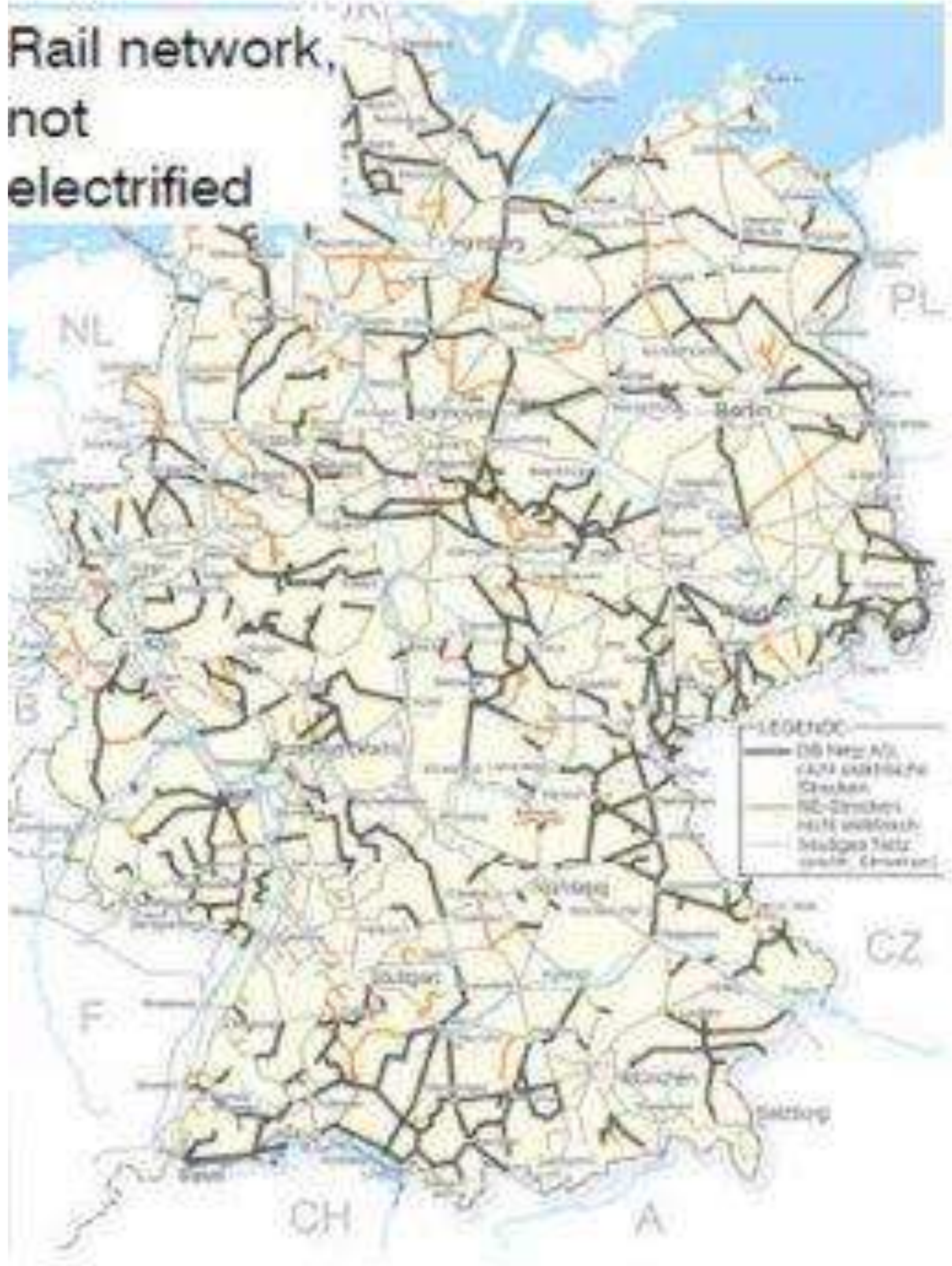
Route demand

Feasibility

Sustainability

Investment

Whole life cost



Direct costs

Capital investment

Maintenance

Energy consumption

Operations

Indirect costs

Carbon emissions

Air quality

Potential incentivisation

Battery capacity

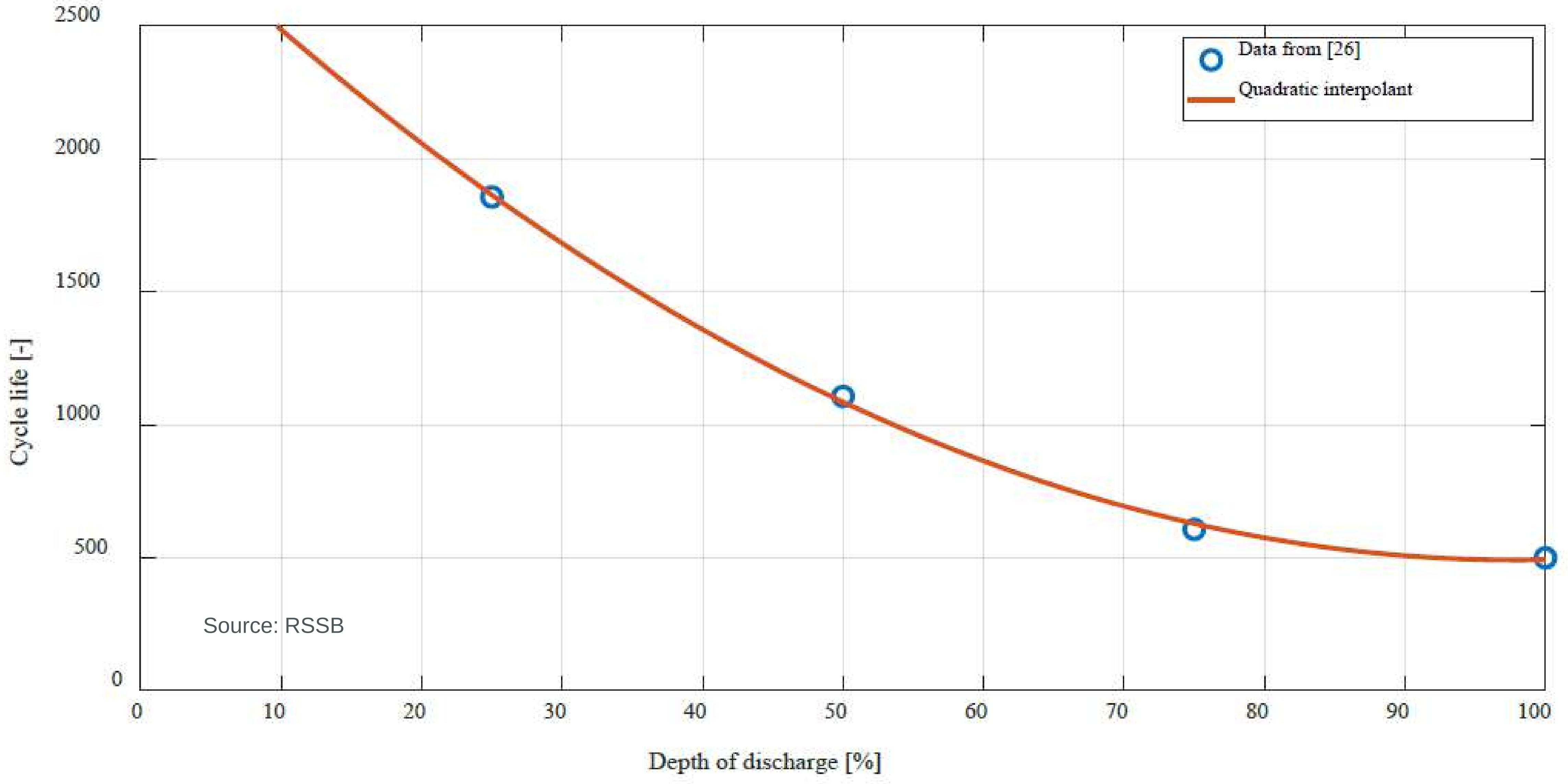
Simulation model
Power delivery
Energy capacity
System architecture

Example system capacity
Baseline train with capacity 16 tonne x 8 axles

I need my battery train to provide a…

Local Shuttle service	End of mainline Branch line service	Extended mainline Performance service
Range 45km	Range 90km	Range 90km
Speed 75 km/h	Speed 75 km/h	Speed 125 km/h
Battery 250 kWh	Battery 500 kWh	Battery 1000 kWh
10000 cycles per year	1000 cycles per year	1000 cycles per year
3 ton battery	5 ton battery	10 ton battery

Battery lifecycle



Service cycles

Sensitive to depth of discharge

Control system health monitoring

Condition management

End of life recovery

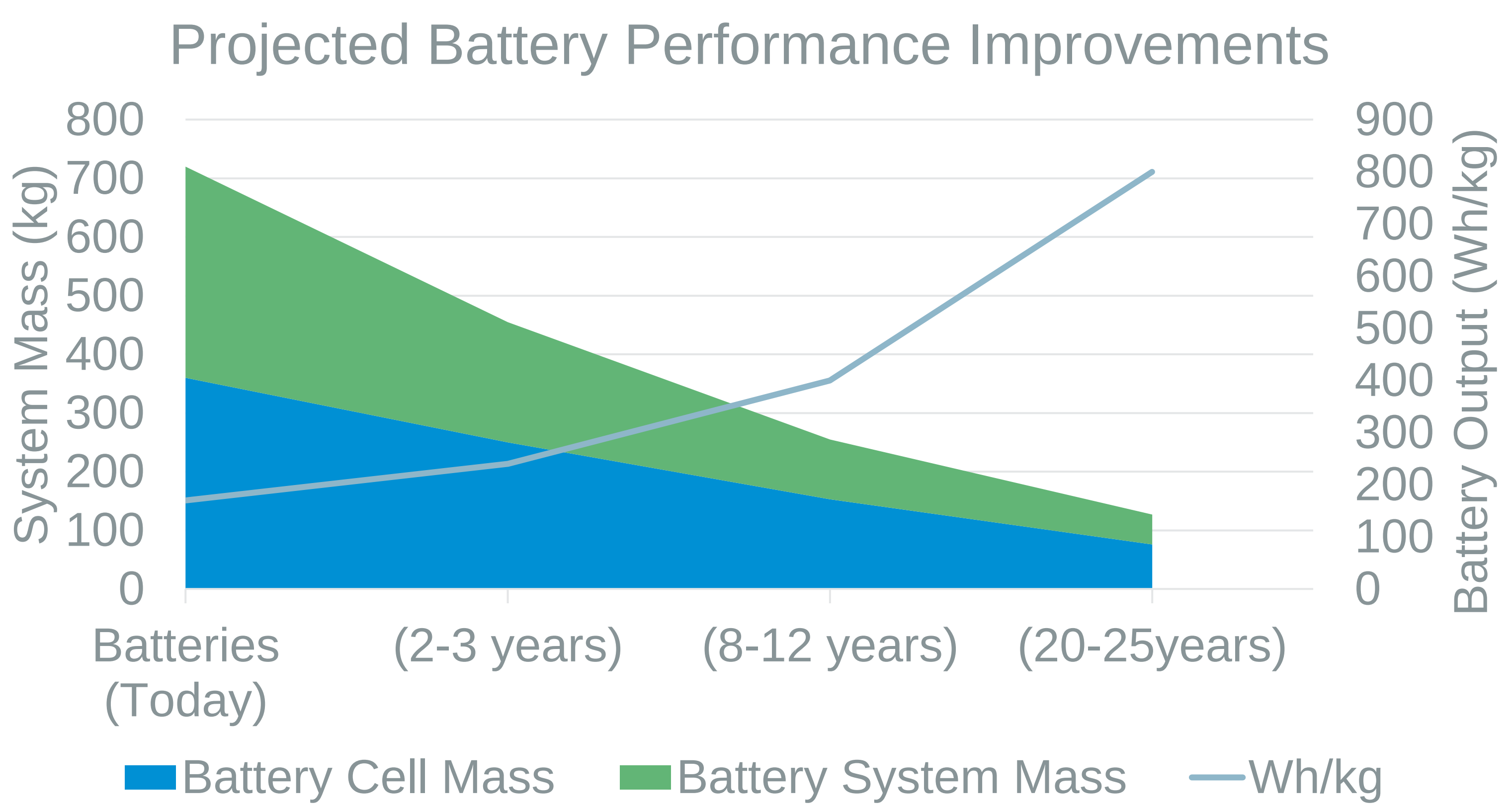
Energy	36.8 kWh
Weight (typical)	430 kg
Discharging power max.*	334 kW
Charging power max.*	184 kW
Continuous power*	92 kW
Capacity	46 Ah
Voltage nom.	799 V
Cycle life**	> 7,000 cycles
Dimension (L x H x W) in mm	1,844 x 750 x 216

Supply chain

Mature battery solutions

Technology watch

Energy density



Future proofing – investment risks

Lifecycle commitment

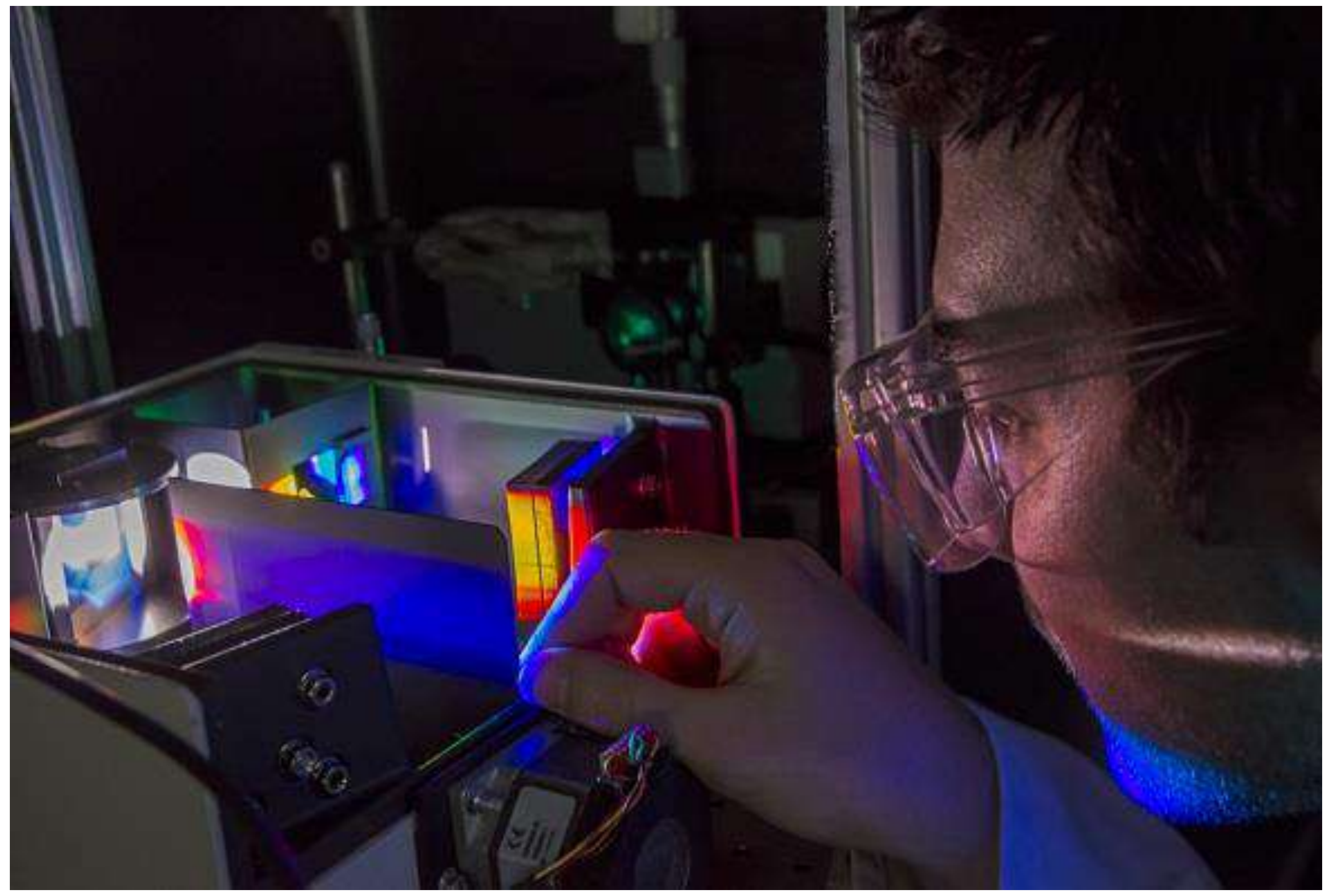
Battery cycle management

Obsolescence management

Mode demand

Independent / charger

Bi-mode



Performance potential

Technology watch

Hybrid battery / power device

Battery module upkeep

Refurbishment

Periodic replacement

End of life recovery

Long life asset

Trains ordered today potentially in service to 2060

Battery train – entry into service

Mature regulatory approach

Interoperability

Component regulation

Common safety method

Commercial investment

Technical

Performance

Service agreements

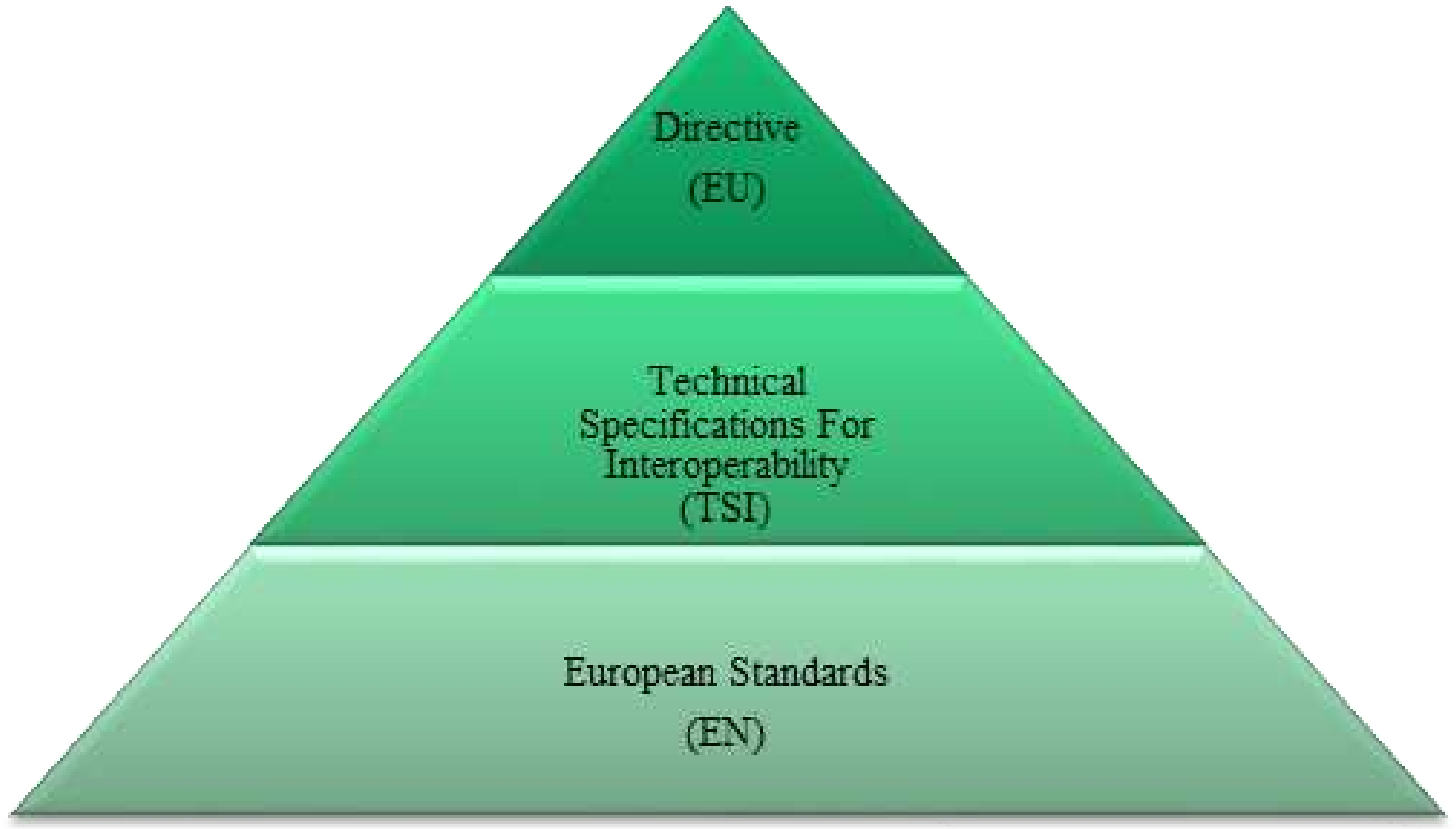
Whole life costs

V&V

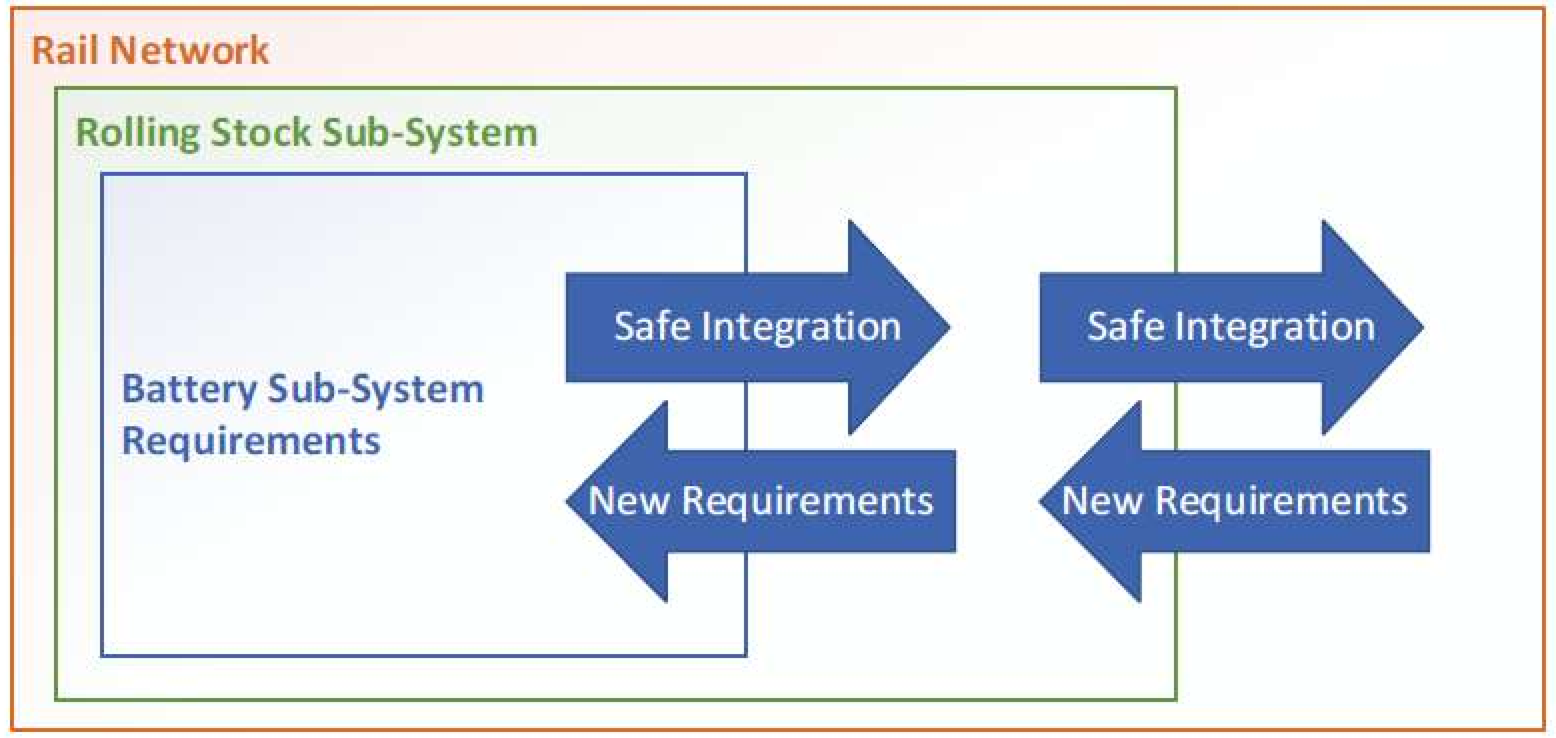
Traction battery sub-system

Rolling stock system

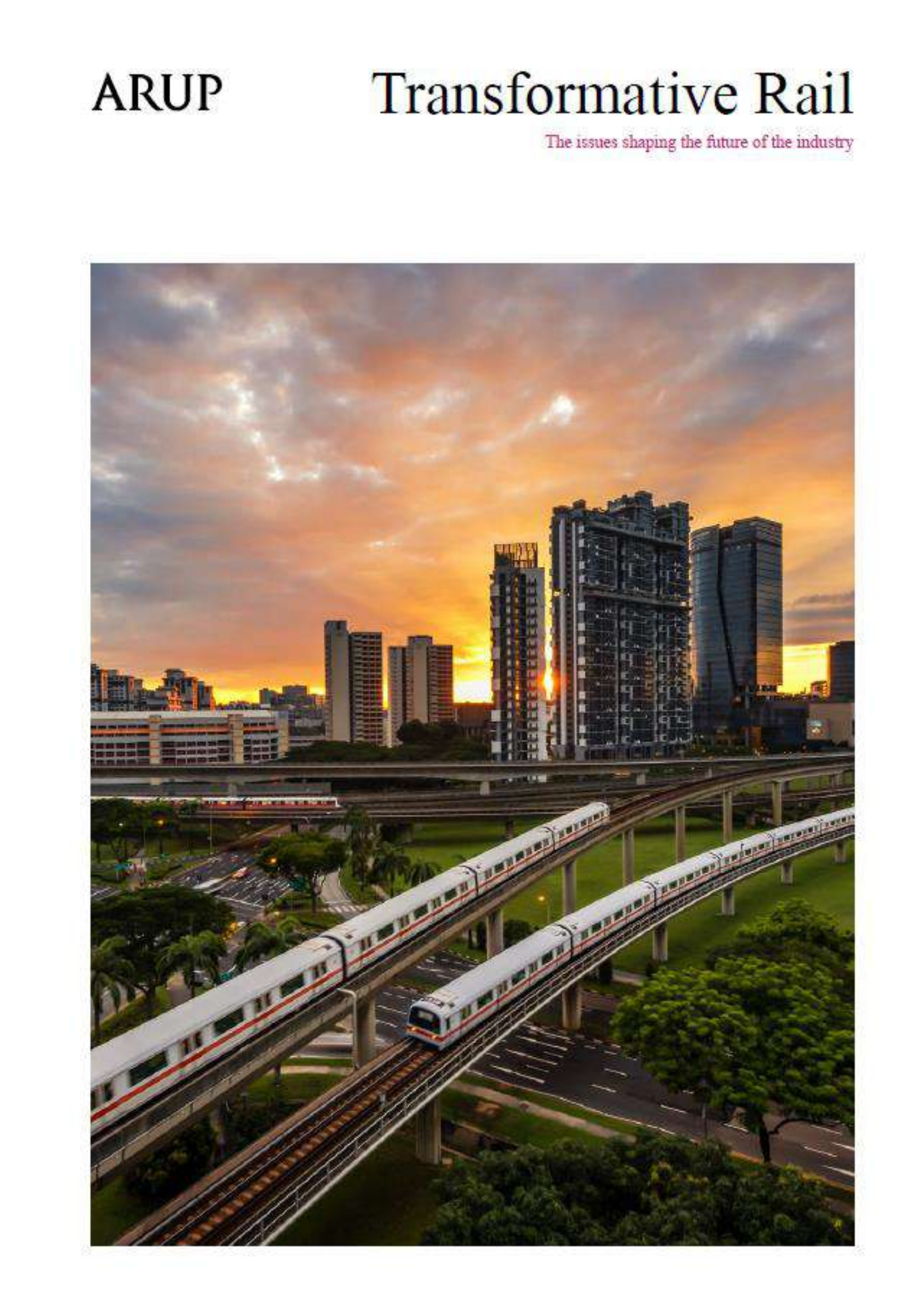
Rail systems integration

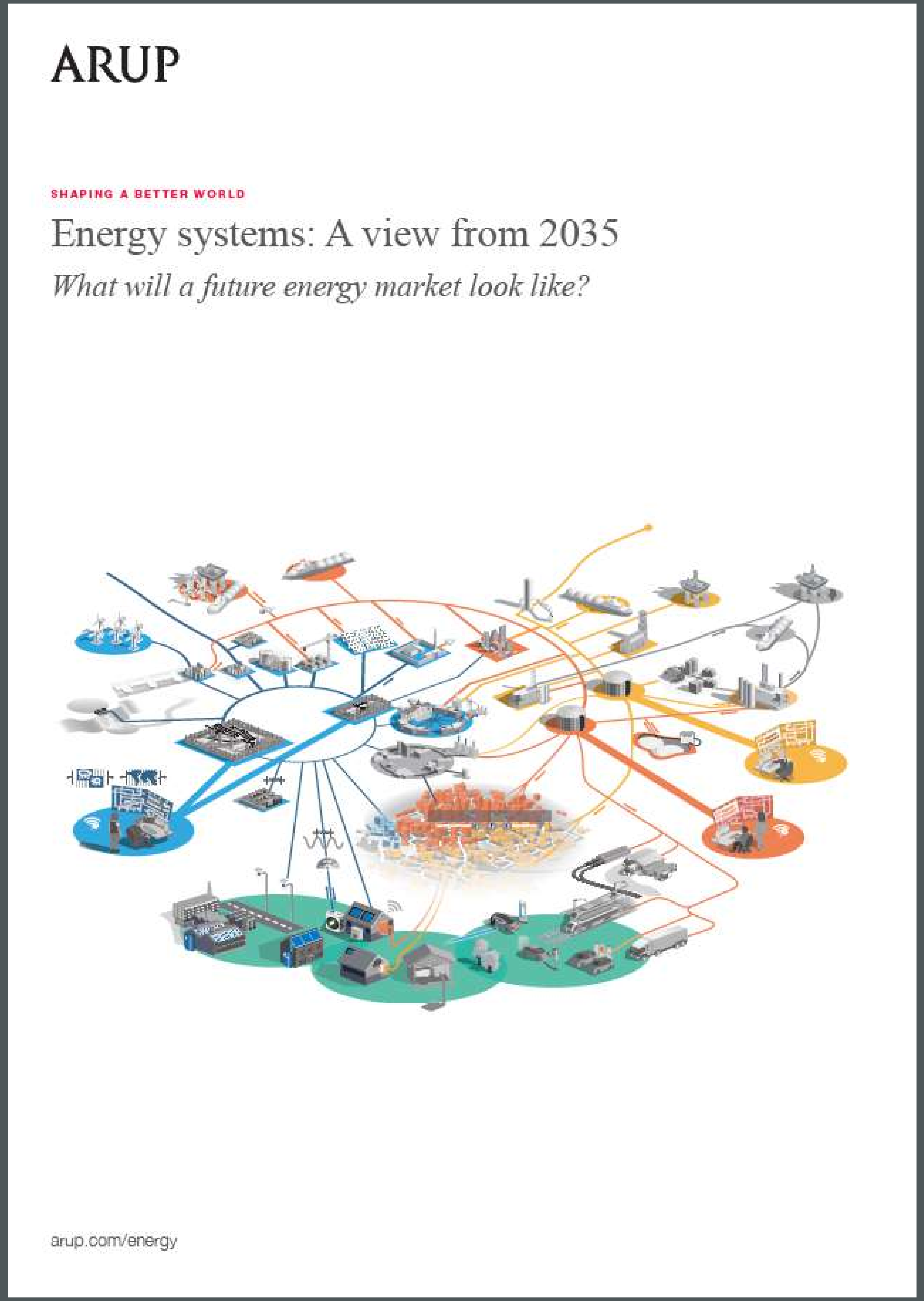


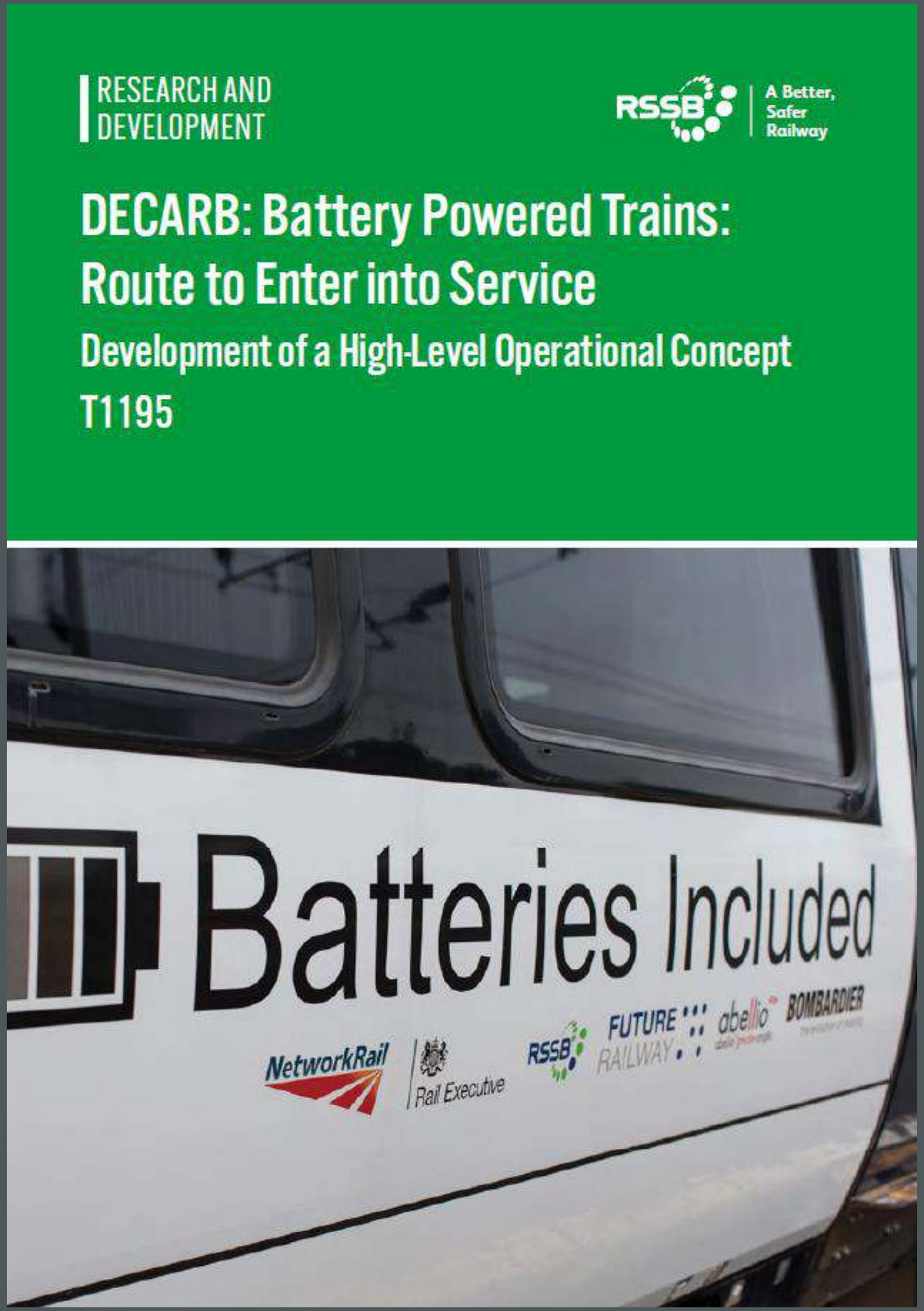
Railway applications – Rolling stock - Onboard lithium-ion traction batteries (IEC 62928:2017)



Thank you from the Arup team







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Questions

Discussion

Robert DAVIES
Global Rolling Stock Leader - Arup

Thank you for your attention.

INTERNATIONAL UNION
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TRANSPORT & MOBILITY LEUVEN

Christophe Heyndrickx

May 12, 2021

ELECTRIFICATION AND OTHER ALTERNATIVES TO DIESEL TRACTION

AN APPLICATION FOR BELGIUM

Elektrificatie van het Belgische spoorwegnet of het gebruik van andere duurzamere vervoerswijzen om de dieseltractie te vervangen

CONFIDENTIEEL

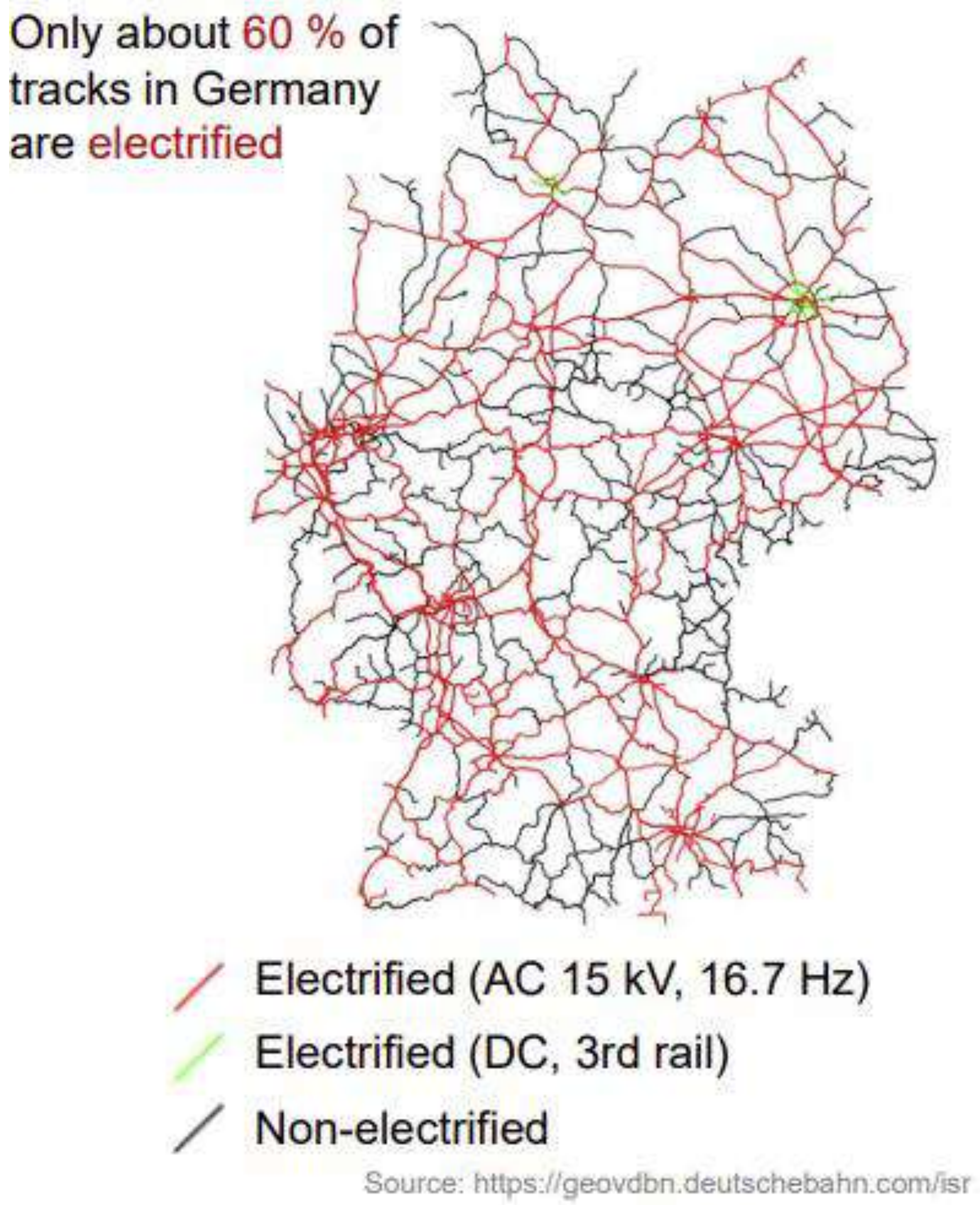
Rapport voor: **FOD Mobiliteit en Vervoer**

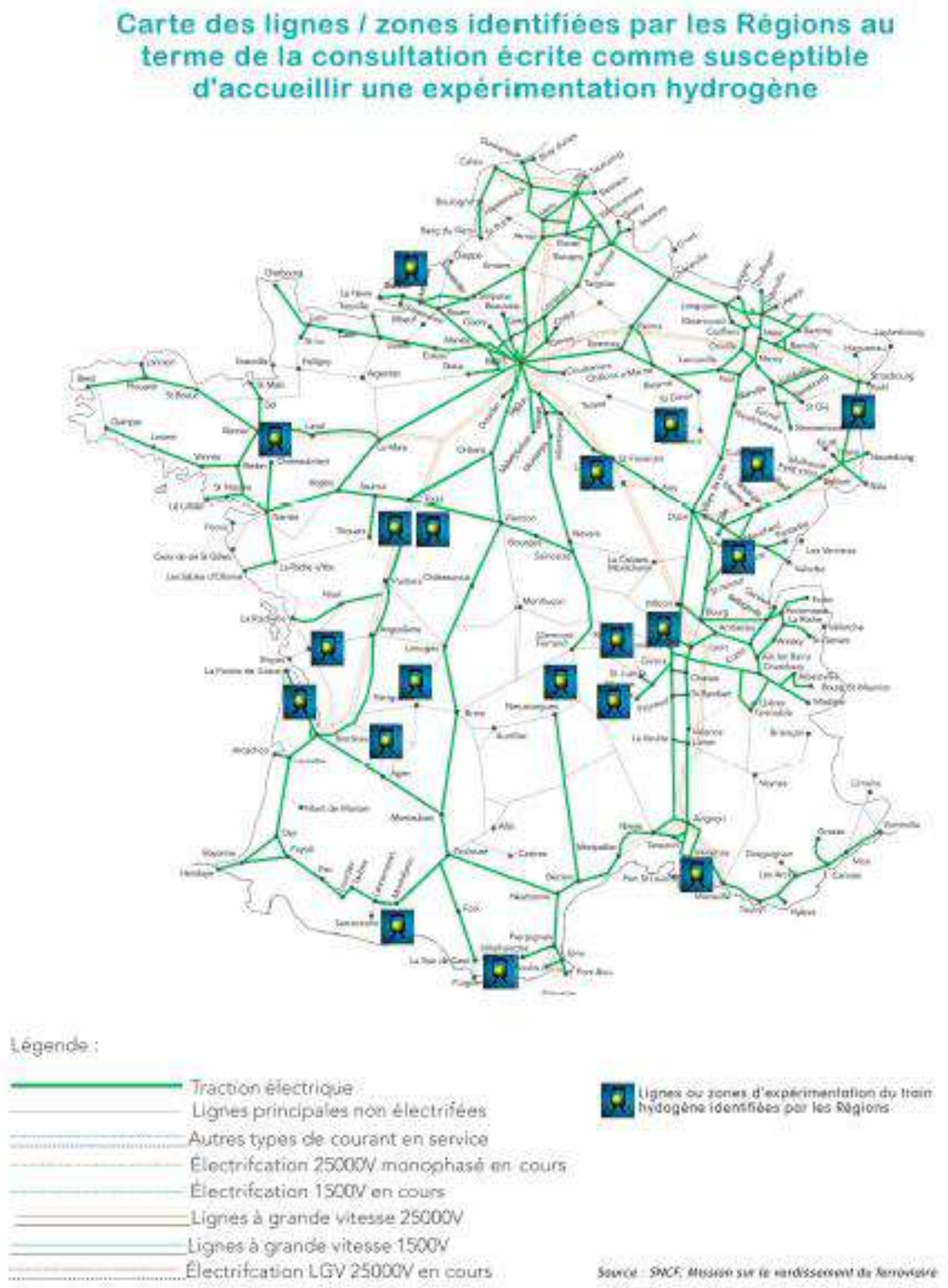
Datum: 11/12/2020

Auteurs: Christophe Heyndrickx, Sebastiaan Boschmans

Public since 19/2/2021

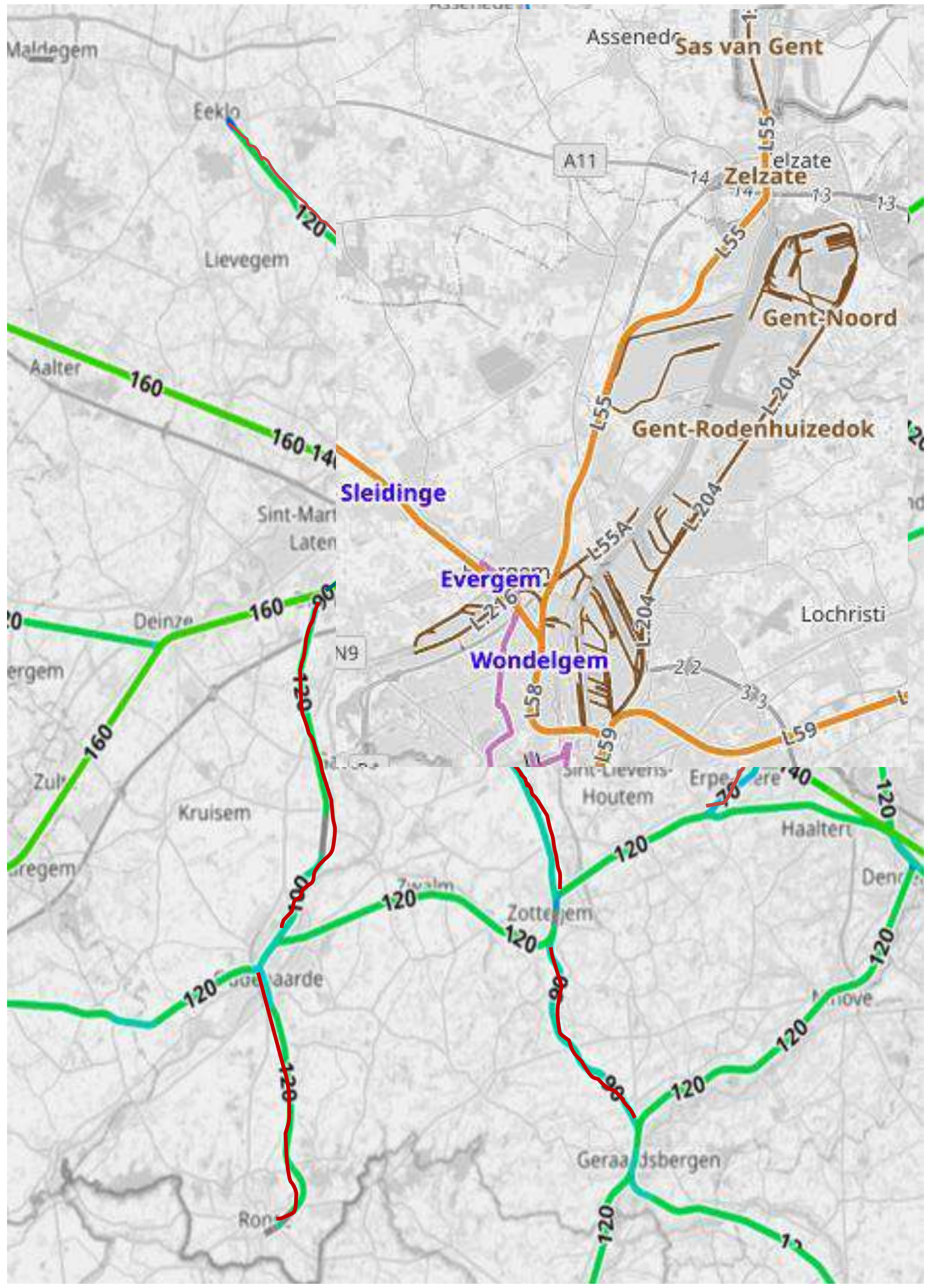
Making rail transport more sustainable



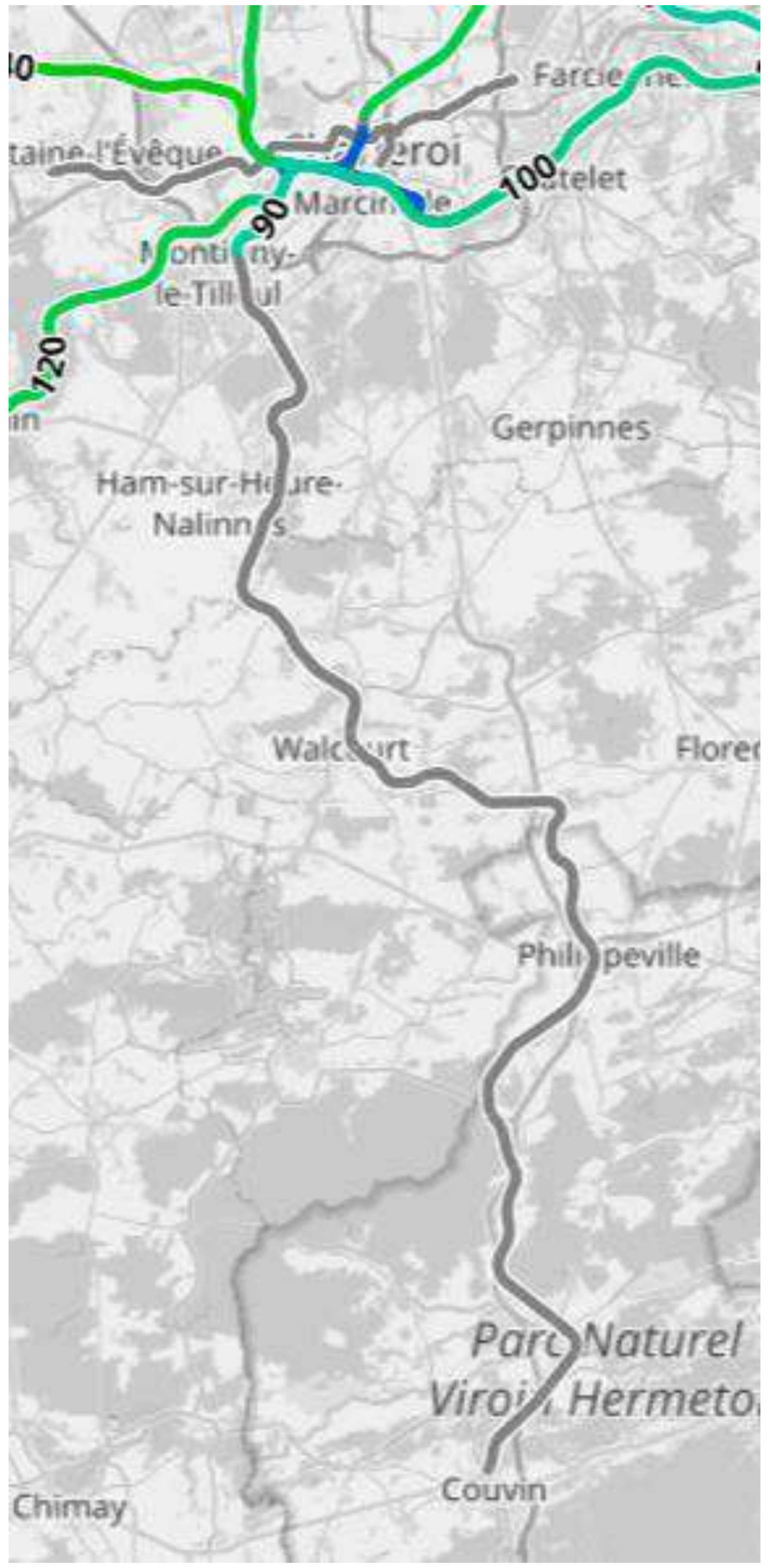


40% of railway lines non-elctrified in Germany, 43% in France

Belgian Situation



A large set of lines around Ghent



Charleroi-Couvin

Genk-Bilzen

‘Alternatives for diesel’ in Belgium

- **Passenger trains**: electrification of lines versus alternatives
- 6 (+1) scenarios:
  - Electrification in 2035 (BAU scenario – end of lifetime MW41)
  - Electrification in 2025
  - Battery train in 2025
  - Hydrogen train in 2025
  - New diesel train in 2025

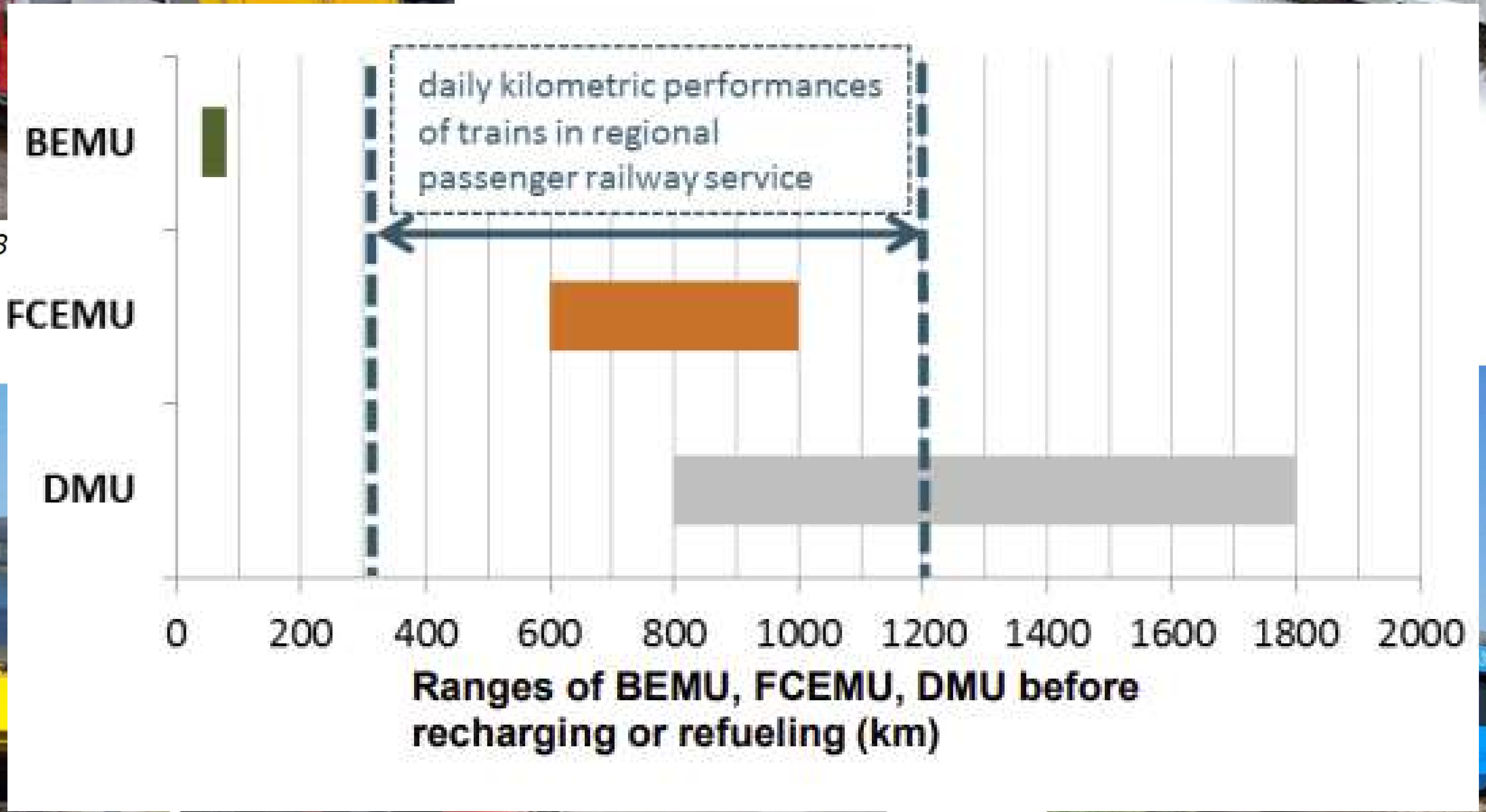
  Compare with zero scenario (diesel until eternity - 2100)

  High and low valuation of emissions (**DG MOVE**/FPB)

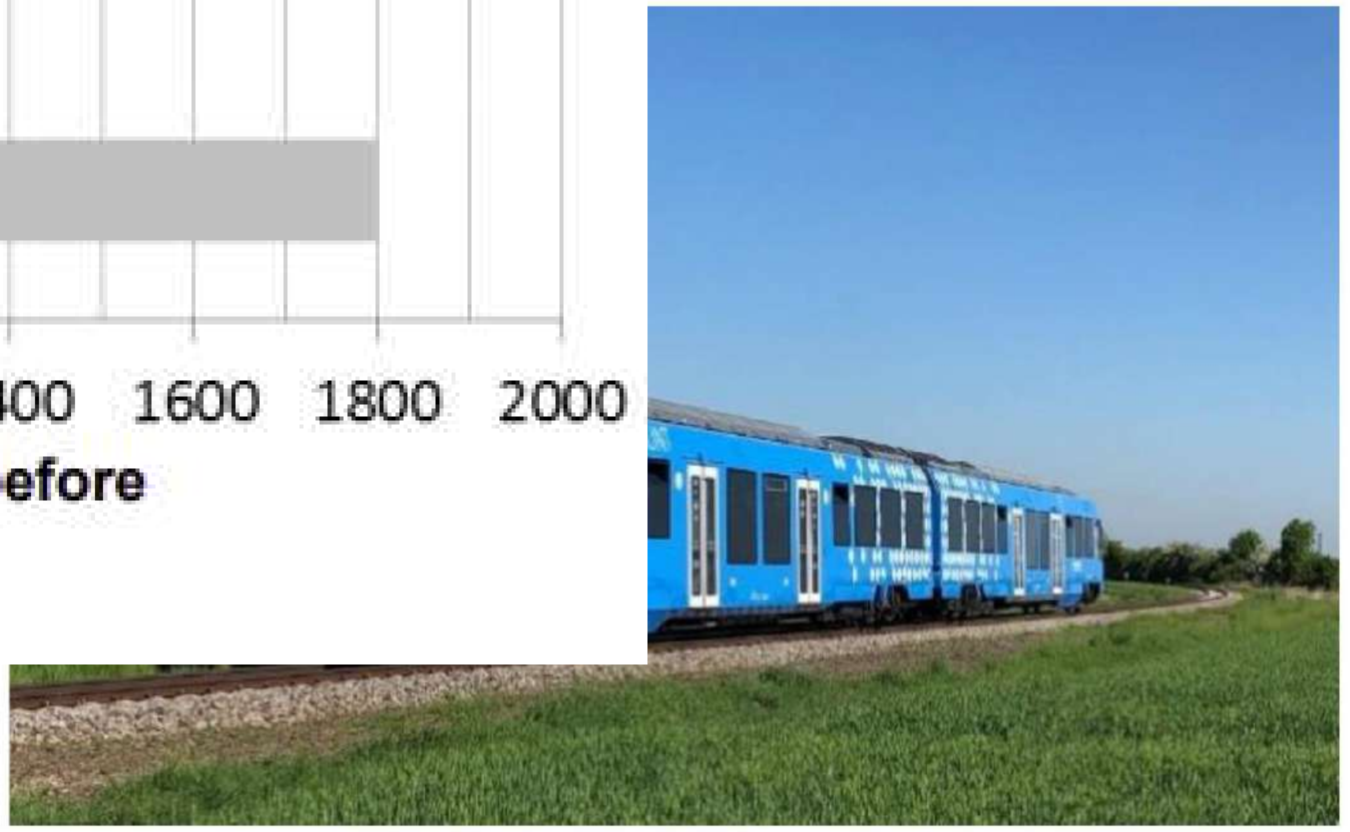
- **Freight train**: limited energy density + nog viable alternative usin hydrogen (possibly in the future)
- Quick-scan analyses voor L21c en L204/L55

Battle of the T(ra)i(n)tans

Figuur 12: MR08



Figuur 11: MW 41 dieseltrein (links), Corradia Lint 41/H in uitbating van Veolia (rechts)



Figuur 17: Coradia iLint

Electric (EMU) /
diesel (DMU)

Battery (BEMU) /
Hydrogen (FCEMU)

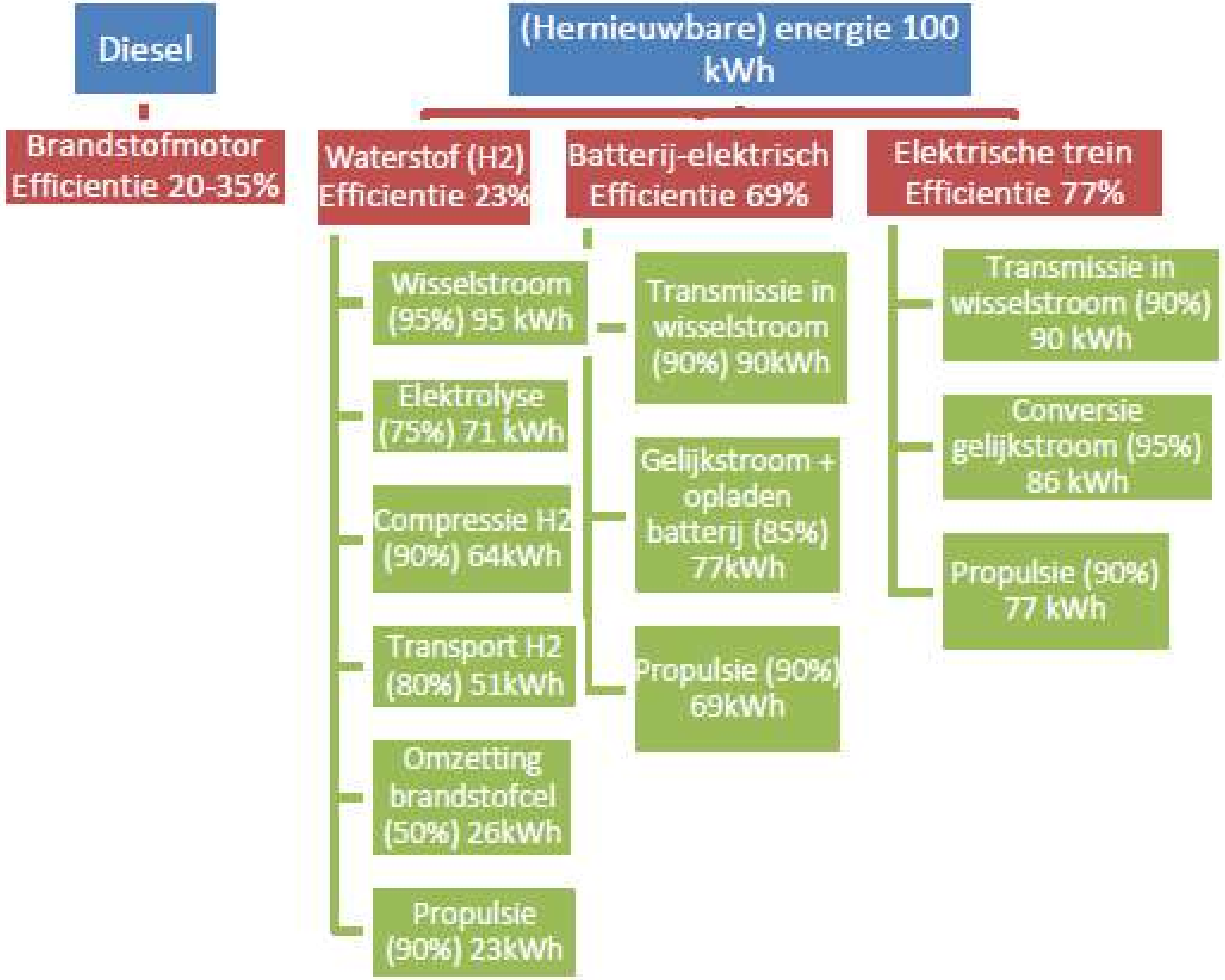
Tabel 7: Overzicht kentallen materieel en infrastructuur

Materiaalkosten				
	Diesel (l)	**Elektrisch (kWh)**	**Batterij (kWh)**	**Waterstof (kg)**
Gewicht	98 ton (MW 41)	102 ton (2-ledige Desiro)	108.12	107.1 ton
Passagiers (zitplaatsen)	150[11] (MW 41) 176 (Nieuw)	176[12]	176	176
Prijs energiebronnen	€0.5	€0.089	€0.089	€2-€5
Verbruik per km	1.62 l (MW 41) 1.2 l (Nieuw)	4.08 kWh	4.76 kWh[13]	0.25[14]kg
Energiekost (per km)	€ 0.81 (MW 41) € 0.60 (Nieuw)	€ 0.36	€ 0.42	€0.5-€ 1.25
Stukprijs materieel	€3.5 mln (MW 41) €6.325 mln (nieuw)[15]	€4.6 mln. (Desiro) € 5.5 mln (nieuw)[16]	€6 mln	€6.6 mln
Onderhoudskosten (per km)	€ 3.60 (MW 41) €2.4 (Nieuw)	€ 0.97	€ 1.8	€ 2.40

Tabel 8: Overzichtstabel infrastructuurkosten

Infrastructuurkost	**Waarde**	**Bron**
Elektrificatie	€0.4 mln/km (enkel spoor)	Infrabel
Tractiestation	€5 mln/stuk	Infrabel
Tankstation waterstof	€10 mln/stuk	Arcadis-Riccardo (2018) / Alstom
Electrolyzer	€2.5 mln/1000 kg synthese per dag +onderhoud €75 k/jaar	Arcadis-Riccardo (2018) / Alstom
Windmolen (3 MW)	€5.5 mln/stuk + onderhoud €150 k/jaar	Arcadis-Riccardo (2018) / Alstom

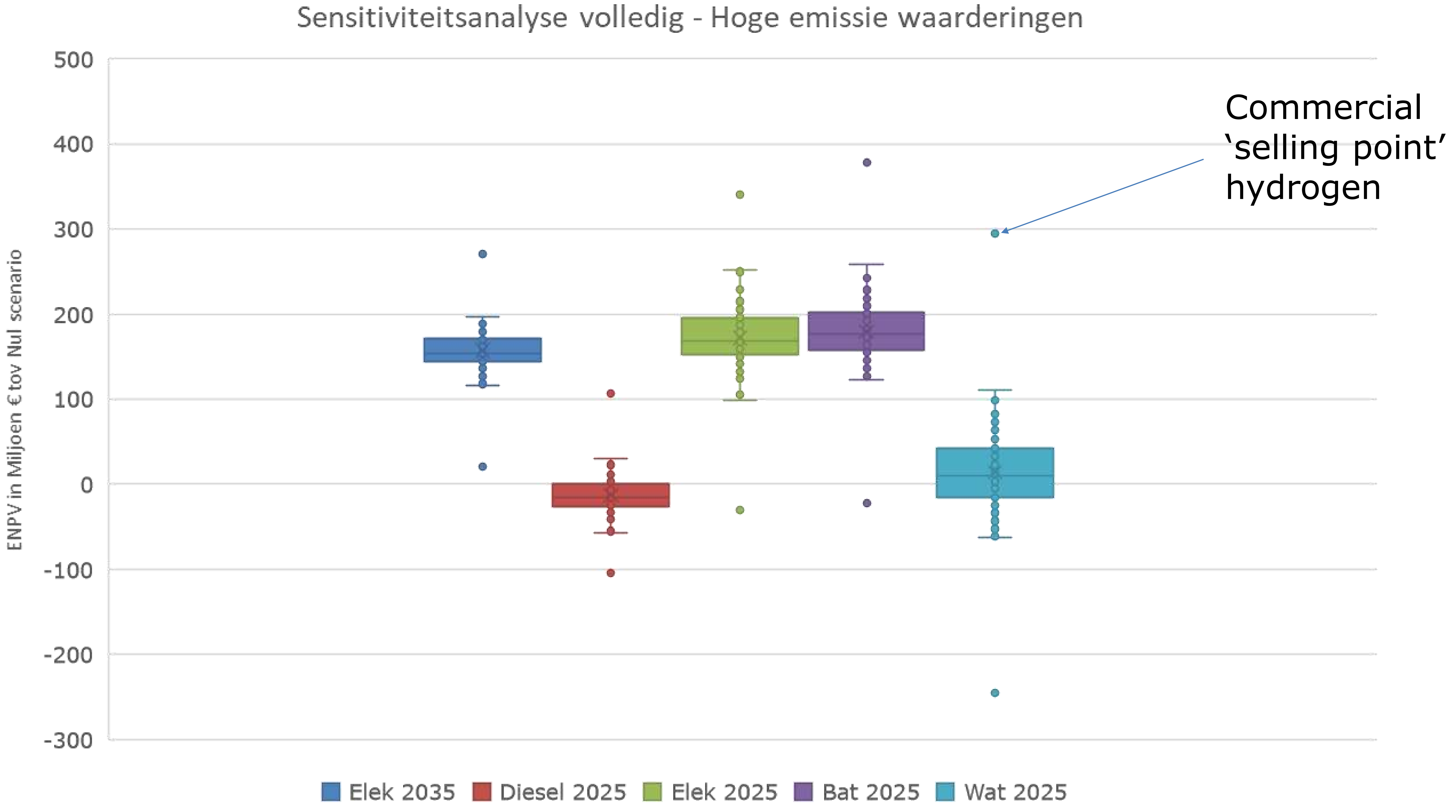
1. Large impact of maintenance cost
2. Energy cost for hydrogen comparable to diesel at 2€/kg
3. Hydrogen trains most expensive / electric trains cheapest
4. Infrastructure cost battery train 0-40% of ‘standard electrification’



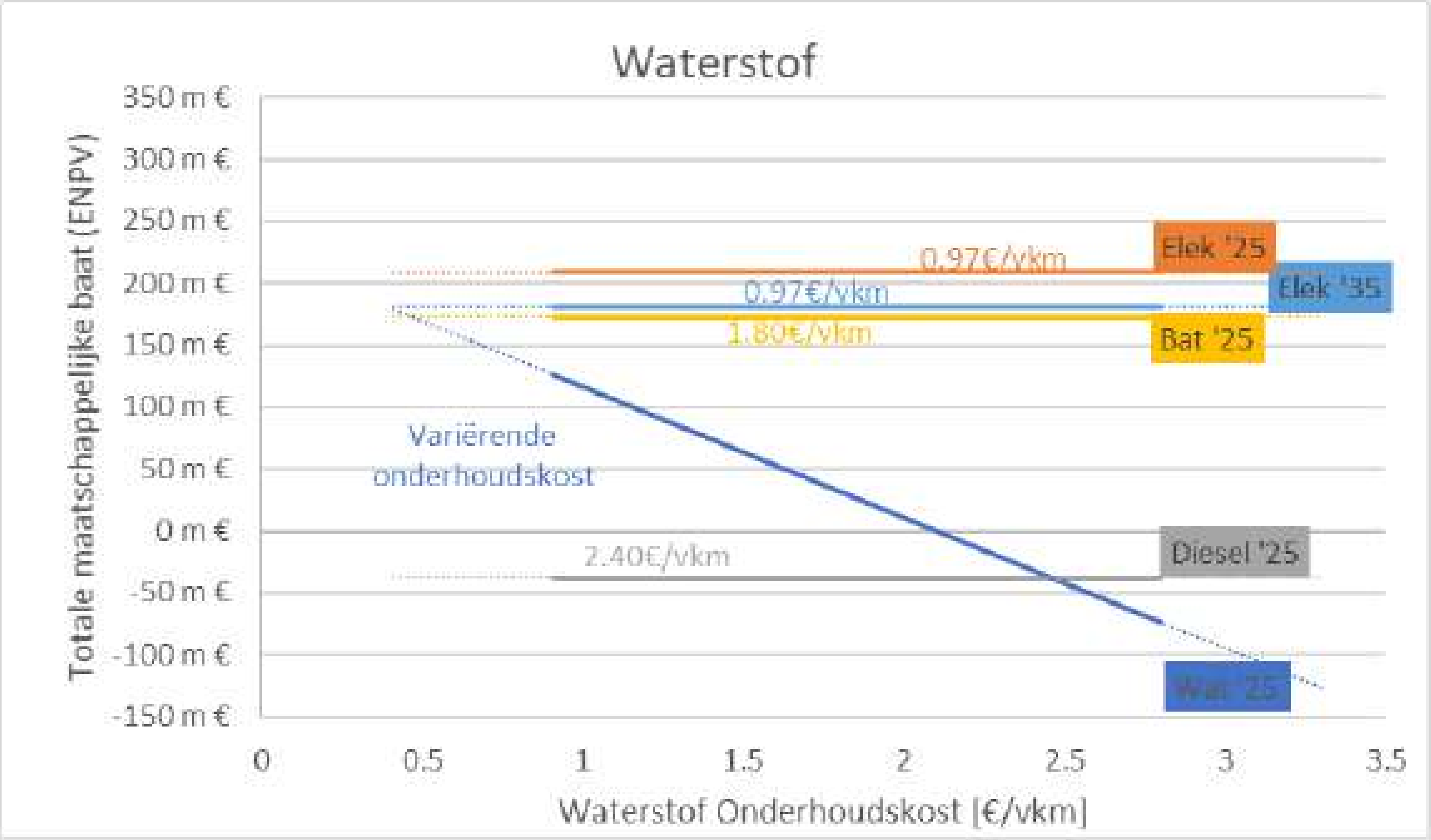
Figuur 20: Alternatieve opties vergeleken met directe elektrische trein: eigen bewerking van Cebon D. (2020) en Hofrichter A. et al (2012)

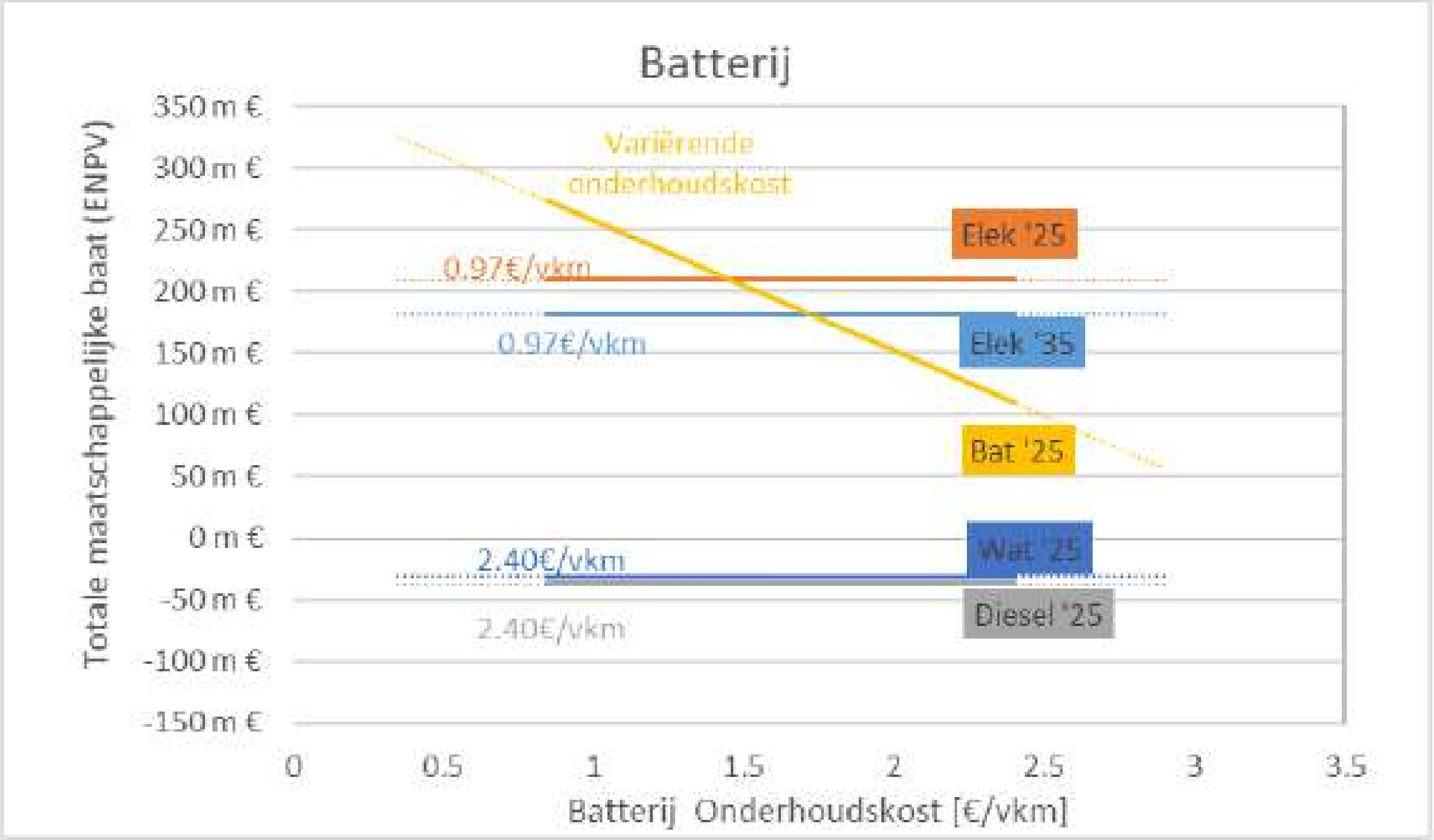
Overall energy efficiency of hydrogen not much better than diesel
Environmental benefits hydrogen comparable for non-CO2 emissions (PM/NOx/..)
+ Low efficiency & vulnerability fuel cells (replace every 2-3 years)

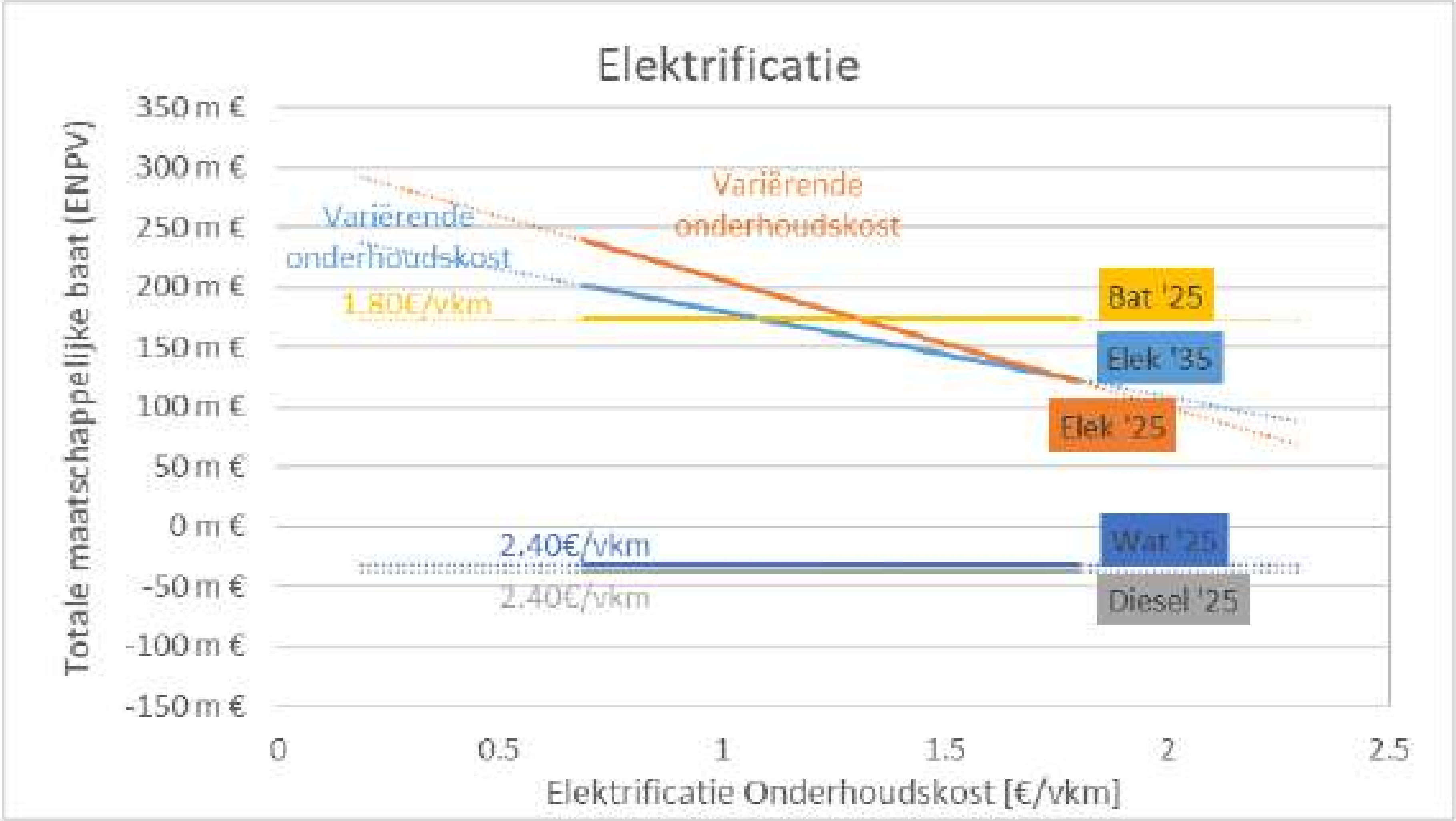
Monte Carlo analysis

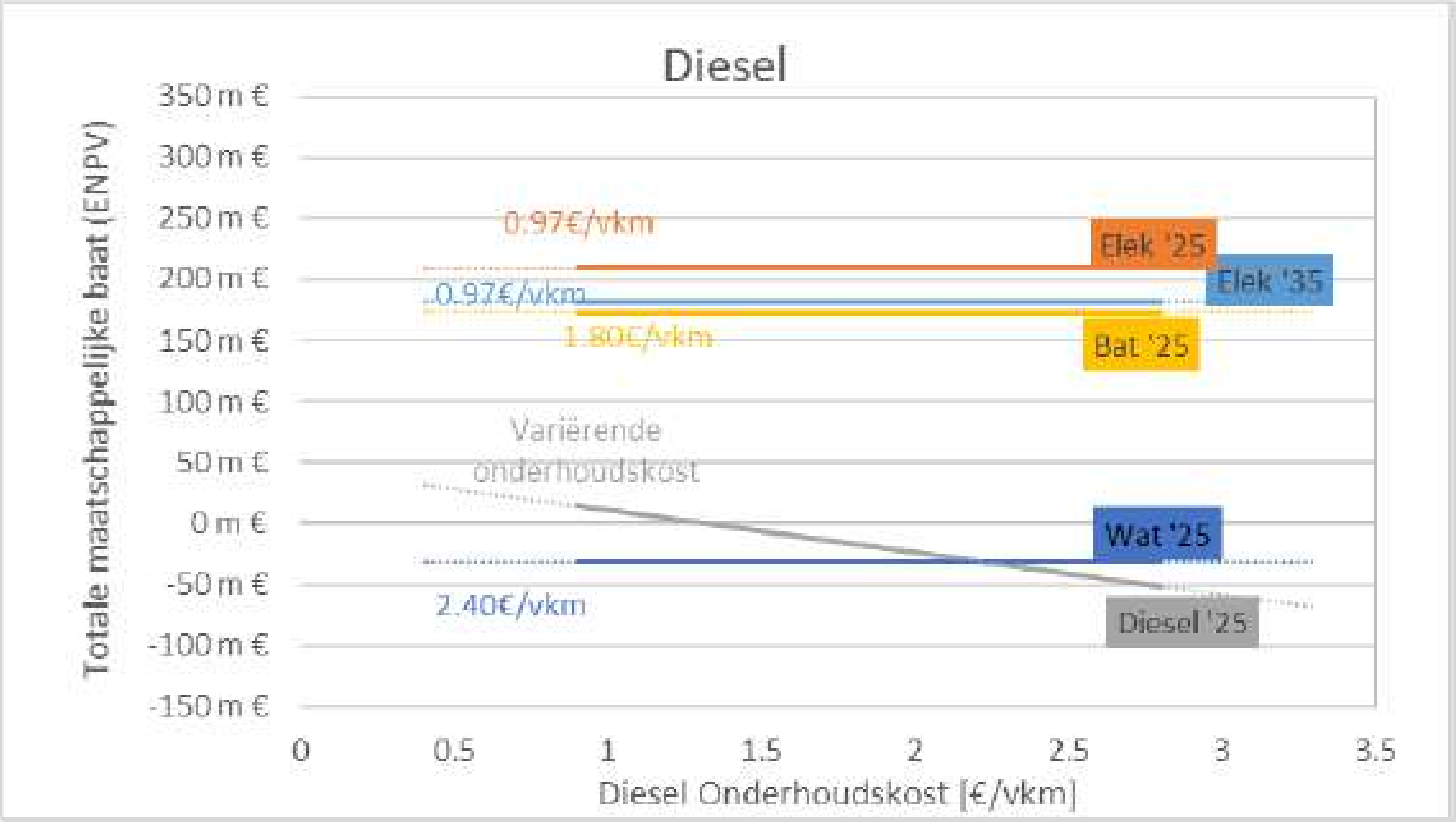


Monte Carlo: Generate results using a triangle distribution-> 1000 NPV simulations => proxy for sensitivity and distribution of result

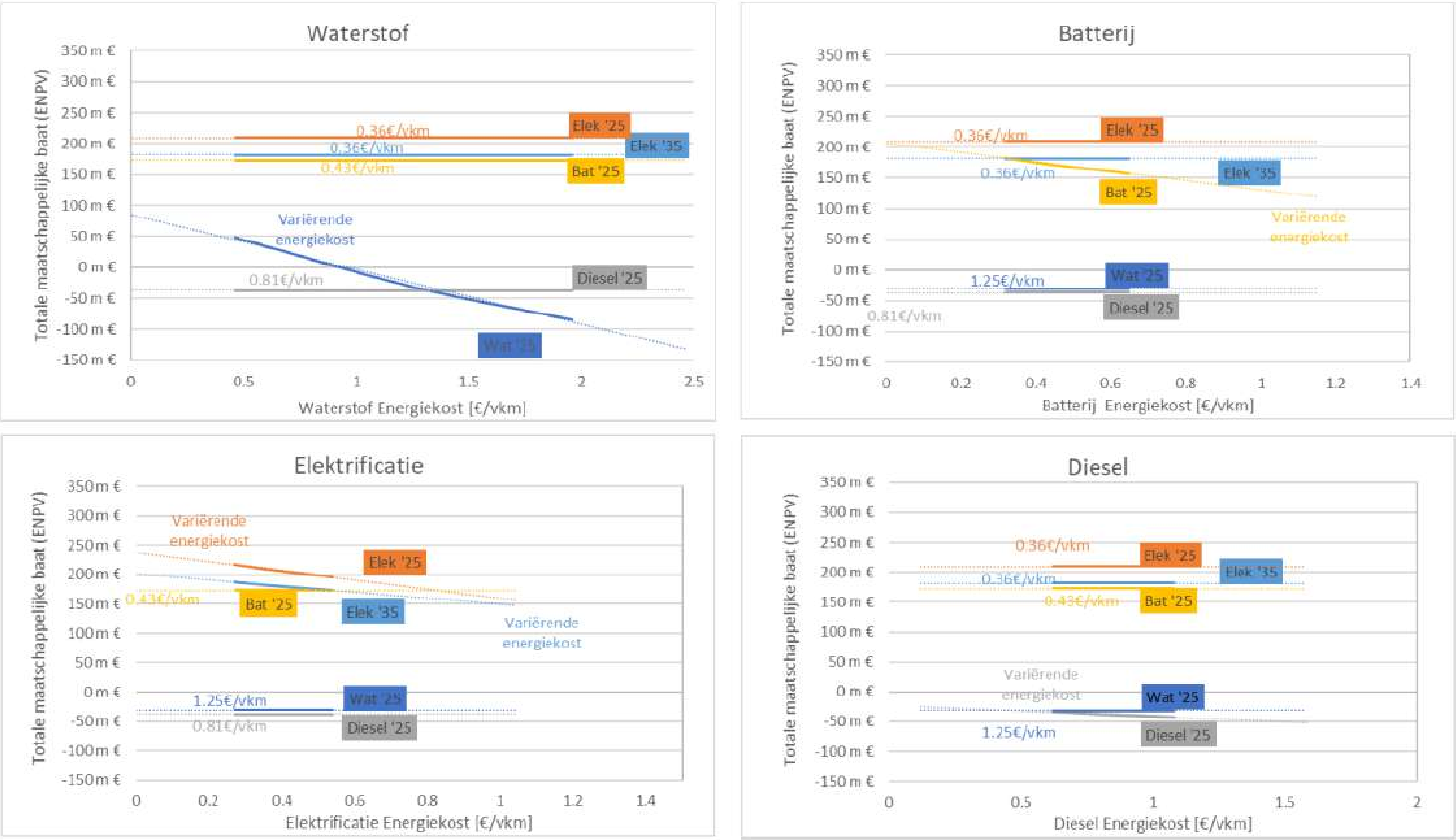








Sensitivity for maintenance cost -> ceteris paribus
Large impact for hydrogen & battery train -> not enough to change ranking



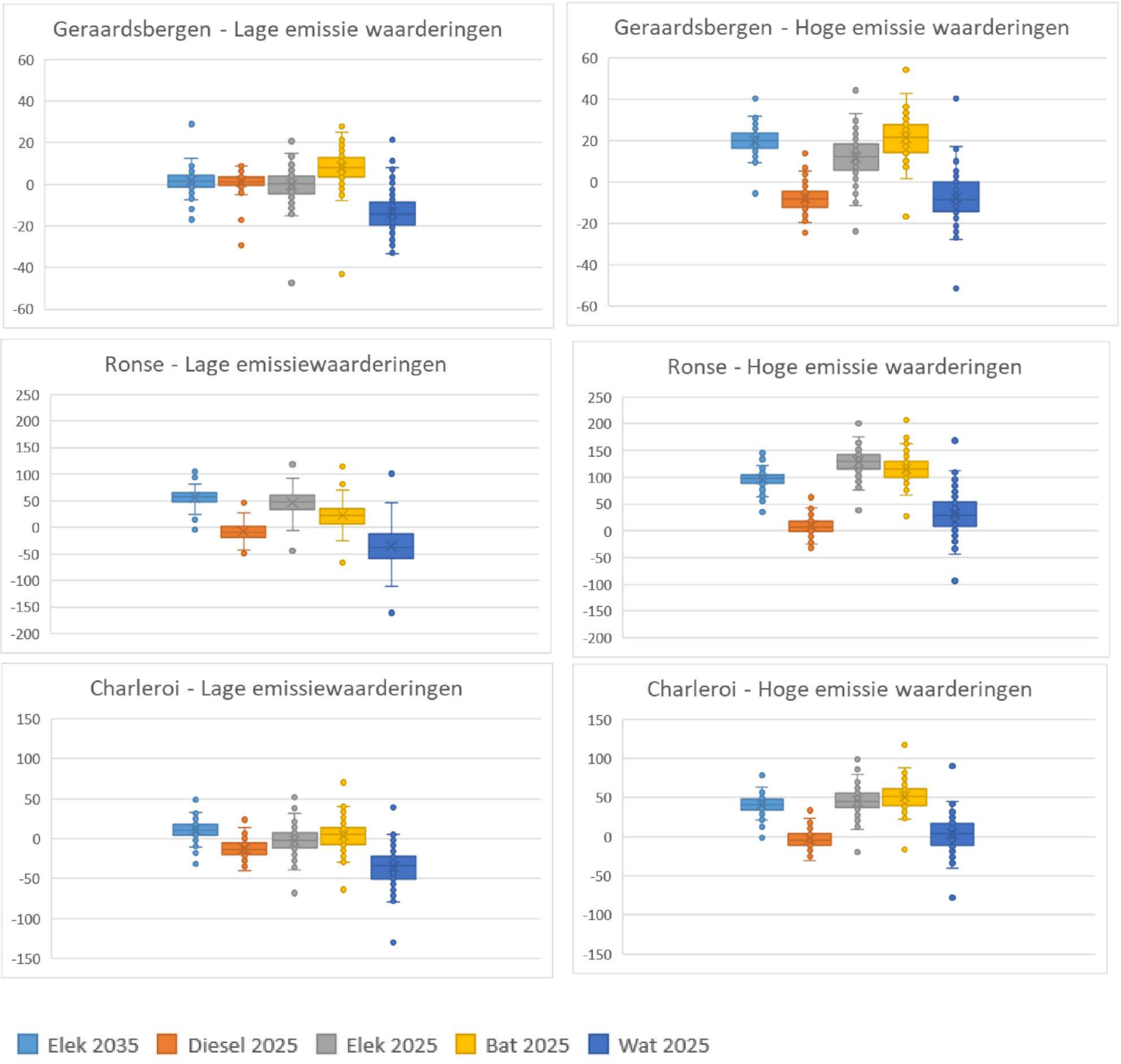
Sensitivity for energy cost -> only relevant for hydrogen, but less than maintenance cost

Differences by line

Geraardsbergen
Battery train looks more interesting

Ronse-Eeklo
Standard electrification

Charleroi
Battery + partial electrification may outweigh high cost of full electrification



Freight lines

Impact	Jaar	ENPV (30 jaar)
Reistijdsbaten (Mln. €_	1.782 €	32.60 €
Emissiebaten (optie) (Mln. €)	0.076 €	1.39 €
Onderhoud (Mln €)	-0.39 €	-7.08 €
Totaal (Mln. €)	1.585 €	26.91 €
Investering in bovenleiding (Mln. €)	12.90 €	
NPV (Mln. €)		14.01 €
IRR (%)		12.50%

L21c (Genk –Bilzen) very high NPV due to large time benefits & bottleneck situation + electrification of Mol-Hamont

	Lijn 204		Lijn 55	
Scenario	ENPV (€)	IRR	ENPV (€)	IRR
Basiswaarde	-3 324 139 €	1.9%	-19 417 786 €	/
Onderhoudskost 2% investering	-613 260 €	3.60%	-16 147 171 €	-9%
Emissiebaten 0.02 € / tkm	3 319 090 €	5.90%	-16 597 481 €	-10.20%
Tijdshorizon naar 40 jaar	-1 672 994 €	3.20%	-19 599 193 €	/
Combinatie van bovenstaande	8 887 303 €	7.90%	-12 676 826 €	-2.45%

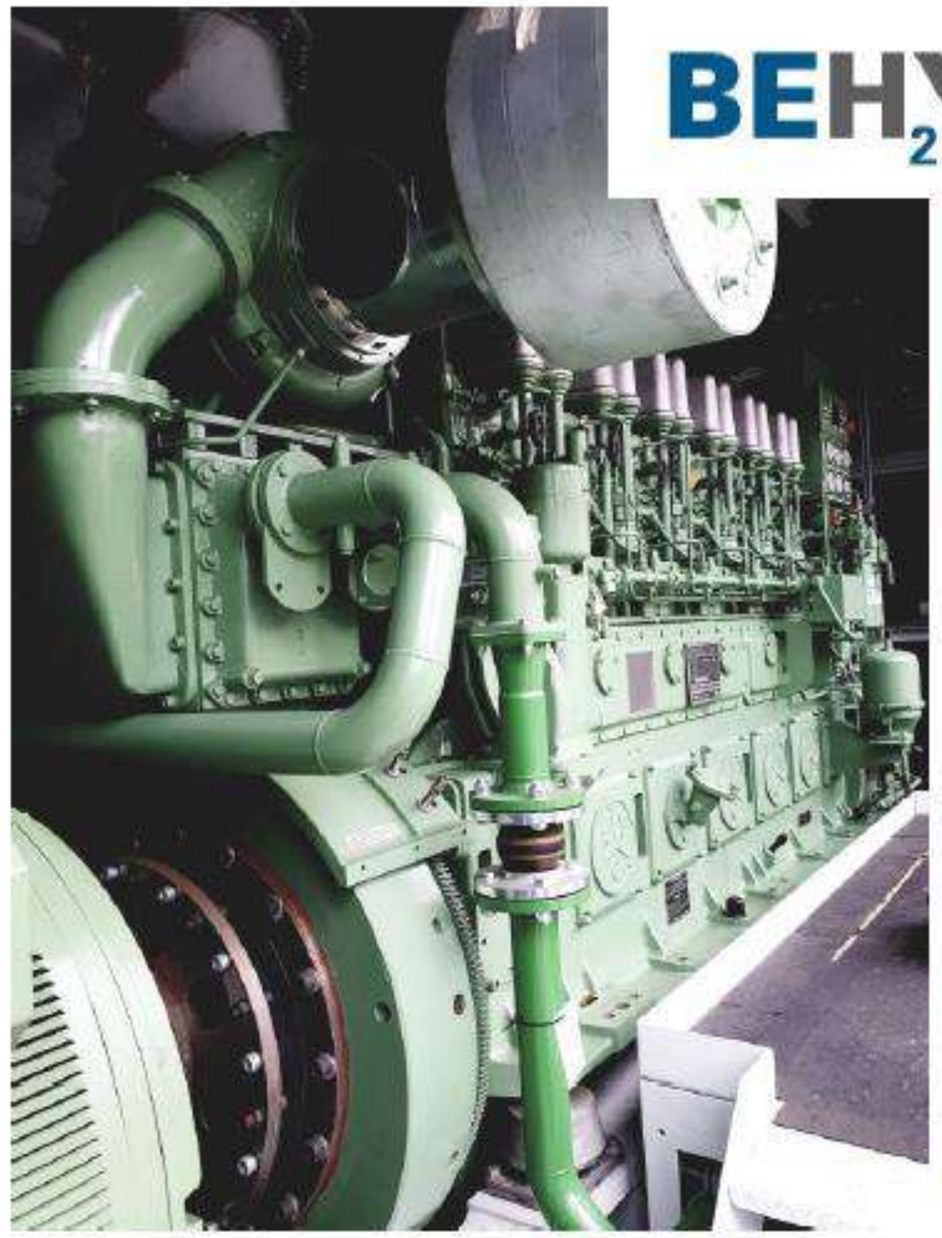
L204 (Gent N. – Zelzate) used more intensively than L55 (Wondelgem-Zelzate-Terneuzen)

L204 has a ‘marginally’ positive score for electrication
L55 very negative -> co-benefit with passenger market possible?

Other solutions for freight transport

Both medium/high speed as well as mono/dual fuel combustion engines are being developed

BEH2YDRO



Medium speed hydrogen engines are base on the proven DZ series from ABC engines

High speed engines are suitable for smaller applications

BEH2YDRO

SIEMENS

Contact | Global | English

Mobility Solutions | Portfolio | Insights | Trends | Company

Search for ...

Portfolio > Rail > Rolling Stock > Locomotives > Vectron > Dual Mode

Vectron Dual Mode

Keeps going where the wire ends

The Vectron Dual Mode is the up-to-date answer to changing route requirements. The dual power locomotives unite the advantages of full-featured diesel locomotives with those of electric locomotives. The combination of powerful diesel drive and equipment for using the overhead wire empowers you to respond flexibly at all times to your traction requirements – so you'll always keep moving, with or without an overhead wire.

Interested in Vectron Dual Mode? Our Mobility experts will be happy to advise you.

> Contact us

Dual mode electric/diesel

Conclusion

- On European market -> substantial amount of lines presently not electrified
- In Belgium largely electrified, but limited amount of lines non-electrified + freight transport often has substantial problems bridging last-mile (port lines often non-electrified)
- Market analysis, including substantial sensitivity analysis, shows that either full or partial electrification of trains is the best solution
- Hydrogen trains in the present analysis show a number of disadvantages, though this may be compensated in the future
- Freight trains: future in hybridisation, either with hydrogen or with a dual mode (diesel/electric). Problem -> cost disadvantage + low range

DANK U!

INTERNATIONAL UNION
OF RAILWAYS

Questions

Discussion

Christophe Heyndrickx

Thank you for your attention.

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TUC RAIL INFRASTRUCTURE INTERFACES

Actual & future battery charging possibilities interoperability & standards

Paul TOBBACK
Lead Design Engineer & OCL expert

Picture: Alstom

Find the *really* new kind of rolling stock and look for the differences !

Introduction

What about the infrastructure ?

Picture: Siemens

Charging station in Paris

Picture: Von Scanné par Claude Shoshany - Collection personnelle, Gemeinfrei, https://commons.wikimedia.org/w/index.php?curid=1516434

Picture: Bombardier

TUC RAIL
BELGIAN RAIL ENGINEERING

INFRABEL
Right On Track

Challenges for the OCL (Overhead Contact Lines) & power supply (energy subsystem)

Legal (EU): TSI's (Technical Specifications Interoperability) & (parts of) EN-standards when referenced

Technical: standards (UIC550, UIC552, EN50546, EN50119, EN50367, EN50388, etc. and their IEC counterparts)

Legal or technical, these documents were not written for trains with batteries for traction purposes !!

Legal - Joint Task Force EIM/CER/EPTTOLA/NBRAIL

Kick off 17/03/2021

Up till now participation from different stakeholders like infra managers, railway undertakings, lessors and Notified Bodies:

- Trafikverket / Bane NOR / Infrabel / SNCF / DB / ÖBB / ČD / RFI / Angel Trains / Sconrail

UNIFE (rolling stock manufacturers) judged it too early to support it already

Despite non-participance by UNIFE a clear interest was expressed during bilateral meetings with Siemens Belgium and Bombardier, but no priority for ERA (European Railway Agency)

→ *unofficial TF, but not forgotten by ERA and the EC (European Commission)*

→ please join if interested and contact your representative body

In parallel on technical level:

Cenelec workstream in CLC/SC9XC for a TS on "*Railway applications - Fixed installations - Requirements for charging stations for accumulator electric traction units based on separate contact line sections*".

- Corresponding CLC WG 25 to further work on the scope and draft the proposed way forward
- The contact line section is not connected to other overhead contact line systems of electrified railway lines and is fed separately

Objectives Joint Task Force

- Facilitate interoperability and support the EU Green Deal

- Key objective short term:

  interoperability requirement proposals for TSIs on short term objectives to allow and facilitate full charging of trains with batteries, without changing other existing requirements neither without blocking other modes of operation for battery train charging purposes **by April 2021** (for next TSIs 2022 version)

- Long term objectives:
  - provide inputs for European standardisation needs
  - reduce costs for the ENE subsystem enabled by the usage of battery trains

Key topics Joint Task Force

- In order to design correctly the OCL for battery trains while charging, it seems necessary to:
  1) define the train needs
  2) then work on OCL

1) Power demand from the batteries ?

3 Examples with proposals from Stadler for BaneNOR (15kV AC):

2 MW = BEMU (common example in many countries and tested/in operation already; “Aramis”, FLIRT)
3 MW (385ton train with 7 cars or last mile freight train; “Athos” locomotive = Eurodual)
4 to 5 MW (1200ton freight train; “Porthos” locomotive = Euro9000 with battery tender)

Train operation studied for Norvegian cases, e.g. a 729km line Trondheim-Bodø, to be only partly electrified over a total of 210km (28,81%, 8 separate electrified sections)

Key topics Joint Task Force

- Short term: main issue: actual requirements on Current at standstill for DC systems only (because of much lower voltages compared to AC systems and thus higher currents to have enough power for auxiliaries like heating & air conditioning in modern rolling stock)

  proposal introduced to include requirements for AC-systems in TSI ENE (energy) and L&P (rolling stock), but referring to actual limits in the standards → to be discussed with ERA

- A summary of all actual possibilities for charging at standstill & auxiliaries and **their limits** (**2 MW** at best):

Solution	System voltage	per pantograph Max current	per pantograph Max power	Standard			
Current collector	25 kV ac 50 Hz	80 A	2.0 MVA	EN 50367			
	15 kV ac 16.7 Hz	80 A	1.2 MVA	EN 50367			
	3.0 kV dc	200 A	0.6 MW	TSI ENE			
	1.5 kV dc	300 A	0.5 MW	TSI ENE			
Plug UIC 552	3.0 kV dc	800 A	2.4 MVA	UIC 552	315 A	0.9 MVA	BE national rule
	1.5 kV dc	800 A	1.2 MVA	UIC 552	600 A	0.9 MVA	
	1.5 kV ac 50 Hz	800 A	1.2 MVA	UIC 552	600 A	0.9 MVA	
	1.0 kV ac 16.7 Hz, 22 Hz, 50 Hz	800 A	0.8 MVA	UIC 552	600 A	0.6 MVA	ÖBB more common value
Shore supply plug	400 V ac 50 Hz 3~	63 A	0.044 MVA	EN 50546			
	400 V ac 50 Hz 3~	125 A	0.087 MVA	EN 50546			
	400 V ac 50 Hz 3~	600 A	0.416 MVA	EN 50546			

Key topics Joint Task Force

- 4 existing target systems for power supply from the OCL through the pantographs
- Towards a 5th power supply system: 15kV AC 50 Hz for countries using already 15kV 16.7 Hz (D, A, CH, SE, N, …) ?
  Increasing the frequency on separate charging facilities has a number of advantages for infrastructure, even regarding the public grid from which the power is sometimes taken, without major consequences on rolling stock, thus reducing overall investment costs.

- Plug solutions have limited power, but can be sufficient for slow charging (≥ 60min), e.g. overnight in stabling yards, using (smart) multiple socket units and offered as a service, with different management, metering and invoicing (per kWh or just per hour).

Example from DB Netze

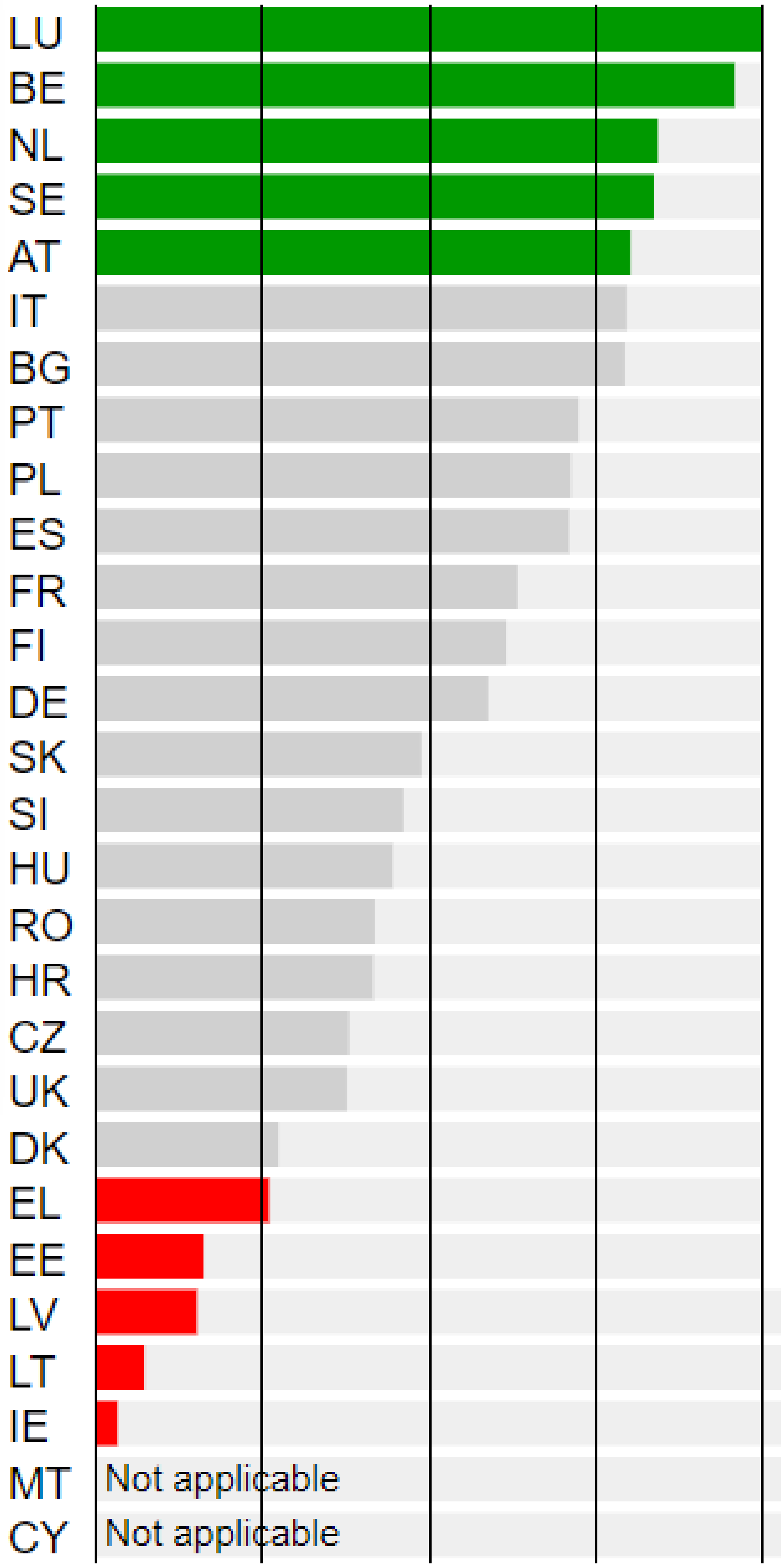
what about the BE case (mostly 3kV DC)?

Study TML ! Infrabel & SNCB strategy 2040 !

SNCB: “no H_2 please, only EMU (or BEMU)”

Benchmarks Railway electrification in Europe

Percentage geëlektrificeerde lijnen EU (Europese comissie – Transport, **2016**)



95% (14/280 km niet-geëlektrificeerd)

86% (500/3600 km niet-geëlektrificeerd; *2023, reizigersnetwerk: 96%*)

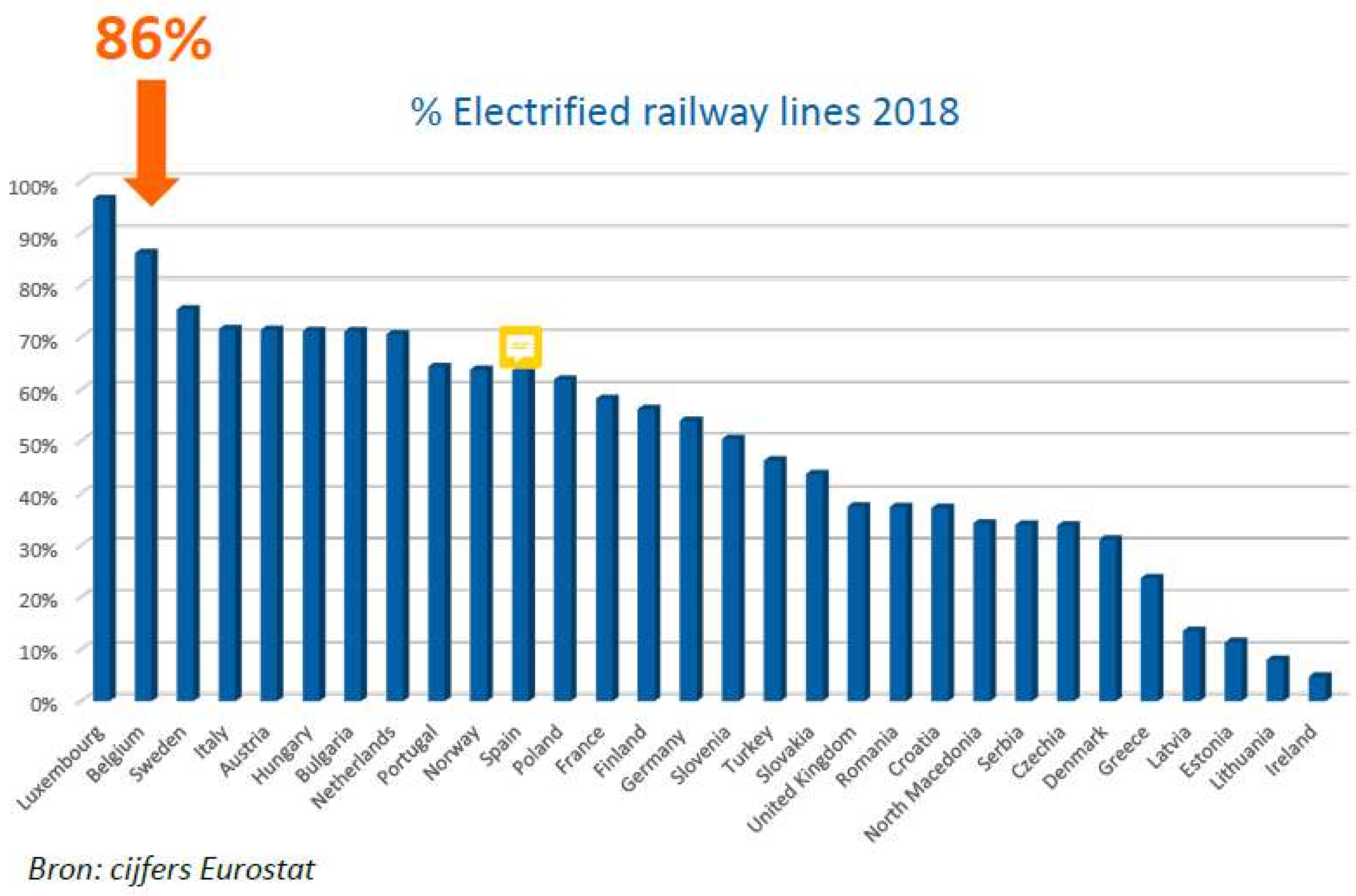
76% (740/3100 km niet-geëlektrificeerd)

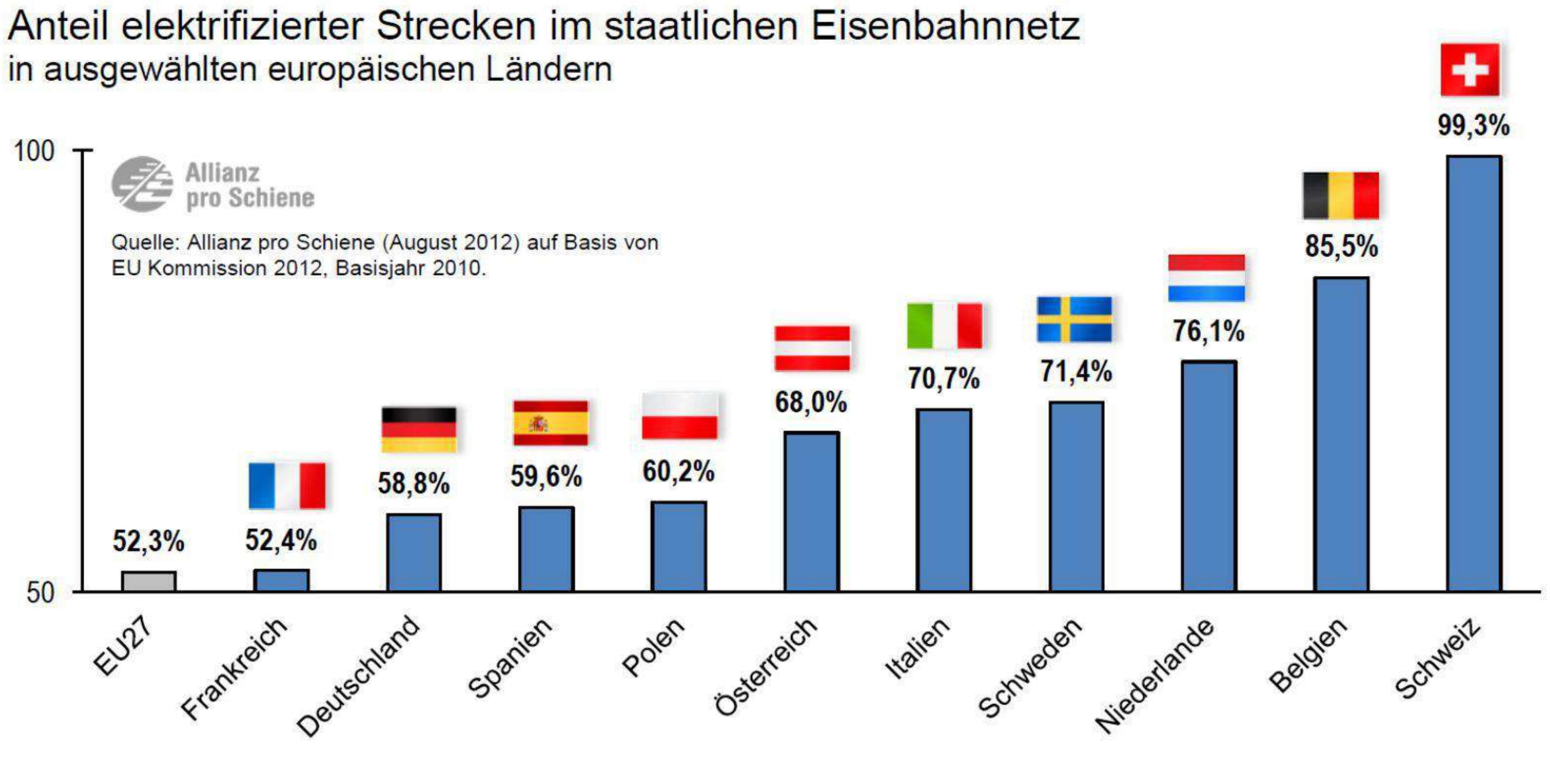
72% (1500/5500 km niet-geëlektrificeerd)

57% (12000/29000 km niet-geëlektrificeerd)

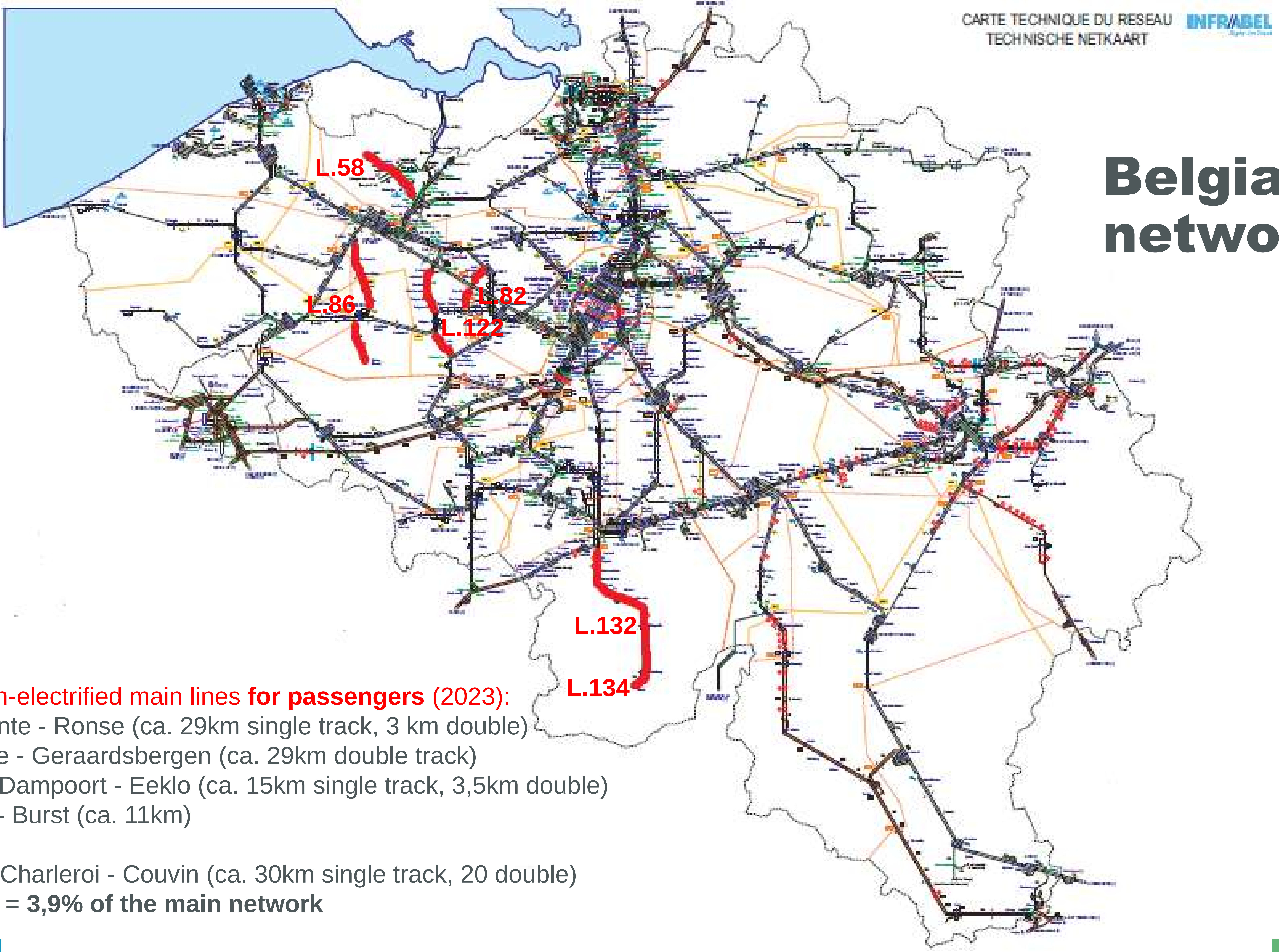
53% (19000/41000 km niet-geëlektrificeerd)

34% (11000/16000 km niet-geëlektrificeerd)





Belgian network



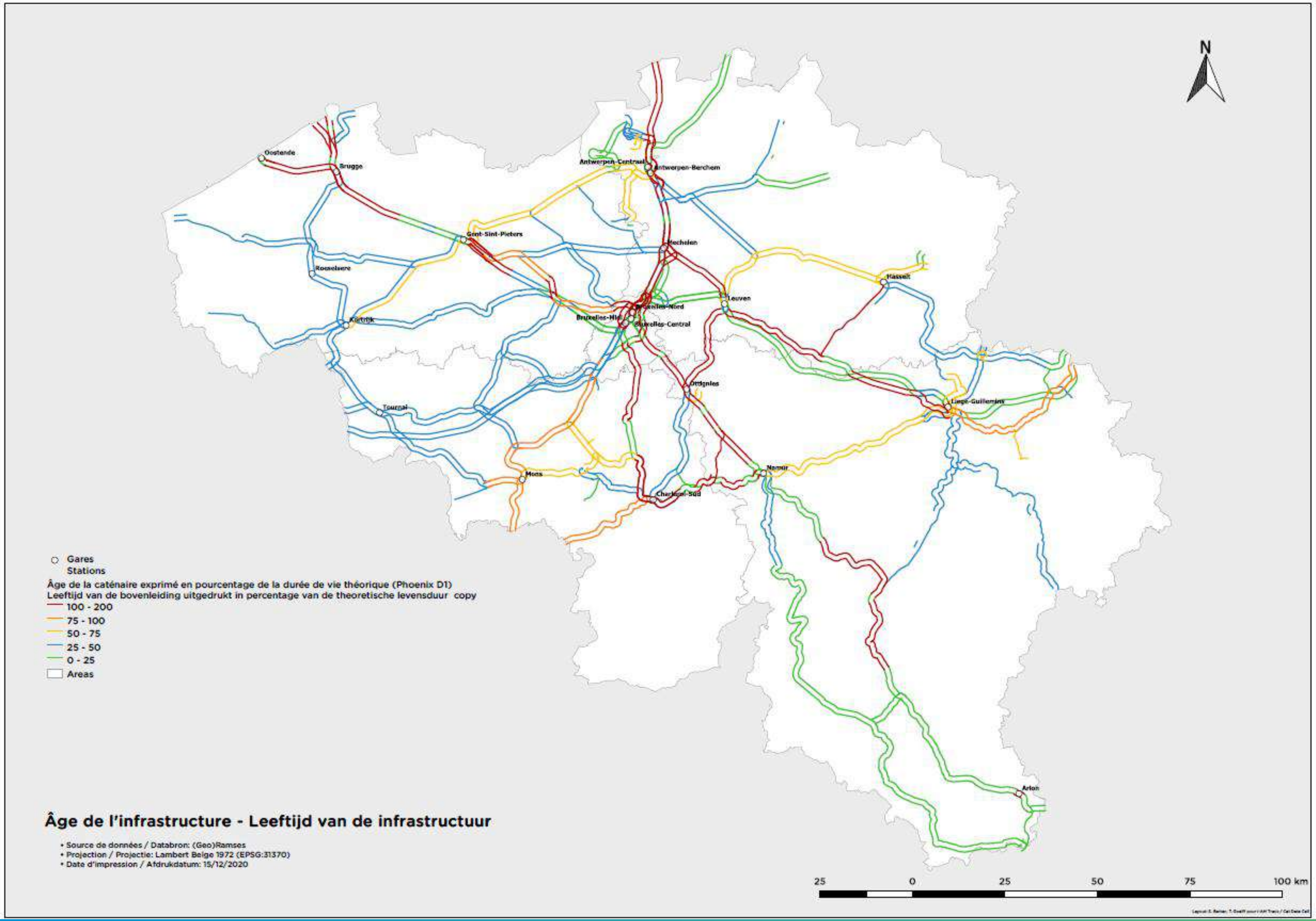
Remaining non-electrified main lines **for passengers** (2023):

- L.86 De Pinte - Ronse (ca. 29km single track, 3 km double)
- L.122 Melle - Geraardsbergen (ca. 29km double track)
- L.58 Gent-Dampoort - Eeklo (ca. 15km single track, 3,5km double)
- L.82 Aalst - Burst (ca. 11km)

- L.132-134 Charleroi - Couvin (ca. 30km single track, 20 double)

140 / 3600 km = **3,9% of the main network**

What will the situation be over 10 years ? An OCL is built for 80 years !



Renewal Strategy OCL & substations

After 20 years

→mid-life upgrade substation

After 40 years

→renewal substation

→mid-life upgrade OCL

After 60 years

→mid-life upgrade substation

After 80 years

→renewal substation

→re-electrification with OCL ? Partly ??

When BEMUs and hybrid locomotives are generally used, future simplifications of the OCL network can be considered

For the remaining 5 non-electrified passenger lines in BE:

- flexibility in scope and timing of electrification

In the long term:

- Avoid difficult/expensive (re-)electrification (tunnels/turnouts…)
  → *Better for punctuality and maintenance costs*

- Less power demand on weak spots of the network / public grid
  → *Less investment needed just for one rush hour train per day*

- Possibility to run through earthed route sections
  → *Less impact of work possessions/detours*

- Possibility to avoid non-profitable re-electrifications (e.g. 12,5km *branch* line Pepinster-Spa, *but which did continue a long time ago !*; electrified >50 years ago)

L132 tunnel with interlaced tracks (and many more obstacles and difficulties)!!

What part to electrify if not the complete route ?

There can be huge differences in cost/km a few km further on a route !

Depends on mainly the terrain for OCL, but on the number of substations (cost/unit, not per km !) to be built and their specific locations with possibilities to connect to the public grid (invest in underground cables or overhead contact lines ?).

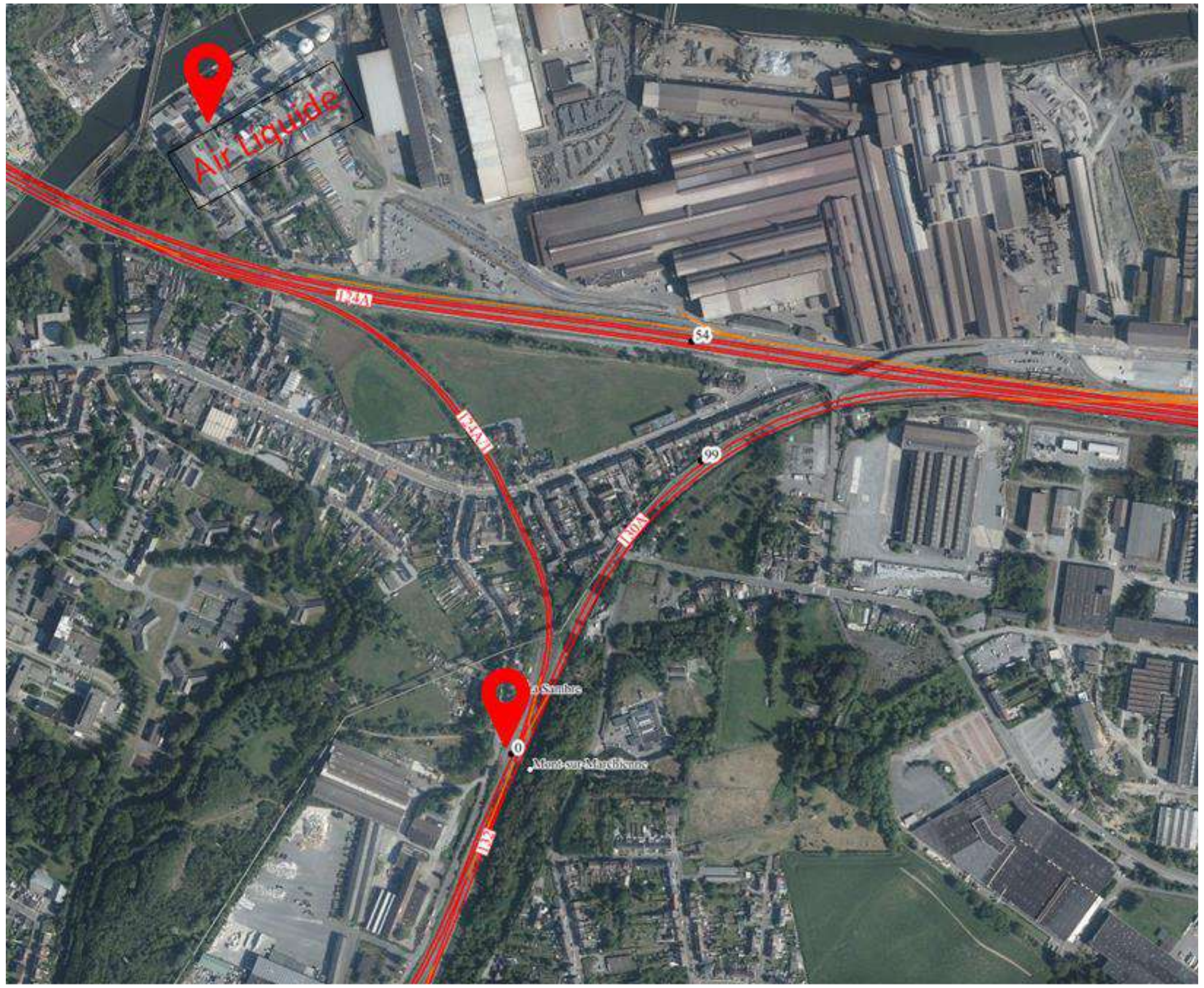
Here or here on L132 ?

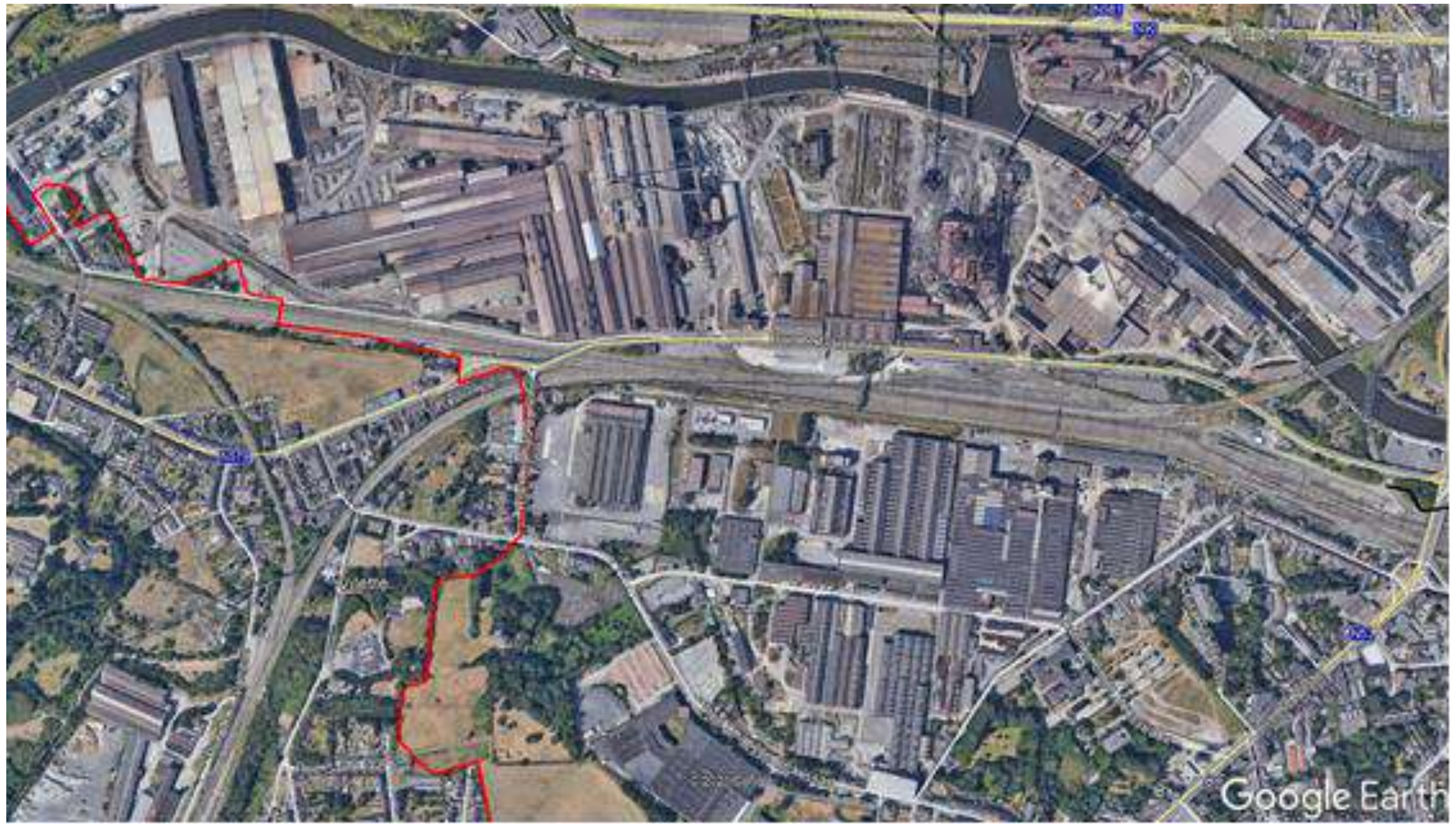
Electrification revisited: never forget the H_2-option

(but that's another workshop)

L.132-134 Charleroi - Couvin (ca. 50km, the longest non-electrified main line in BE): H_2-pipelines in the immediate vicinity and even crossing the railway network !
And close to the start of the non-electrified part, but a bit further from the stabling yards & workshops !!

HEMU = BEMU with about 30-40% of the battery energy and a FC-range extender !





Key topics

→ EVOLUTION of STANDARDS in TSI ENE:

EN50119:2019: new version ! *Transpose changes in IEC 60913*

EN50367:2020: amendment 2021 finished on 14/04/2021, waiting for comments and vote; adapted regarding current at standstill

EN50388-1 and 50388-2: still under revision, but including some elements on battery train operation

Solutions

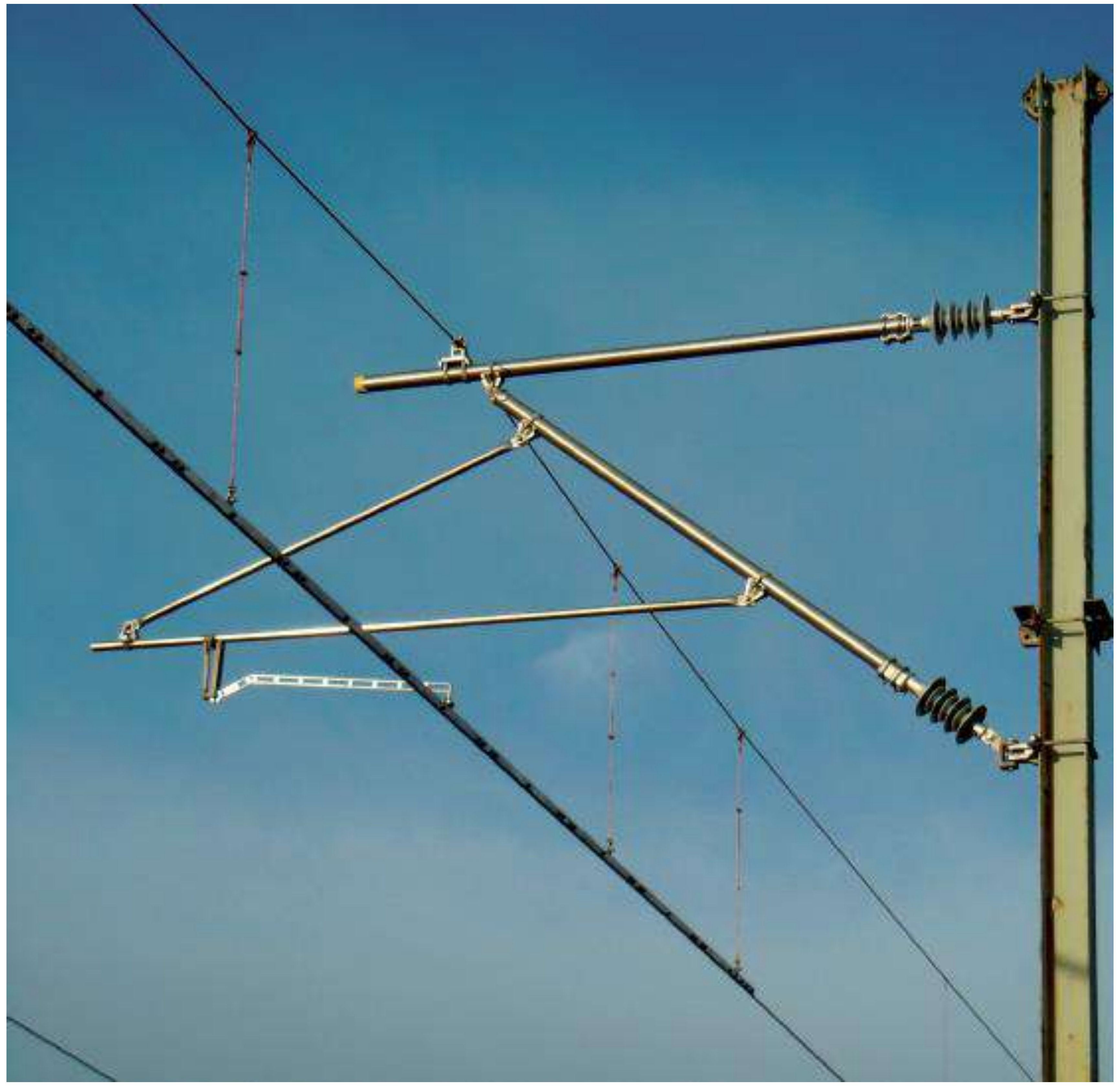
e.g. From the actual legal 300A under 1,5kV DC to 500A

Tübingen(D) 15kV AC – 80A/pantograph – ROCL = Rigid OCL

https://www.swtue.de/geschaeftskunden/energie/strom/voltap.html

On the INFRA side

Reinforced OCL – e.g. SNCF RER C (Dourdan) / Depot Sweden (Västerås) / Metro Line 5 India (Delhi)



Profile to be added on an existing catenary to better dissipate the heat at the contact point between the contact wire and pantograph Reinforced OCL

On the RST side

SNCF SALTO project (nothing new !):

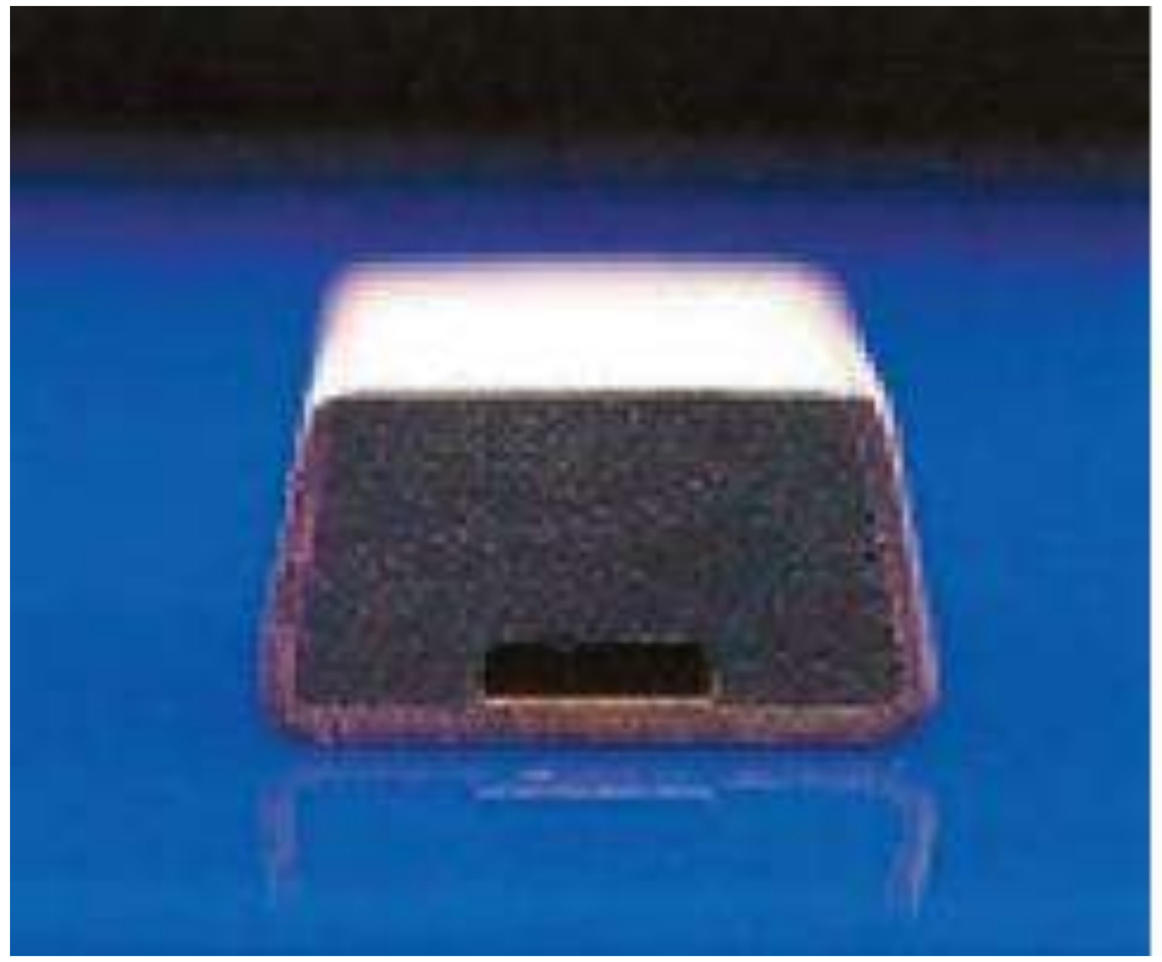
•At standstill, a mobile copper strip on the pantograph is raised to the OCL

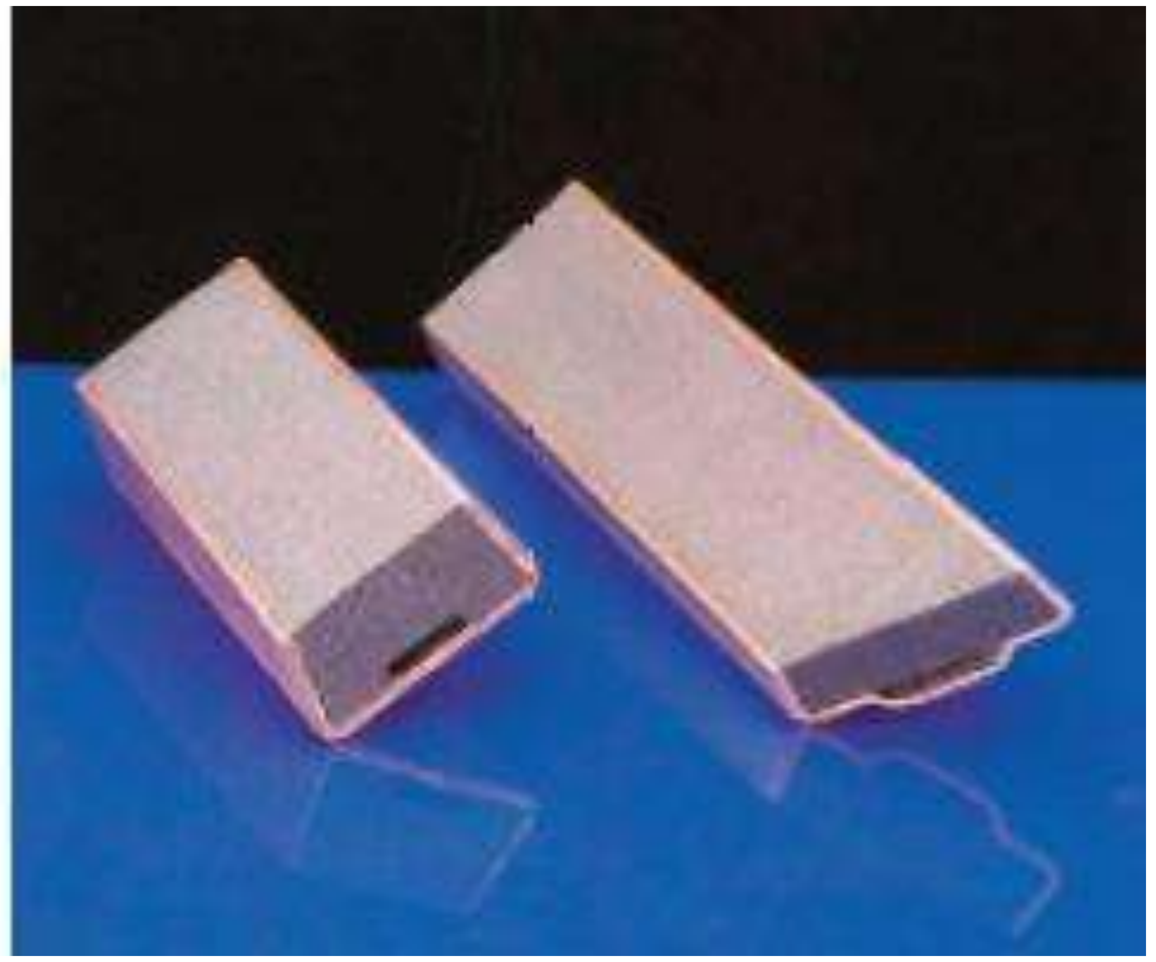
•It is lowered as soon as the train exceed 8km/h

•Under 1,5kV, the equipment was tested up to 500 A and it worked. It could probably work with higher values.

On the RST side

“Kasperowski” contact strips (nothing new again ! Still used e.g. in BE, FR and CH on older type of heavy pantographs):



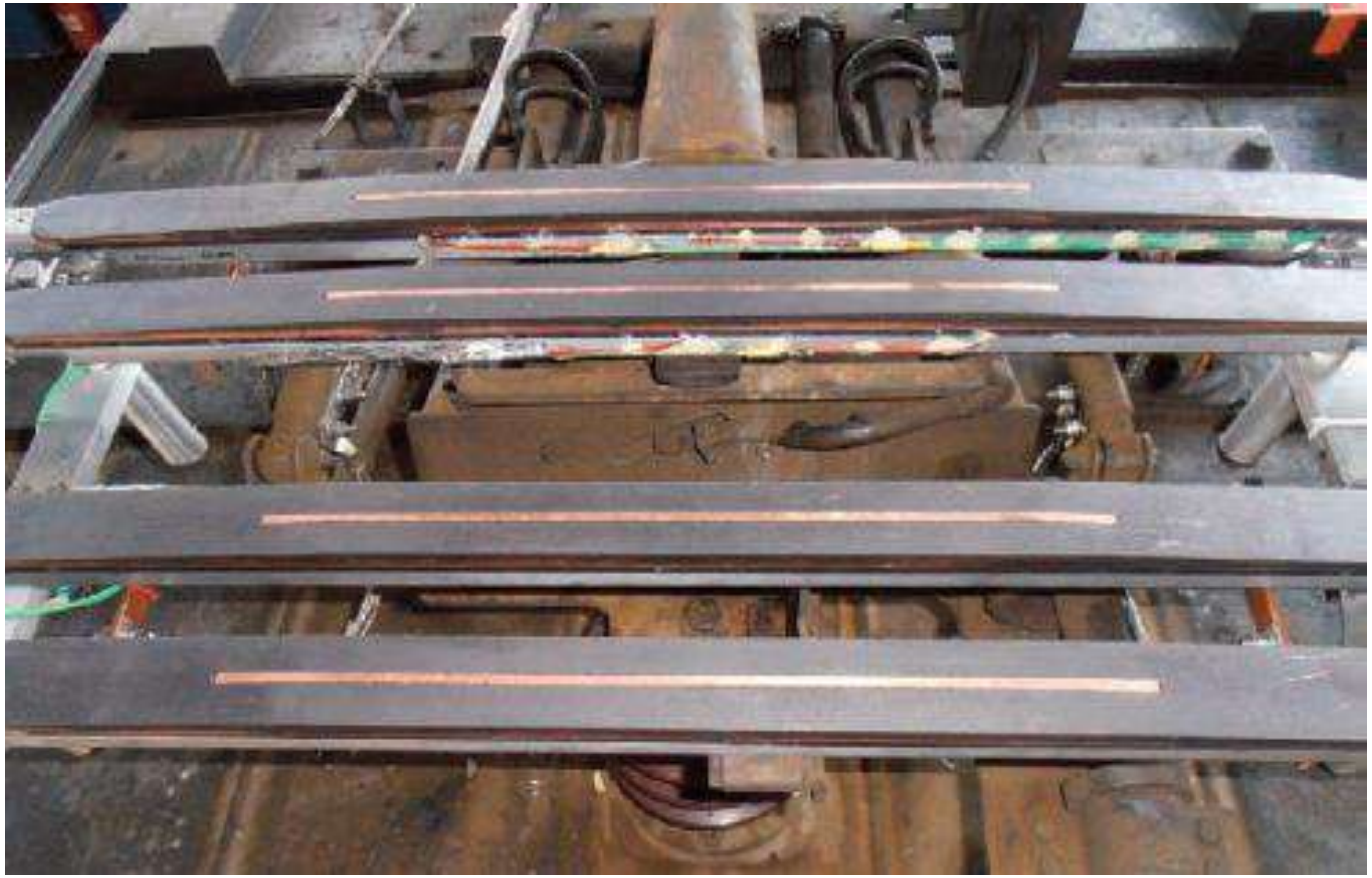


But some problems in winter time with frost on the contact wires: Cu melted because of arcs

On the RST side

Use of Cu inserts in the centre of the contact strips

Revue Générale des Chemins de Fer, Decembre 2015, p.15-21



research/projects

current at standstill : (on going) tests by RSSB (UK), TU Dresden (D), IfB (Infrabel), RFI, Ricardo (NL/F), etc.
→ EN50367 Annex A3.

to evaluate possibilities of charging from an OCL (rigid or flexible) under real circumstances (identify margins between more common circumstances and rare worst cases)

Overview of ongoing tests on current at standstill

Tests TU Dresden: see article Elektrische Bahnen 119 (2021) Heft 3, p.100-109

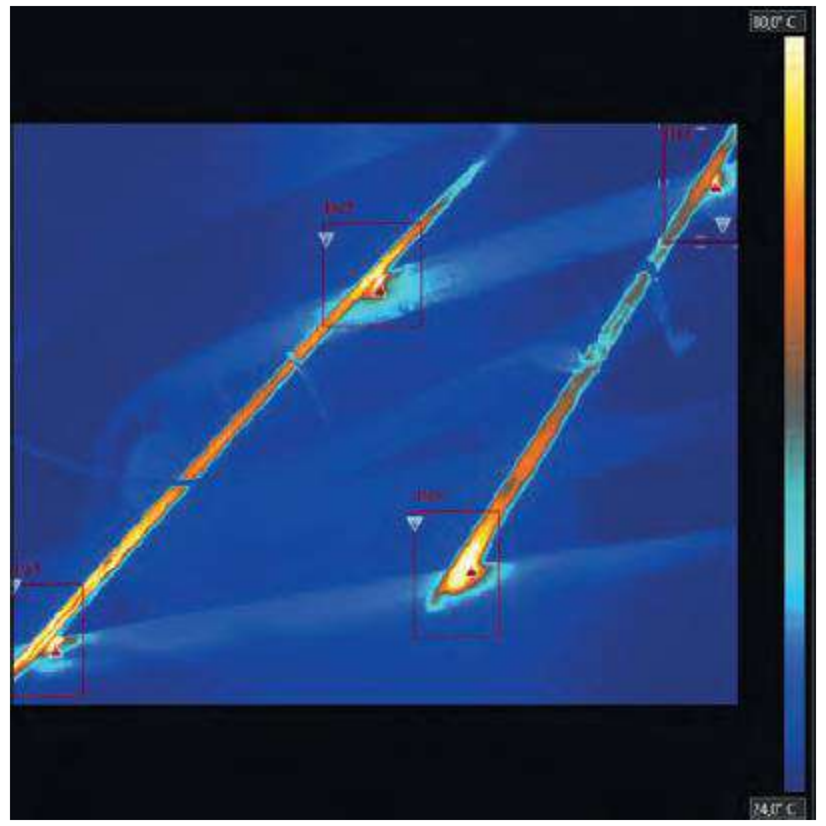
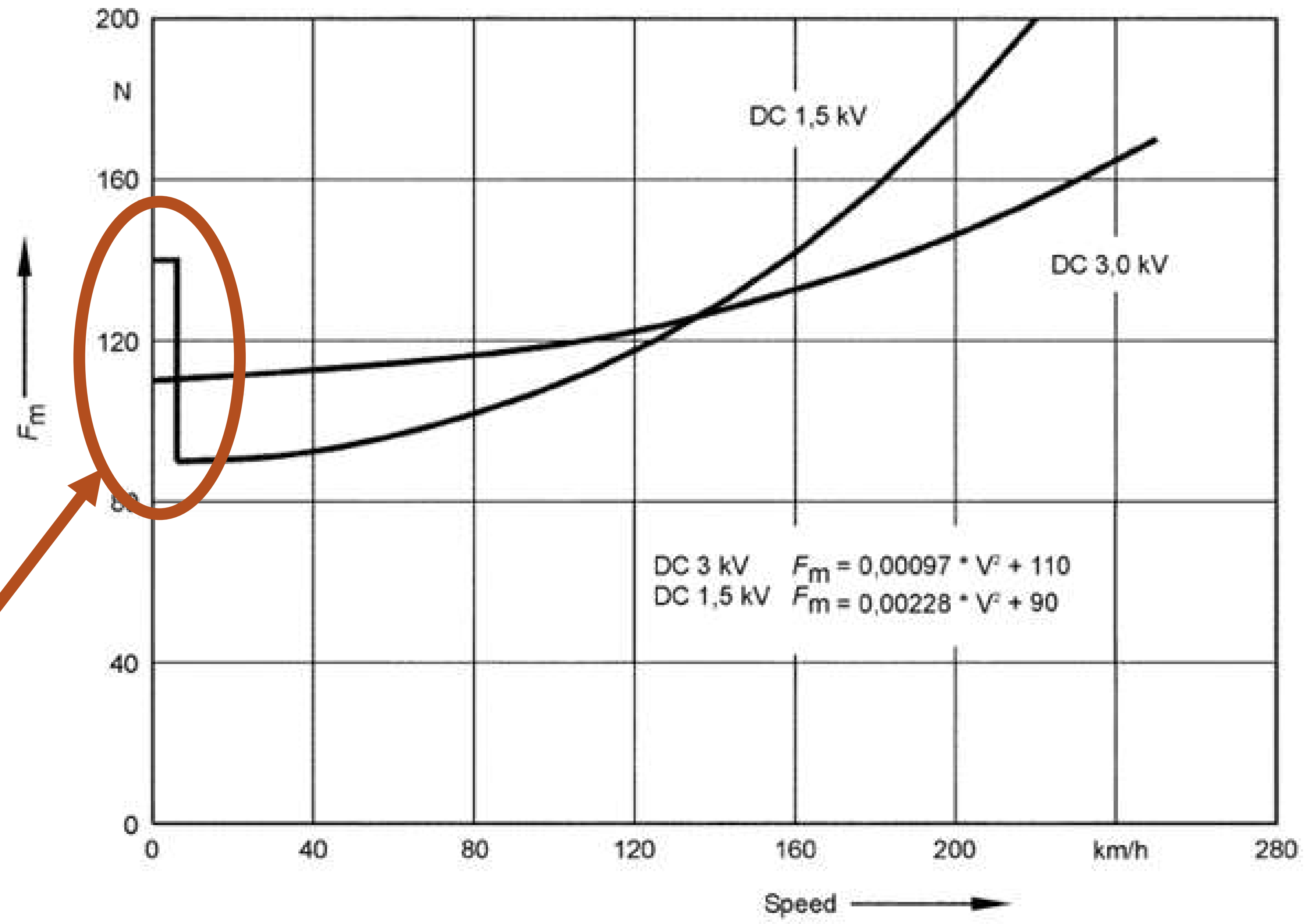


Figure 5.2

Target for mean contact force for F_m for DC 1,5 kV and DC 3,0 kV lines depending on the running speed



With plain carbon contact strips, depending on the configuration:

- 140N static contact force instead of 70N as usual in AC systems
- 2 rigid OCLs with a CuAg 120mm² wire, spaced 40 cm apart

it is possible to go from the actual legal 80A to 220A !

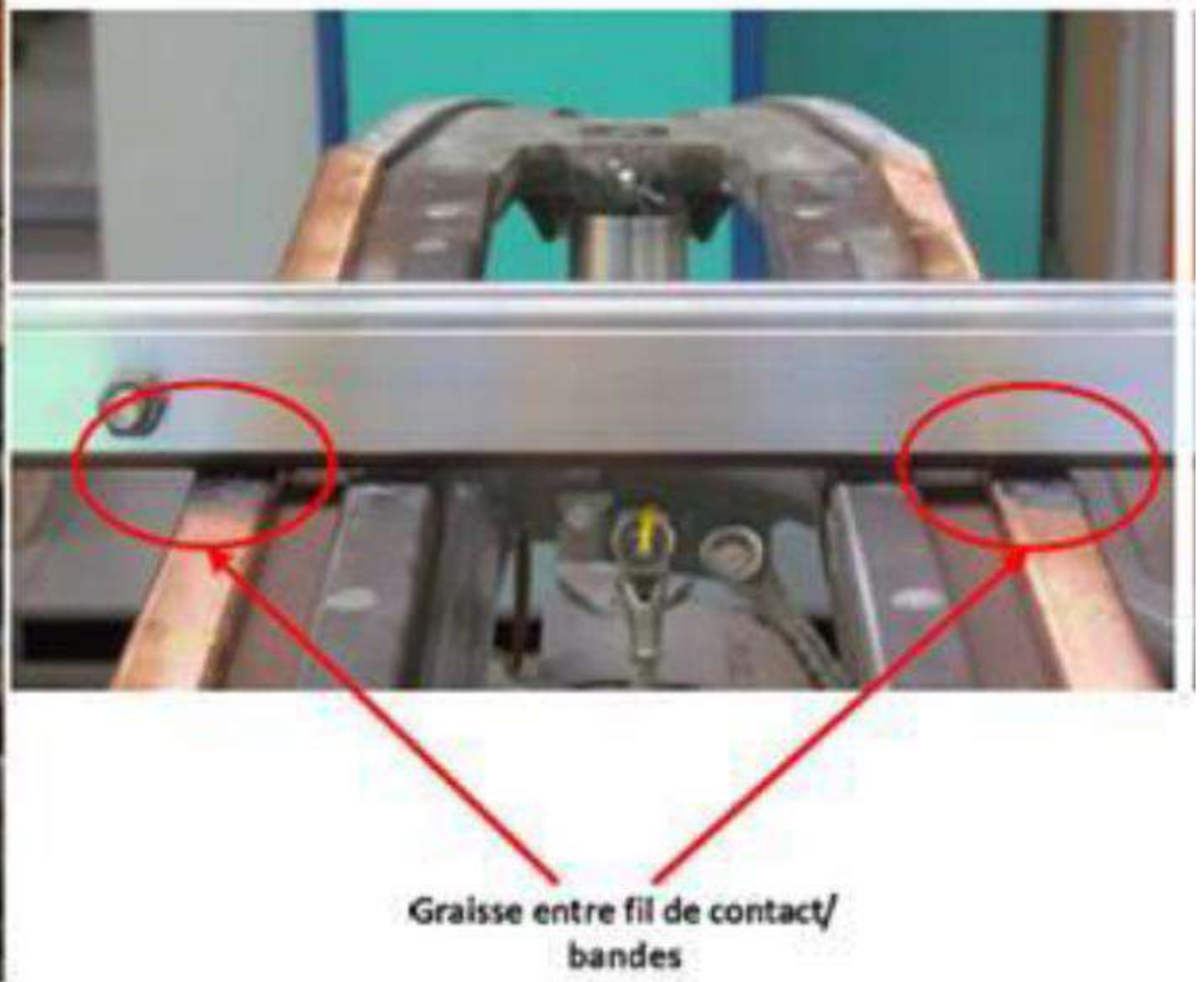
→ **3,3 MW** under 15kV AC

→ **5,5 MW** under 25kV AC !

→ With Cu impregnated carbon contact strips, this can even be improved.

Overview of ongoing tests on current at standstill

On contact wire with the reinforcement profile : SNCF test has demonstrated that it works under 1,5kV up to 1000A during 30 minutes with a pantograph used on AGC trains (copper contact strips !)



Overview of ongoing tests on current at standstill

RFI: from the actual legal 200A to 300A under 3kV DC without need to change infrastructure ? We would even need 400A !

Infrabel: tests done in January 2021 on twin contact wires: huge margins towards temperature limits on **new** flat bottom wires (**as required by EN50367 Annex A.3**), but far less on **worn** wires due to contact force imbalances.

SNCF/PRoRail (1,5kV DC networks): more tests to be done soon (divergent results)

From previous tests by SNCF:

- Important parameter is the contact surface, more than the contact force
- 2 wires/ 1 wire or 2 strips/ 1 strip, it is not sufficient to divide by 2 or 4, test needed
- The more contact points the better
  - Increase the contact force increase the contact surface → Favourable
  - Increase the number of wire increase the contact surface → Favourable (even if spaced a few cm apart)

On the RST side (part 2) – possible future solutions ?

Carbon contact strips with integrated Optic Fibre to actively monitor in real time and under real environmental conditions the temperature of the contact point(s) instead of the current (and not the contact forces to assess dynamic behaviour as already done in e.g. the UK)

→ Functional requirement on the critical parameter instead of an indirect one (but difficult to measure and manage, hence all the tests with divergent results)

→ Direct and automatic possibility on the trains themselves to cut power demand at standstill to protect the infrastructure

→ Only if necessary when the passive solutions presented above are not sufficient

On the INFRA side (part 2) – possible future solutions ?

Monitor the temperature of the contact point(s).

This could be needed to avoid tripping by the circuit breaker feeding the section and send a message to the trains to cut power demand in case more than 1 train is charging, without individually passing the temperature (or current) threshold, and there’s too much current demand in total (which in DC would be surprising compared to traction current, but maybe not in AC).

As for the battery cars, trains may have different battery charging strategies

- a) *Long time charging cycle*: energy taken from OCL per pantograph corresponds to the capacity of existing OCLs (300A for 1500 V; 200 A for 3000V; 80 A for AC)
- b) *Medium* charging cycle: charge in a shorter time, with higher current
  e.g. for 1500 V DC: 600 A 5 min, then 300 A indefinitely
- c) *Quick charging* cycle : charge in 15 min
  e.g. for 1500 V DC: 1000 A 15 min, then 500 A 30 min and 300 A indefinitely

→ We need charging management, certainly for multiple trains, considering State of Charge (SoC) of the batteries, timetable, *auxiliaries*, etc. Link to control & command systems to pass coded messages between infra & rolling stock

→ Pay attention to high inrush currents when switching on !
Hence 15kV AC 50 Hz !!

Questions

Discussion

Paul TOBBACK
Lead Design Engineer & OCL expert

Thank you for your attention.

INTERNATIONAL UNION
OF RAILWAYS

BREAK

Break

Railways and UIC members are invited to join the

UIC project:

“H2TR - Operating hydrogen powered trains”

In partnership with the IEC

If interested, please reach out to stefanos@uic.org

Restarting at 11h05

Break

Restarting at 11h05

https://uic.org/events/battery-trains

Online workshop coming up next:

September 2021

Call for speakers on ***stationary energy storage****,*

contact stefanos@uic.org

Restarting...

11 h **Second part**

• SNCF	**François Degardin** **Bogdan Vulturescu**	**Matthieu Renault** **Benoît Gachet**
• Siemens	**Katrin Seeger**	
• Eaton	**Akos Labady**	

SNCF
BATTERY Trains PROJECTS

- **François DEGARDIN**
  - Energy project manager at the Innovation & Research Department of SNCF
  - Leader of the regional hybrid train project and biogas feasibility study

- **Matthieu RENAULT**
  - Technical manager at SNCF Voyageurs rolling stock engineering centre
  - In charge of the regional hybrid train and regional battery train projects

- **Bogdan VULTURESCU**
  - BEMU project manager at Innovation & Research Department of SNCF

- **Benoit GACHET**
  - Product director high capacity regional trains, Alstom

INTERNATIONAL UNION
OF RAILWAYS

SNCF
BATTERY TRAINS PROJECTS

UIC Workshop

Battery trains

19/05/2021

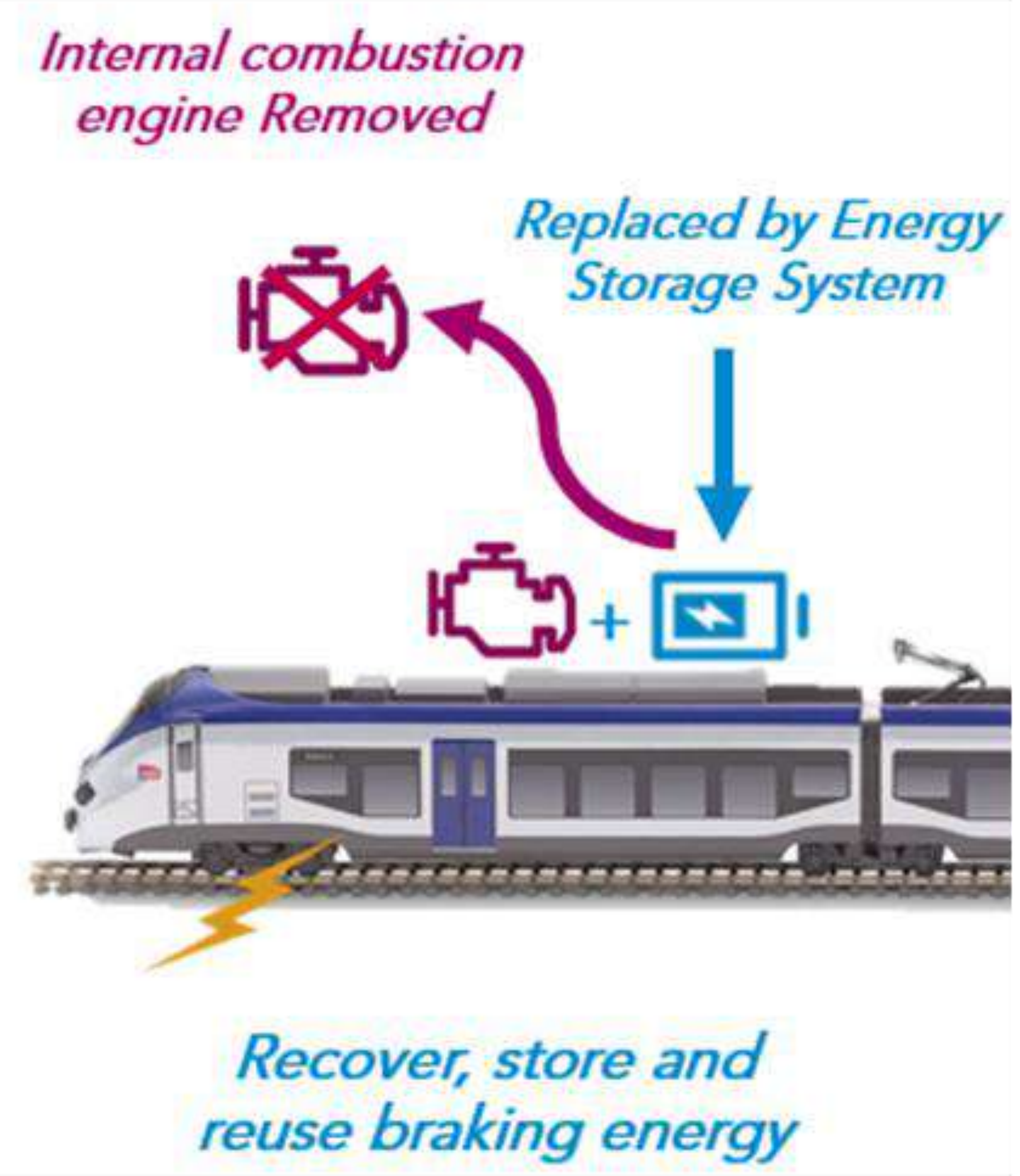
Agenda

Solutions portfolio

Overview of hybrid train projects

Hybrid train

Principles



Energy Storage System

Power converter

5 battery packs

Liquid cooling unit

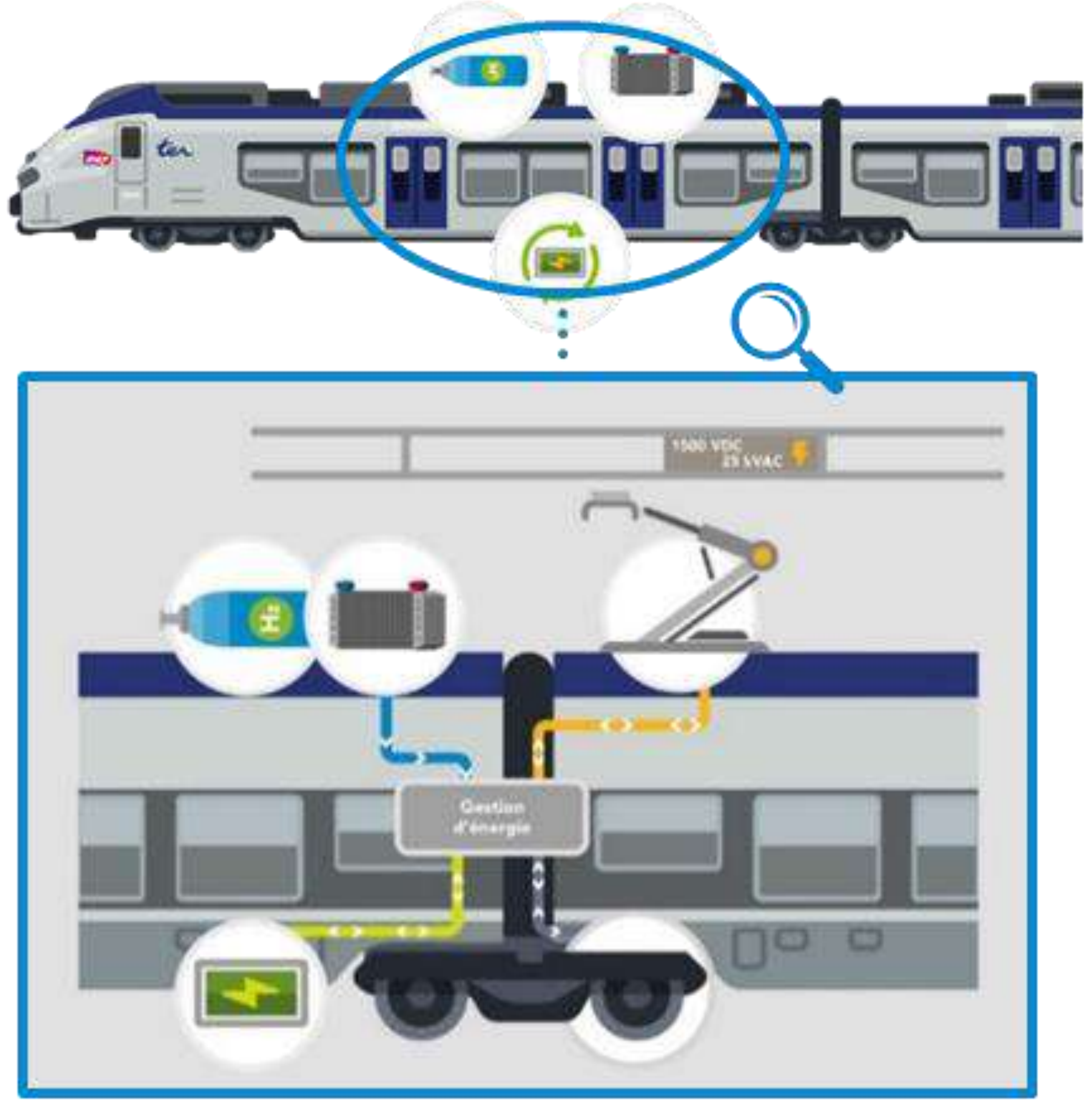
+ Batteries packed by FORSEE Power
+ Cells : LTO Technology (Toshiba)
+ Power : ~ 300 kW discharge
  ~ 500 kW charge per ESS
+ Total capacity ~ 70 kW.h per ESS
+ Pack voltage : ~ 800 V (nominal)

Next steps

+ 2021 : Modification of 1 train set
+ 2021/2022 : Testings
+ 2023 : Commercial operation (1 train set)
+ 2024 : Go / NoGo for deployment
+ Stakeholders :

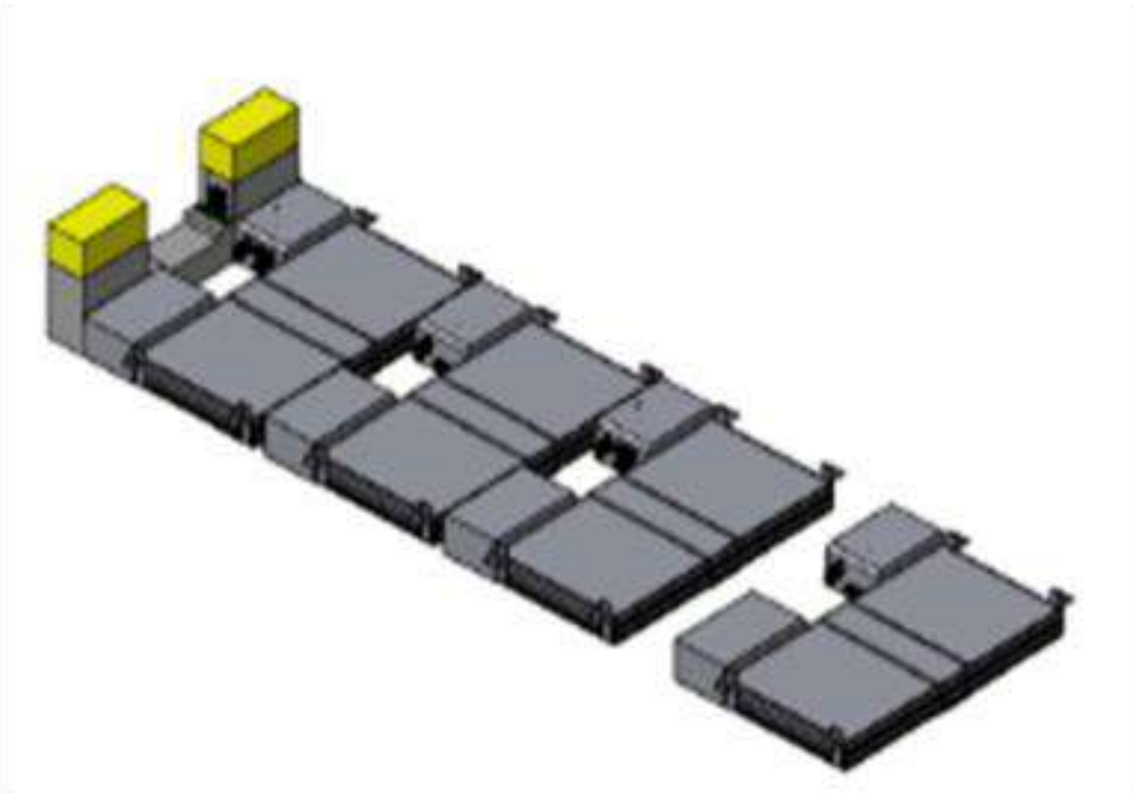
Hydrogen train

Principles



+ Diesel engines and gazole tanks removed
+ Replaced by H2 fuel cells and batteries
+ Batteries recover brake energy, and assume power peaks

Energy Storage System



+ Cells : LTO Technology (SAFT)
+ Pack voltage : ~ 800 V (nominal)
+ Total capacity around 100 kW.h per ESS
+ Power : ~ 250 kW discharge
  ~ 300 kW charge
+ Liquid cooling

Next steps

+ End of march 2021 : Contracts signed (12 new train sets)
+ End of 2023 : Testings
+ End of 2025 : commercial operation (1st train set)
+ Stakeholders :

RÉGION BOURGOGNE FRANCHE COMTÉ · Occitanie · La Région Auvergne-Rhône-Alpes · Grand Est · Centre-Val de Loire · SNCF · ALSTOM

BATTERY TRAIN
AGC BEMU PROJECT

UIC Workshop
Battery trains
19/05/2021

Bogdan Vulturescu (SNCF)
Matthieu Renault (SNCF)
Benoit Gachet (ALSTOM)

Fleet: Automotrice Grande Capacité

700 trainsets of the AGC family:

- X76500 class: 163 trains 100% diesel
- B81500 class: 185 trains, dual mode (1.5kVdc & diesel) – 160km/h max, 130/240 places (3/4 coaches)
- B82500 class: 141 trains, dual mode (1500Vdc/25kVac & Diesel) – 160km/h max, 130/240 places (3/4 coaches)
- Z27500 class: 211 trains 100% electrical

- 2004-2011 Supplied by Bombardier at SNCF
- 2022-2032 Midlife maintenance - to give potential for another 20 years

Retrofitting principles

- 20 years old trainsets retrofitting (build before TSI) **– <u>first time in Europe !</u>**
- Diesel propulsion removal and replacement with NMC Li batteries, on both motor cars (1M T 2M)
- **Train software modification**

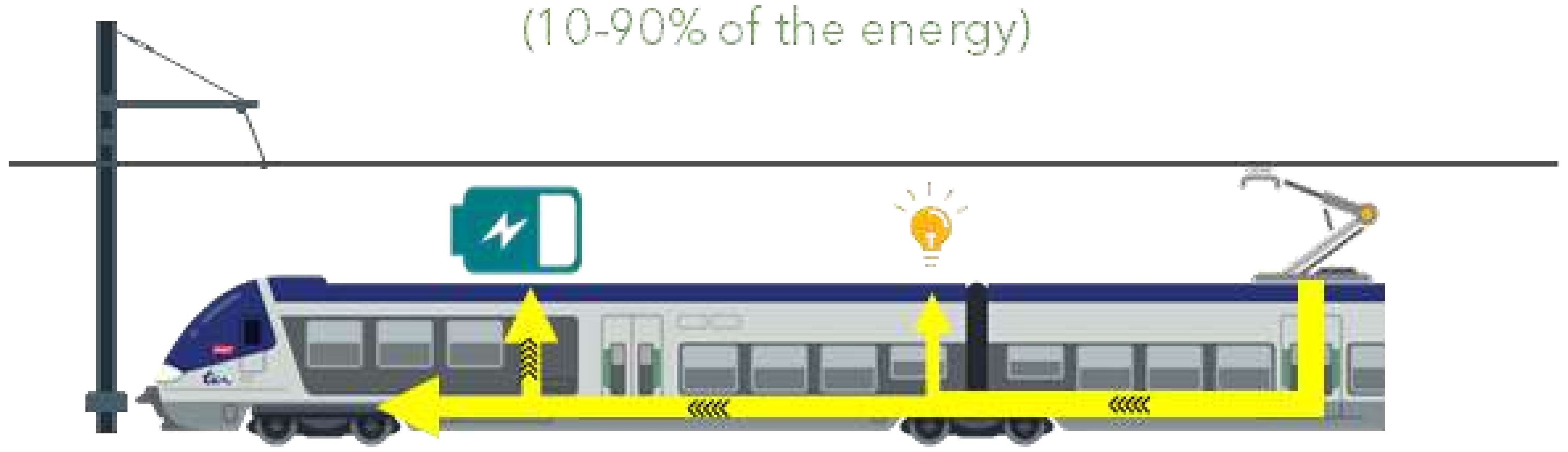
BEMU features

Autonomy	**80km + reserve** (20km or 1hour comfort AUXILIAIRES at full power; autonomy corresponding to only 50% of DoD used !)
Traction	Identical to original BGC: 160km/h, 1.8MW under catenary & 1MW under non-electrified line, braking energy recovery (new)
Battery full charge time (400kWh)	40min (running under catenary or under 25kVAC at standstill) 60min (at standstill under 1.5kVDC)
BEMU coupling	Inter-BEMU & with the rest of the AGC regional non-modified fleet (BGC and ZGC)
DC/DC converter redundancy	4 DC/DC converters, each driving 4 traction battery units (50kWh, 800V) – liquid cooling
Distance gauge (km) estimation	The driver knows, on live, the “equivalent distance” remaining energy

Energy management

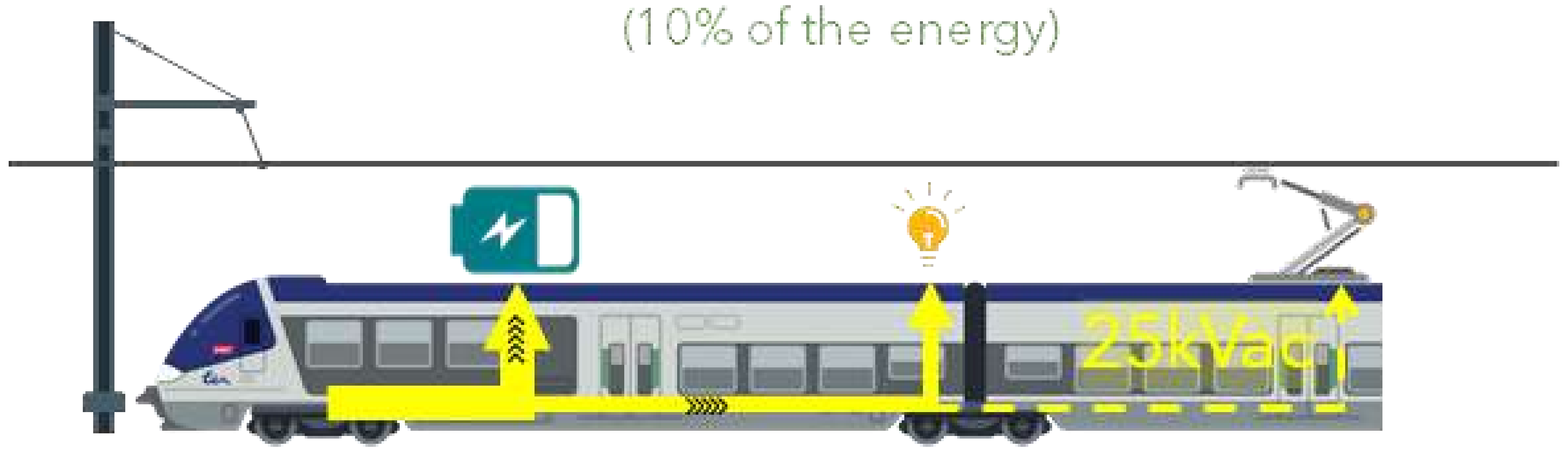
Traction under catenary

Main battery charging mode
(10-90% of the energy)



Braking under 1.5kVdc & 25kVac

Secondary battery charging mode
(10% of the energy)

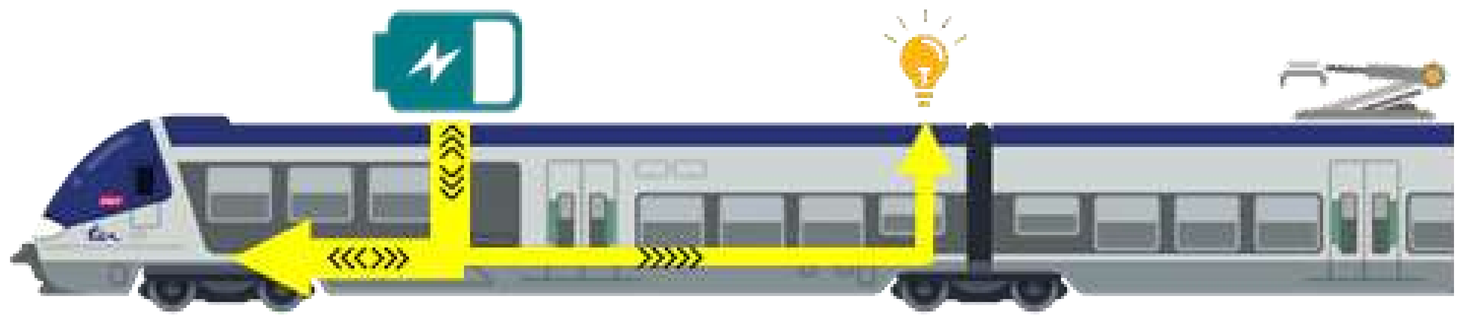


Standstill charge (terminal)

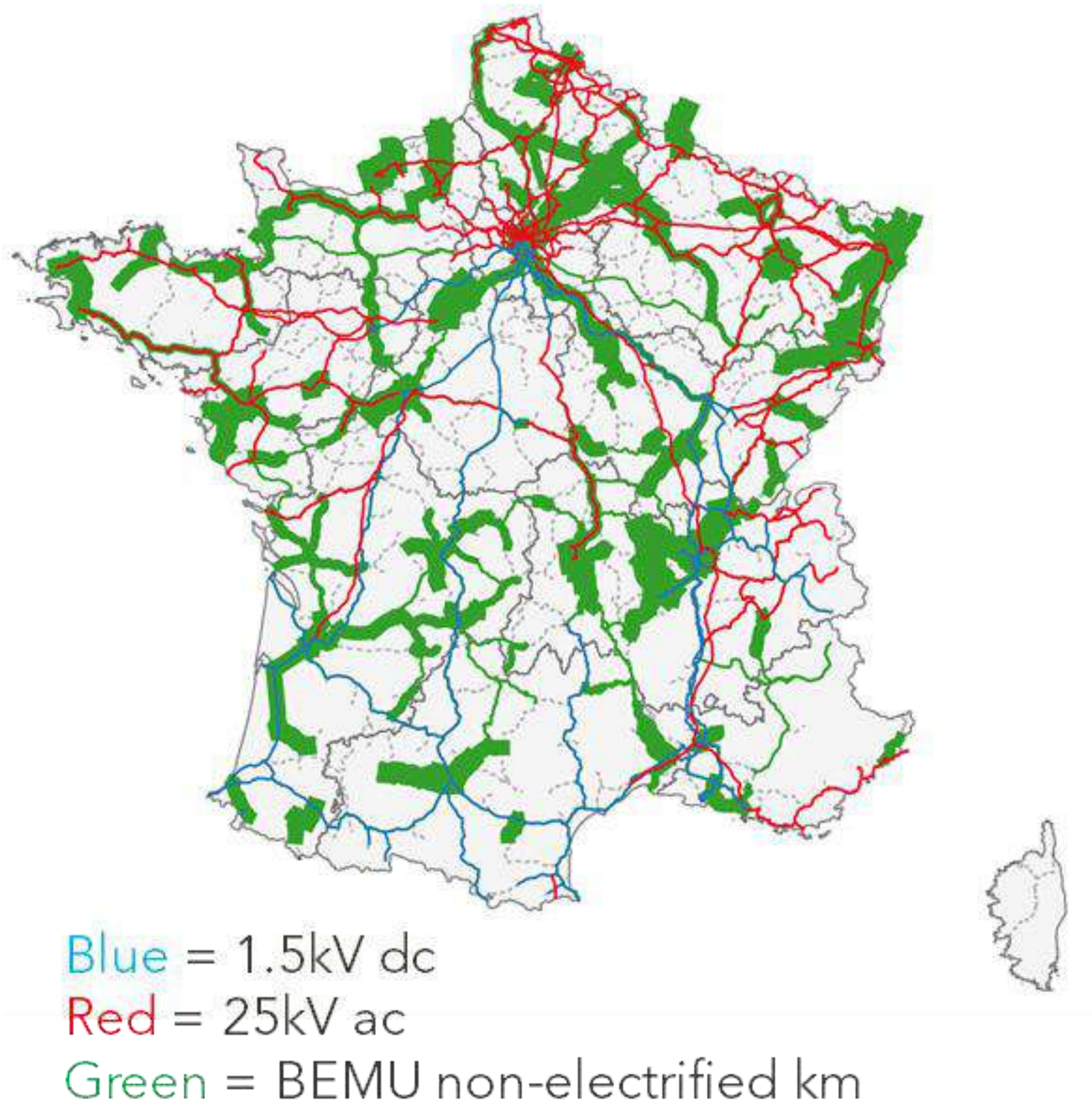
Main battery charging mode
(10-90% of the energy)

Running under non-electrified line

Traction/braking by battery



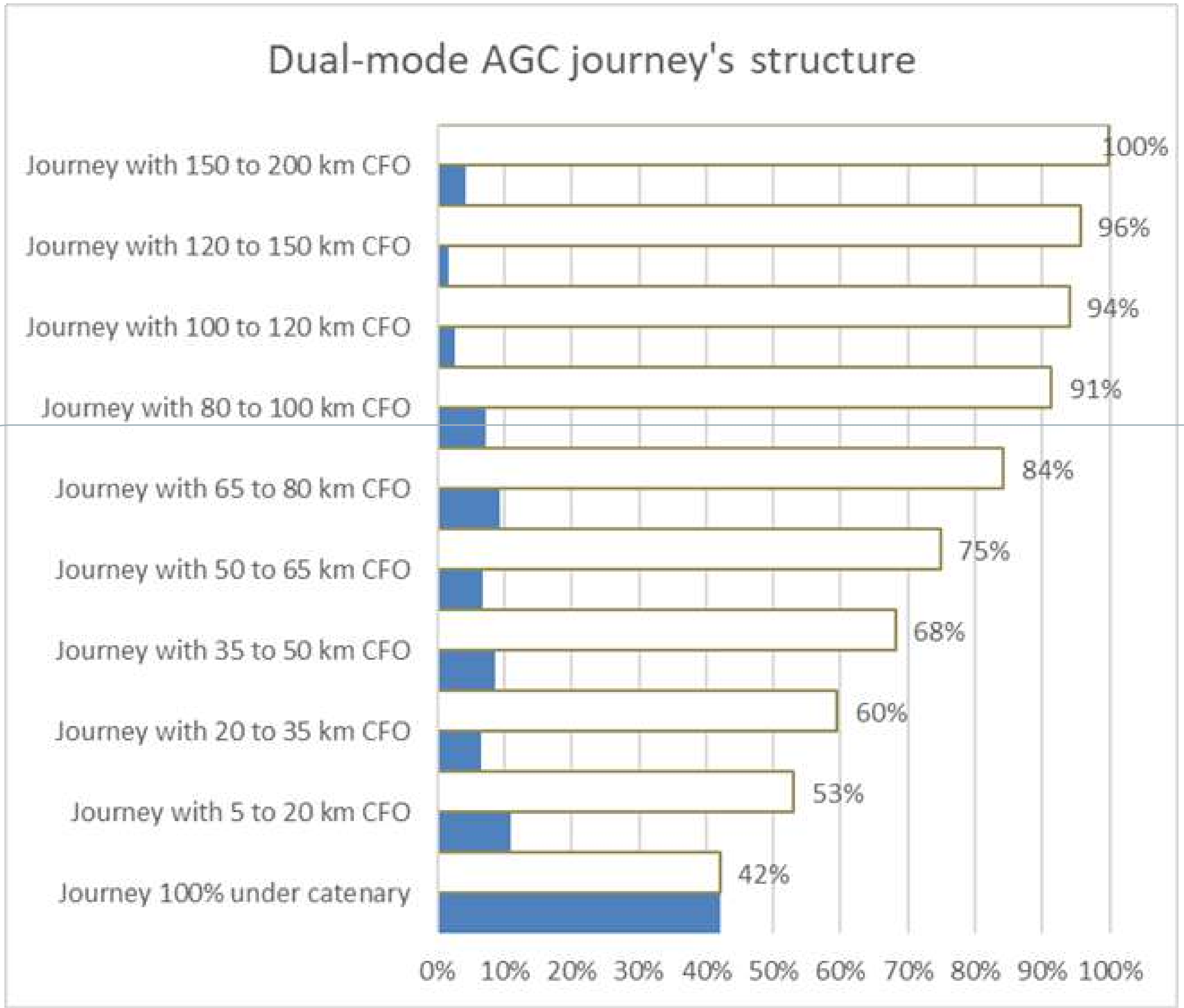
Relevant area – infrastructure (without any modification)



- 16600km electrified lines in France
- 5100km non-electrified (or partially electrified) compatible with 80km BEMU one journey autonomy (12000km non-electrified lines in France).

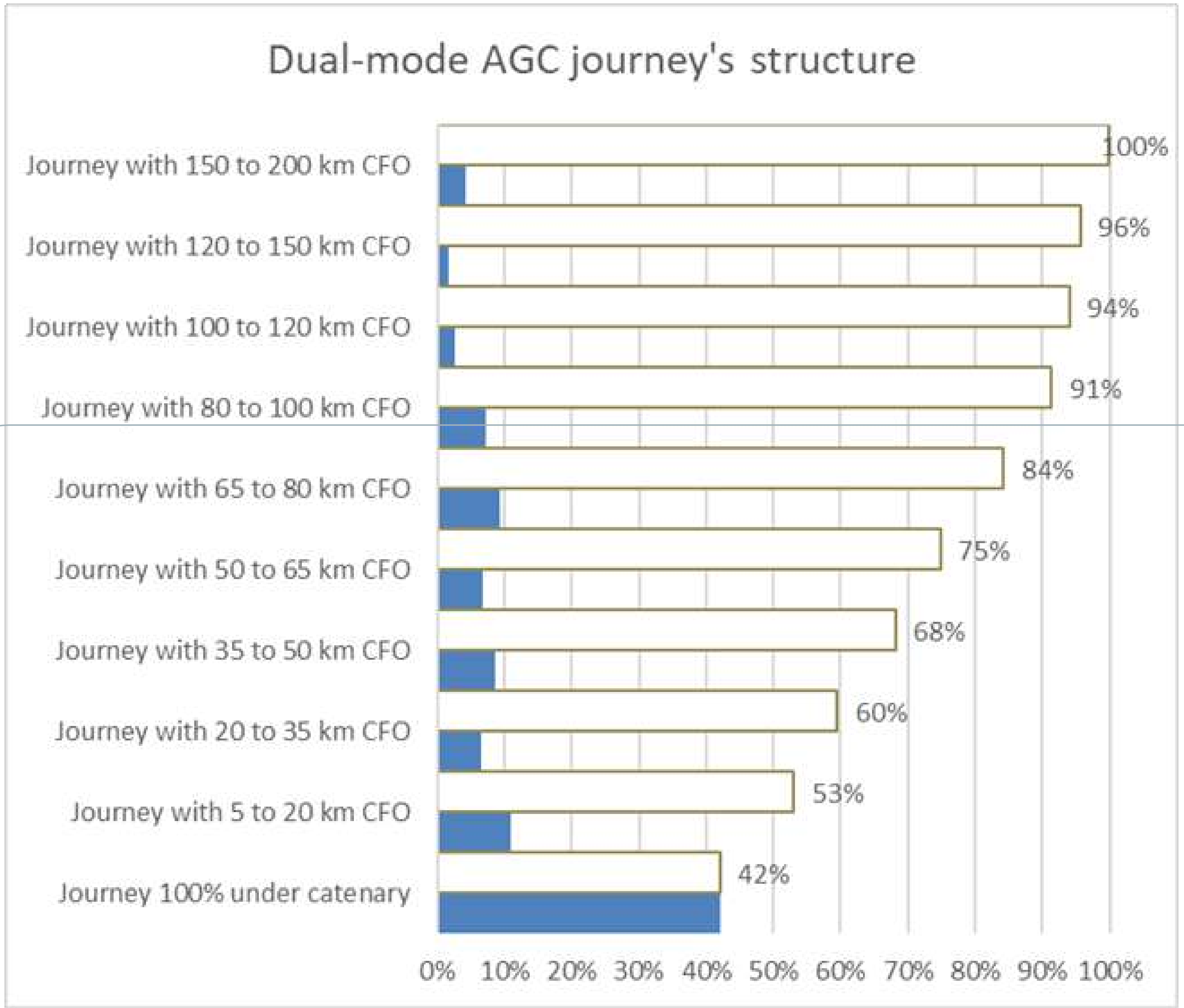
***100% km electrified lines + 42% km** non-electrified lines*

Relevant area – Journey operation analyze



84% of the journey distances are les than 80km.

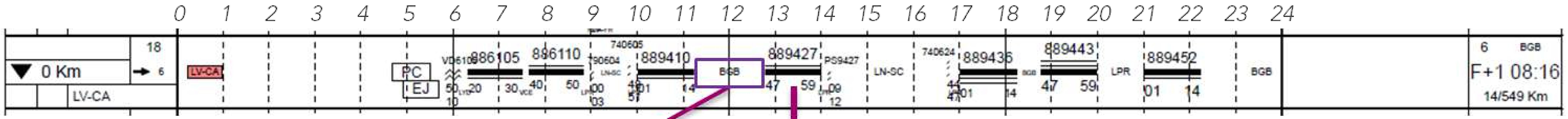
Relevant area – Journey operation analyze



1. ~~Operation modification~~
2. **New infrastructure**
3. **Increase the onboard storage**

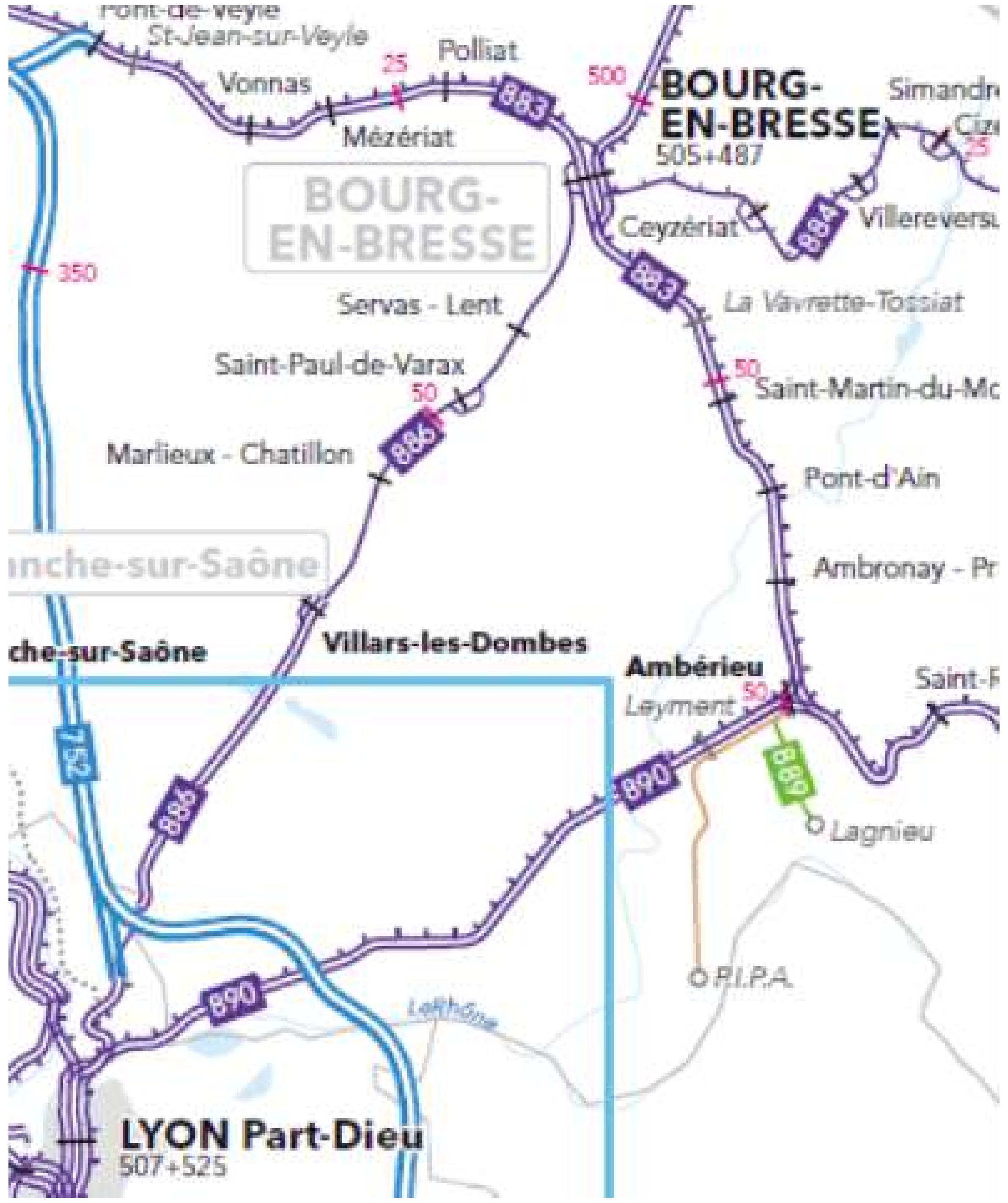
84% of the journey distances are les than 80km.

Relevant area – daily operation analyze

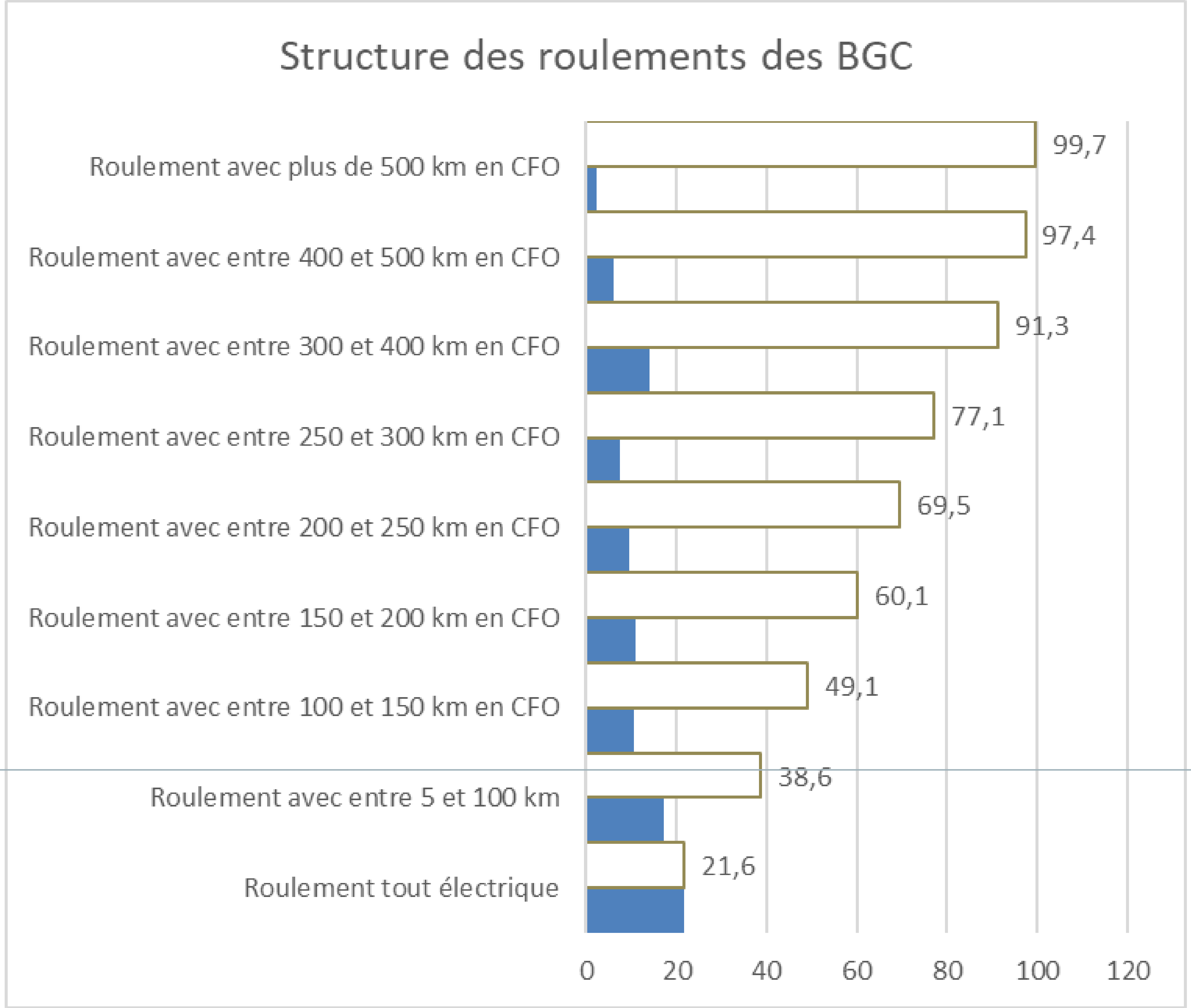


Stop/parking time
during day: 33 min, 62min, … 181min
enough to charge the battery.
Trip duration: 73min

Journey distance: 60km
Lyon → Bourg-en-Bresse
(549km daily operation)



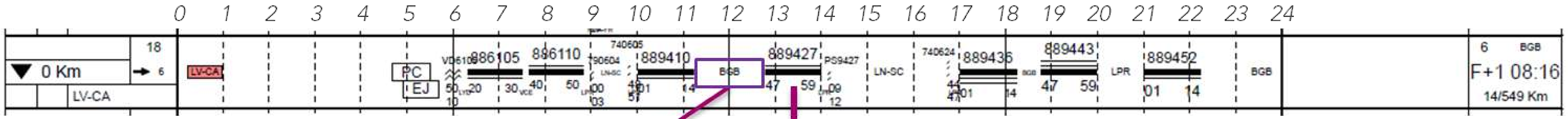
Daily journey operation analyze



X % of these <u>long daily operation</u> are compatible with our AGC BEMU (eg. shuttle Lyon ↔ Bourg-en-Bresse daily op).

38 % + ***X*** % of the daily operation are less than 80km – compatible with our AGC BEMU without any infrastructure/rolling stock modification.

Increase the relevant area – Daily operation analyze



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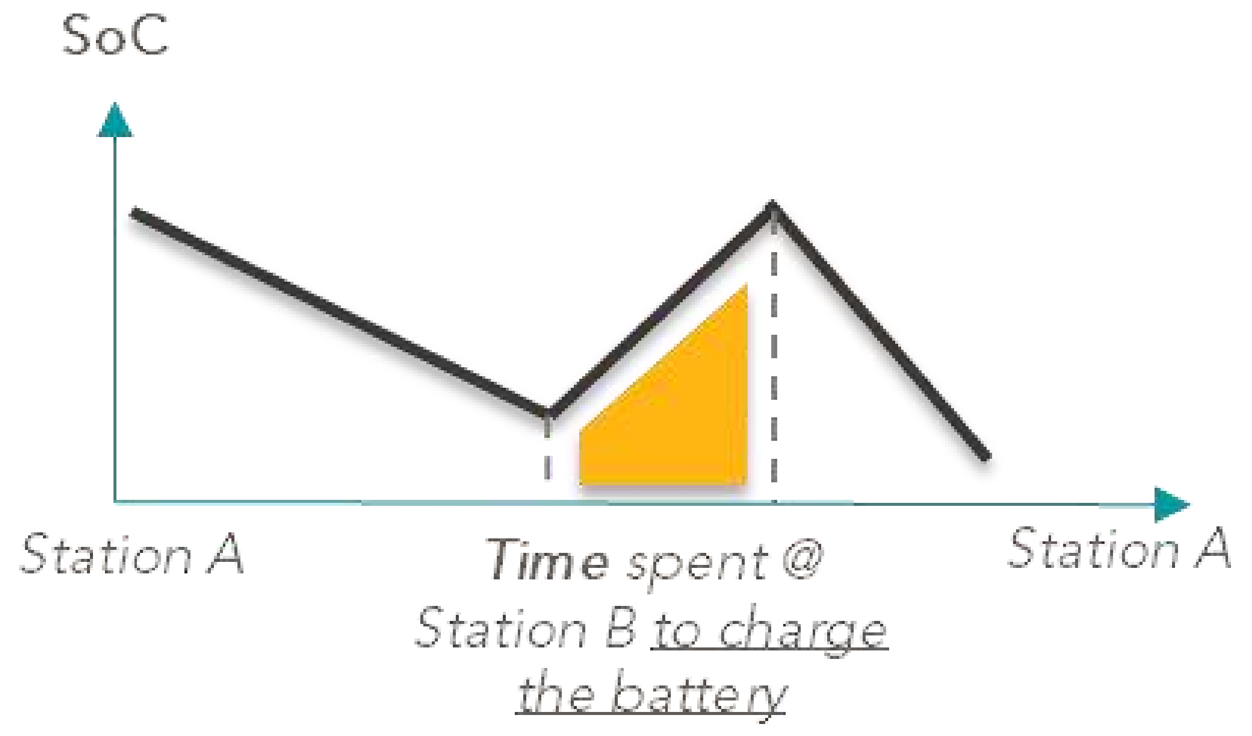
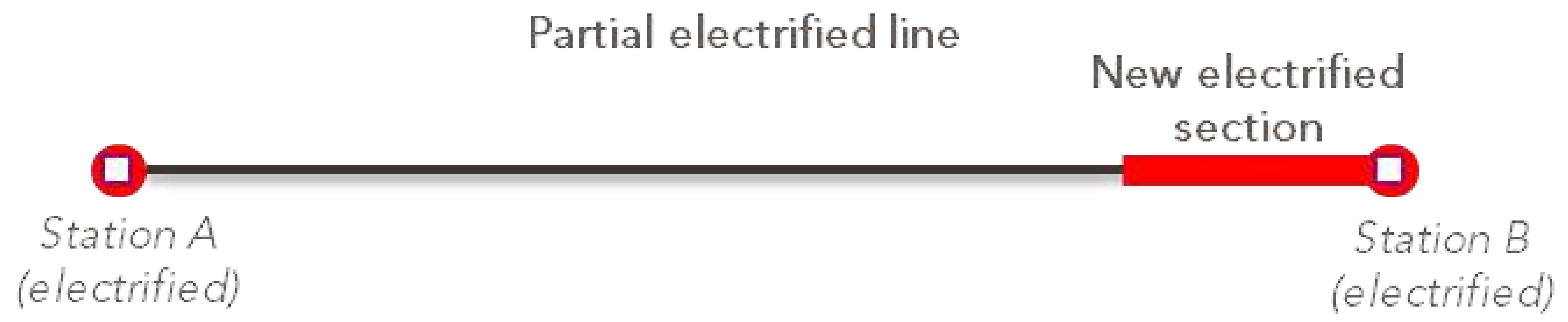
(549km daily operation)

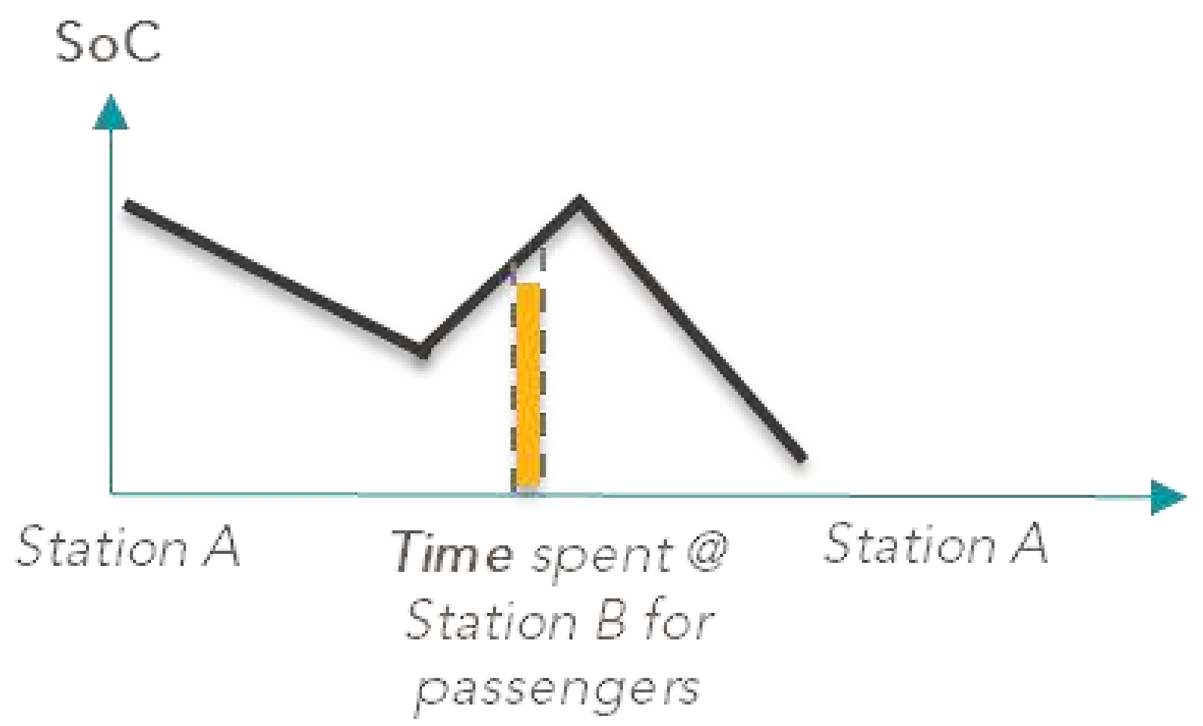
1. Stop/parking time modification
2. New infrastructure
3. Increase the onboard storage / fast charge

Increase the Relevant area – Daily operation analyze, round trip exemple

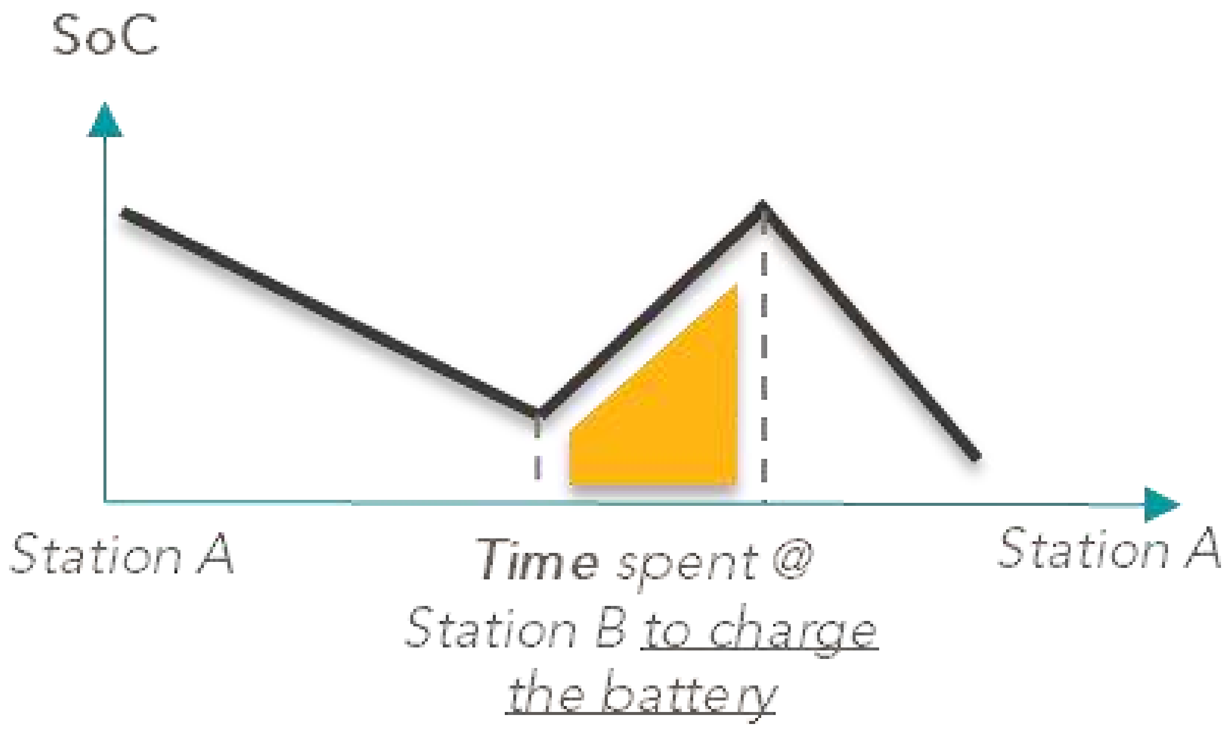


1. Stop/Parking time modification
2. New infrastructure:
3. Increase the onboard storage / fast charge

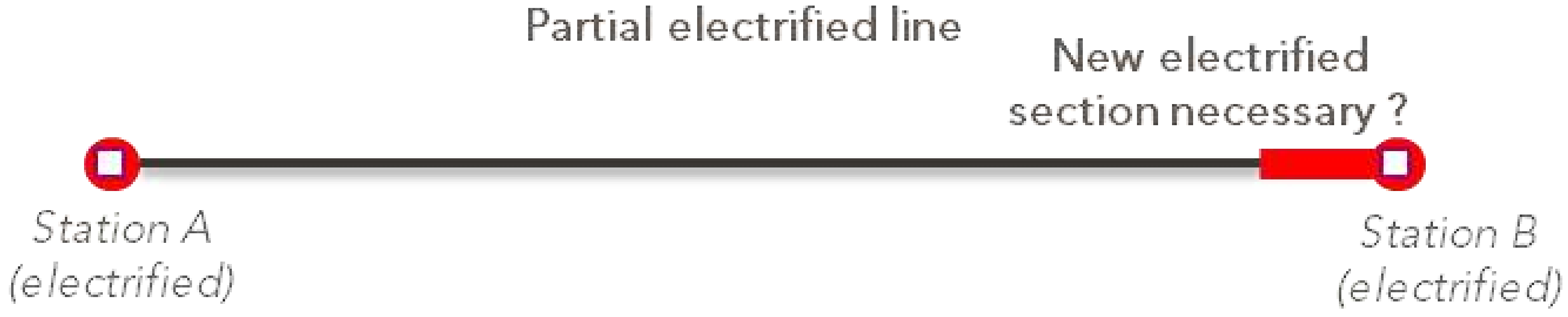


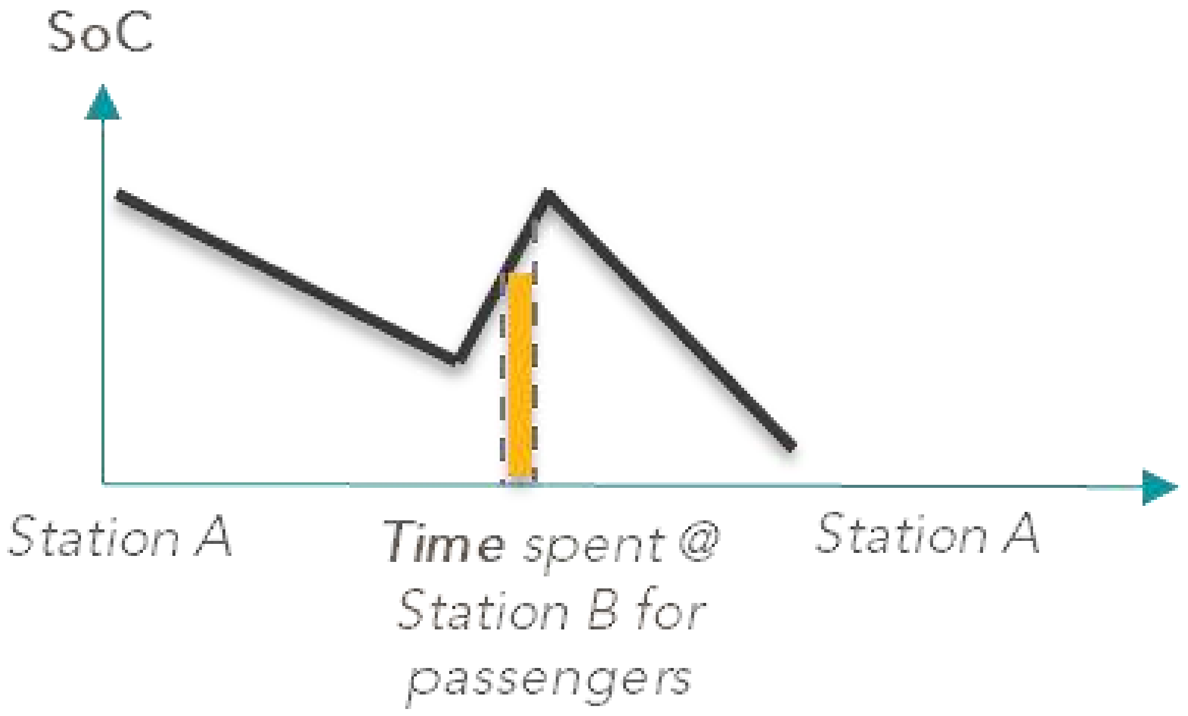


Increase the Relevant area – Daily operation analyze, round trip exemple

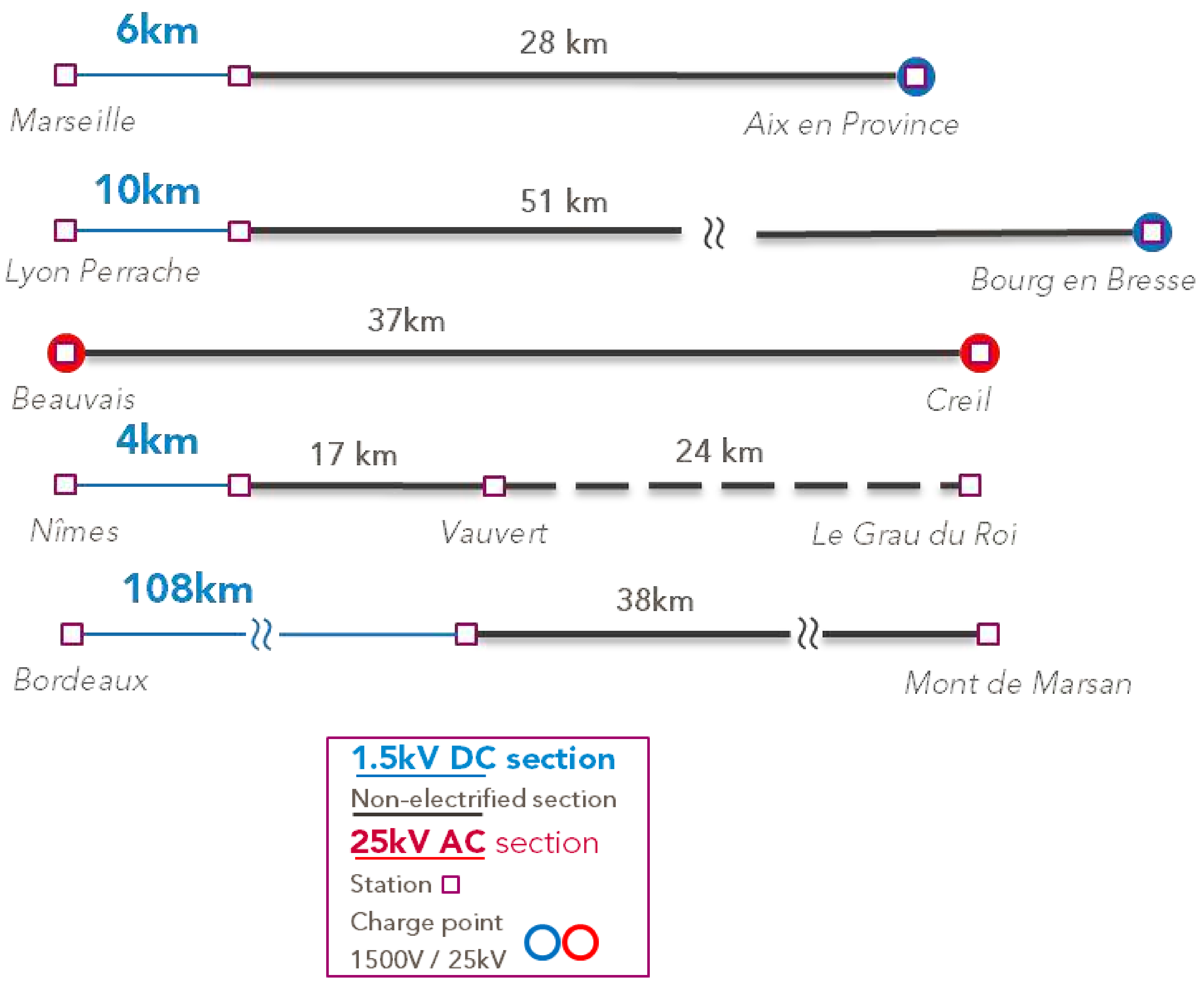


1. Stop/Parking time modification
2. New infrastructure:
3. ~~Increase the onboard storage~~ / fast charge





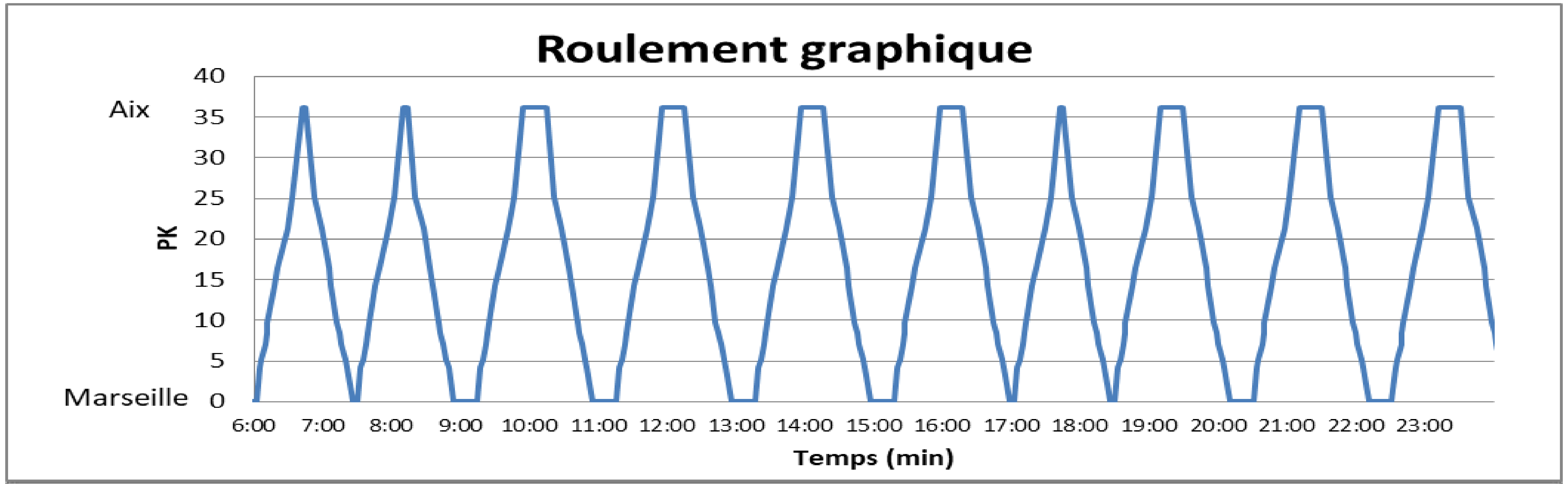
First use cases – without any infrastructure modification

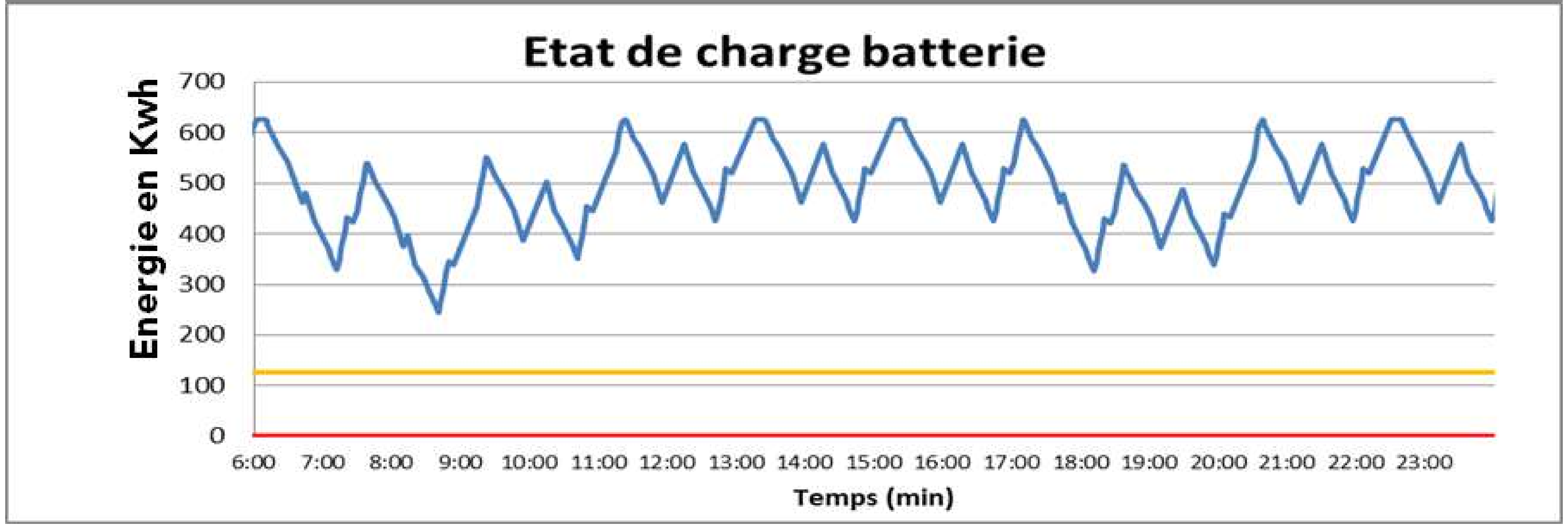


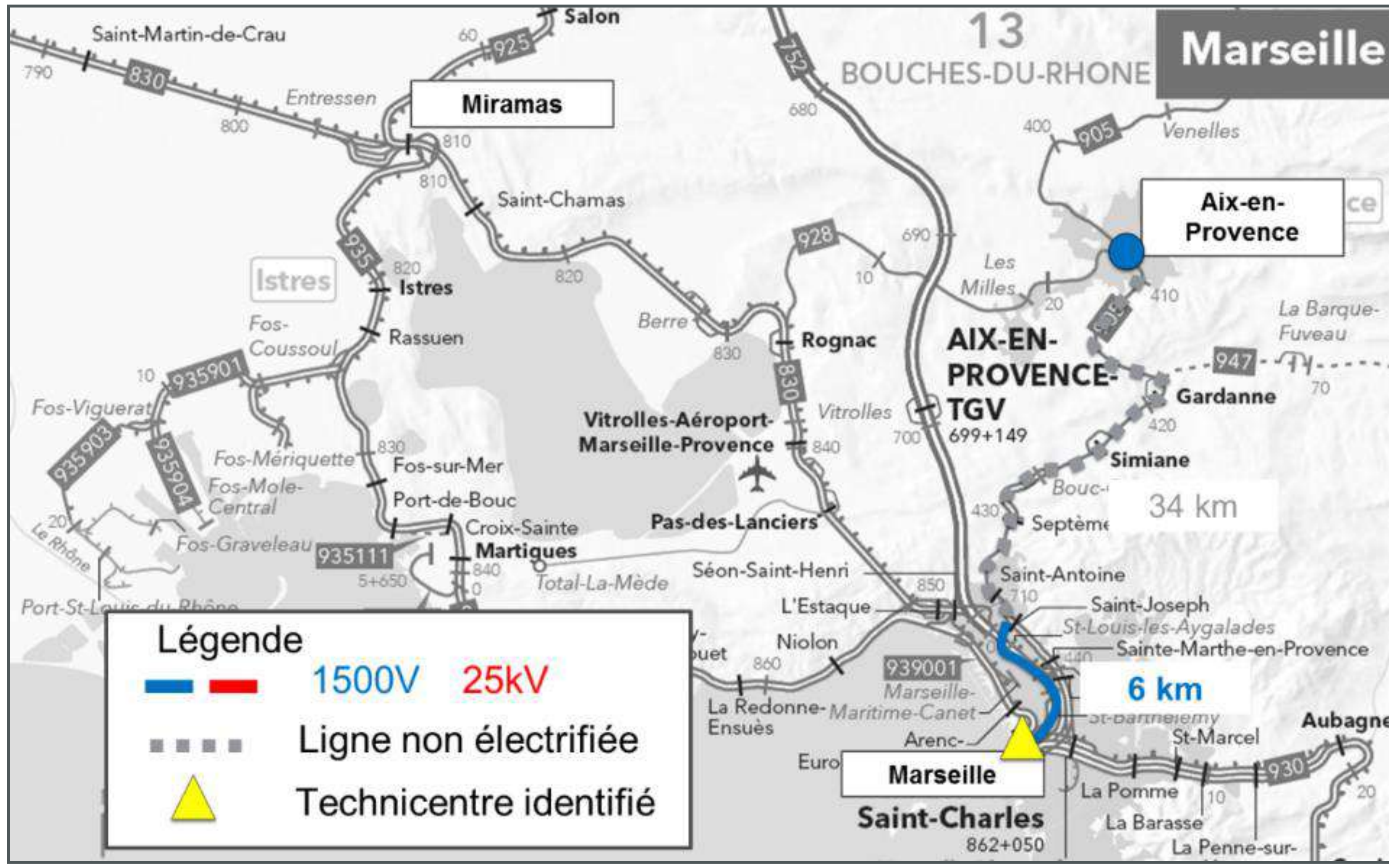
300 à 1000 tCO2e avoided/year, annual emissions of 180 to 650 cars for only one BGC !

Diesel	Battery train
~**8,5** kgCO2éq/km	**0,5** kgCO2éq/km
6 to 10 kgPM/an	0
1 to 3 tNOx/an	0

Marseille – Aix







Partners

La Région Auvergne-Rhône-Alpes

RÉGION SUD PROVENCE ALPES CÔTE D'AZUR

RÉGION Nouvelle-Aquitaine

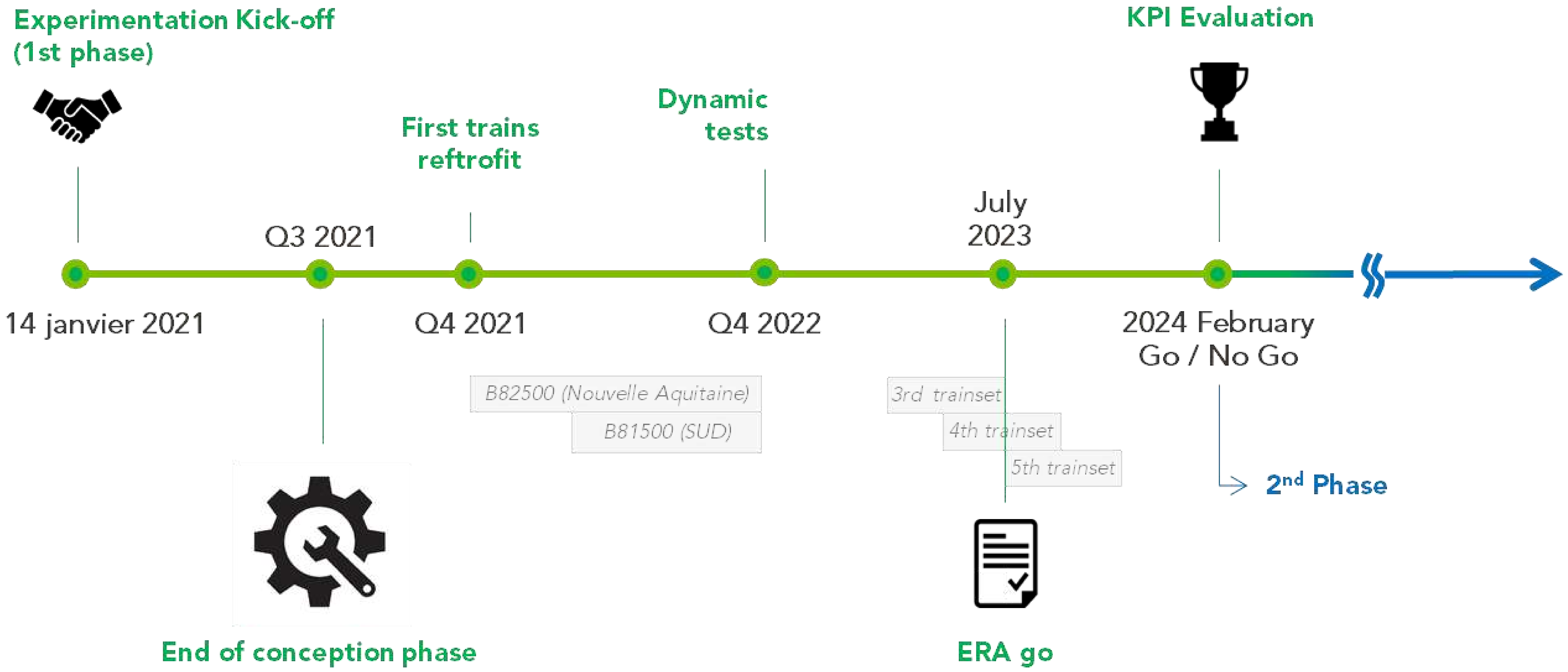
La Région Occitanie Pyrénées - Méditerranée

Région Hauts-de-France

SNCF

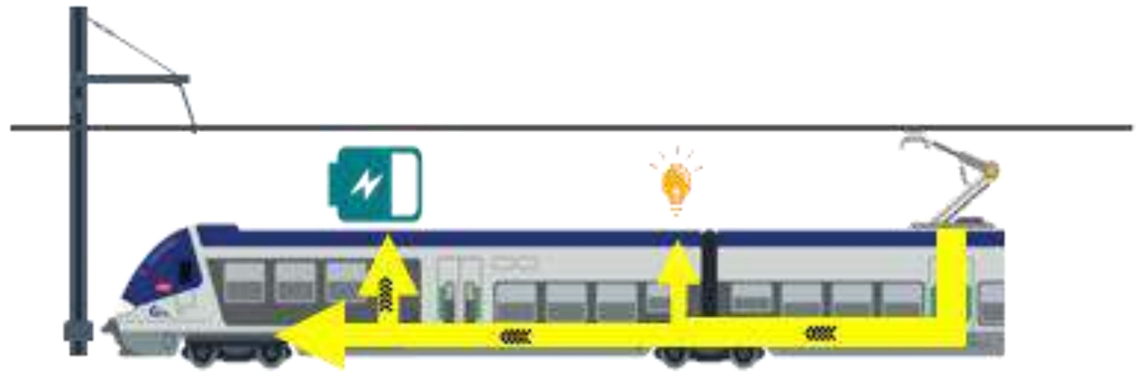
ALSTOM • mobility by nature •

Projet milestones



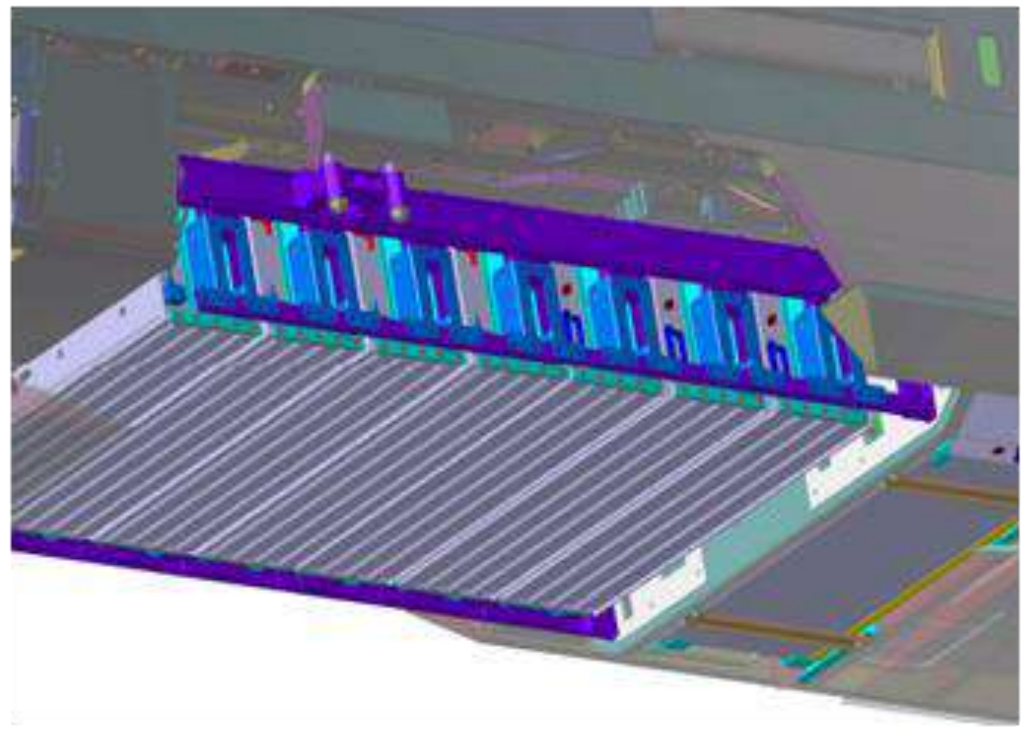
AGC BEMU

Principles



+ Batteries are mainly charged by catenary but are also used for recovering braking energy.
+ Batteries provide energy for traction and auxiliaries consumption
+ Dual mode train: catenary-battery

Energy Storage System



+ Battery system designed by LECLANCHE
+ DCDC designed by AT
+ Power per ESS : ~600 kW discharge
  ~500 kW charge
+ Total capacity ~400 kWh per ESS
  (~200 kWh used)
+ Reserve capacity ~60kW.h per ESS
+ Pack voltage : ~800 V (nominal)

Next steps

+ 2021 : Notice To Proceed, Kick Off project
+ 2021/2022 : Tests
+ 2023 : Commercial operation (5 train set)
+ 2024 : Go / NoGo for deployment
+ Stakeholders :

RÉGION SUD Provence Alpes Côte d'Azur · La Région Occitanie · Région Nouvelle-Aquitaine · La Région Auvergne-Rhône-Alpes · Région Hauts-de-France · SNCF · ALSTOM

INTERNATIONAL UNION
OF RAILWAYS

Questions

Discussion

François Degardin (SNCF)
Bogdan Vulturescu (SNCF)
Matthieu Renault (SNCF)
Benoit Gachet (ALSTOM)

Thank you for your attention.

INTERNATIONAL UNION
OF RAILWAYS

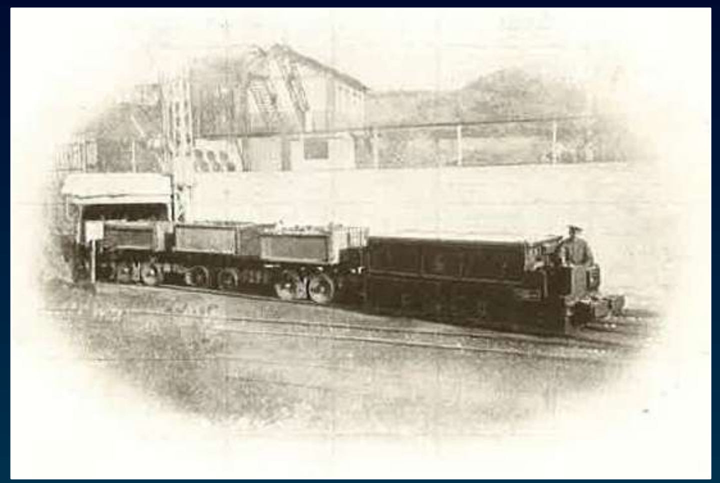
SIEMENS MIREO PLUS

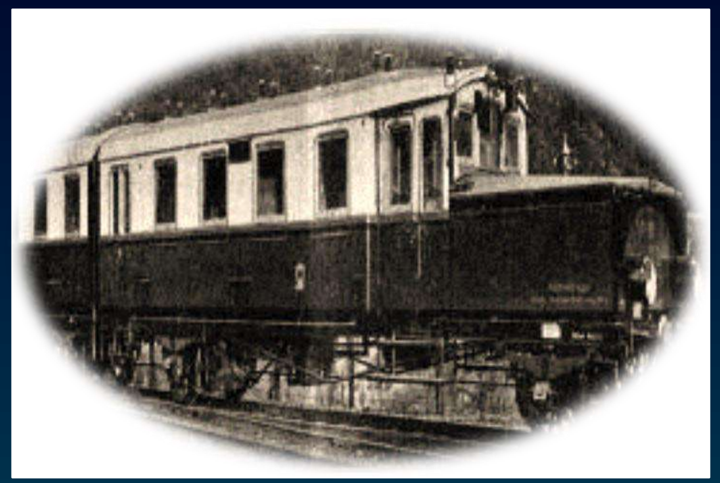
A strong train now becomes even stronger

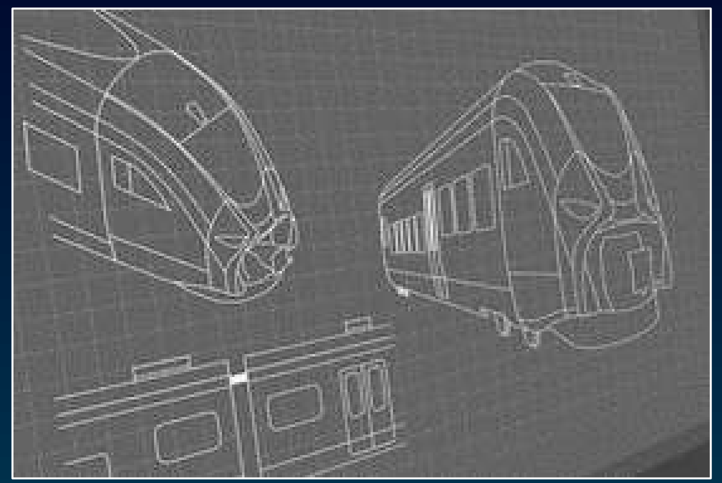
Katrin Seeger
Siemens Mobility - Head of Battery Technology Commuter & Regional Trains

19.05.2021

The Mireo Plus combines the latest alterna-tive traction systems with the lightest EMU







1900

First battery locomotive

1909

“Wittfeld-Akkumulator-triebwagen”

2017

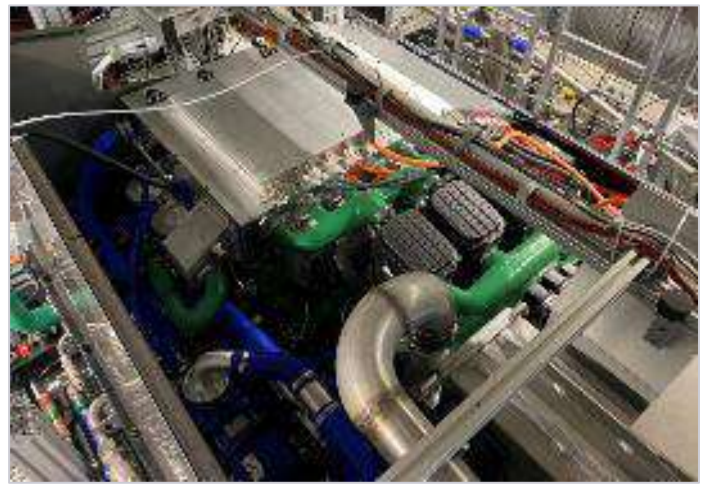
Start of development of Mireo Plus

2019

Desiro ML Cityjet eco prototype for ÖBB

2020

Mireo Plus B Ortenau



2018

Test bench operation of fuel cell

2020

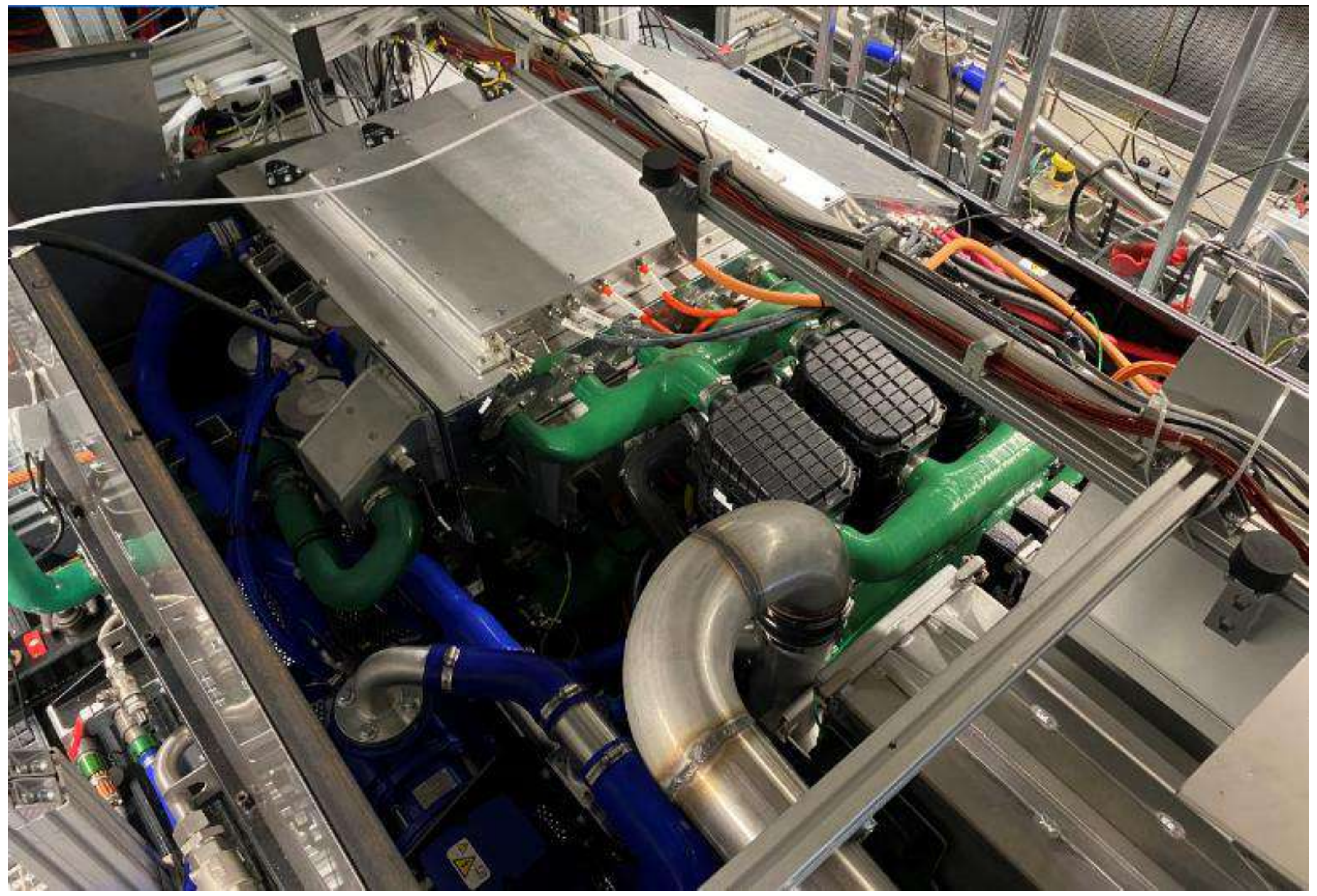
Mireo Plus H prototype with DB

SIEMENS

Extensive experience gained during development and testing

Battery System

- Active in design of battery systems for mobility applications since 2009
- Co-design with experienced partners I-ME Actia and Toshiba
- Owner and distributor of the battery systems
- Excellent results from passenger operation with Cityjet eco have confirmed a reliable, robust and long-lasting battery system



Hydrogen System

- Active in H2 systems since 1960s
- Applications in marine business as well as for electrolyzers laid foundation to enhance this technology for mobility applications
- Experienced partner Ballard Power for development of the next generation fuel cell system
- The new fuel cell system has been extensively tested in a system test laboratory for > 2000 hours operation to optimize the interaction between fuel cell and battery system

SIEMENS

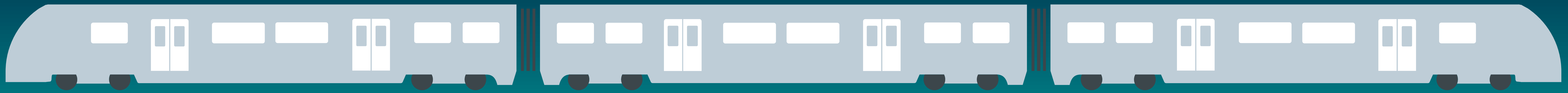
Desiro ML Cityjet eco in successful passenger service for more than one year

Operation in battery mode
\> 65.000 km

Battery capacity
528 kWh

Traction power
Up to 2,6 MW

140 km/h
in AC-mode



120 km/h in
battery mode

Range in daily operation
~80 km

- Operated in height difference of 325 m
- No restrictions in hot summertime detected due to active cooling
- Reduced range due to active heating (65 km)
- Routes throughout all regions in Austria

Achievements

- No downtime; high reliability of batteries
- Operating parameters could be optimized
- Validation platform for simulation modeling

07/2017	08/2019	09/2019	12/2020
Start of development	Homologation certificate received	Passenger operation on 11 different routes throughout Austria	Trial operation successfully completed

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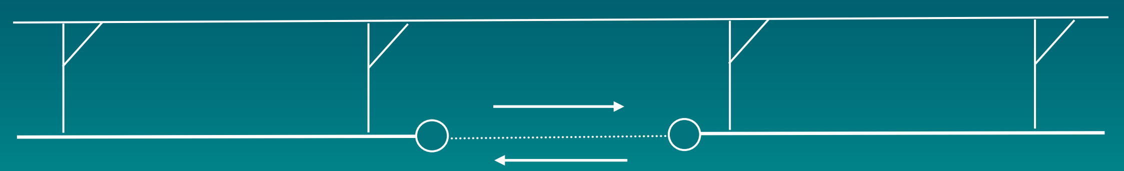
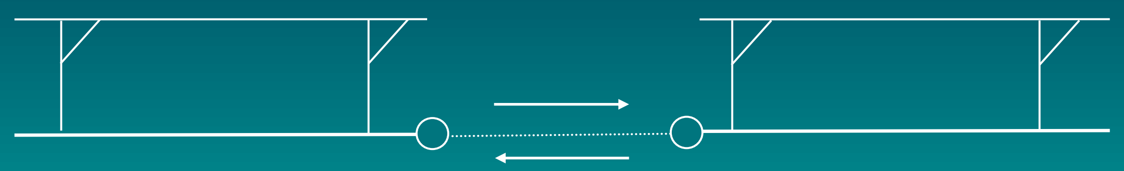
Mireo Plus –
For operation on non electrified lines

Electrified lines



Connecting electrified lines



Last mile

No catenary

Mireo

For electrified lines

Mireo Plus

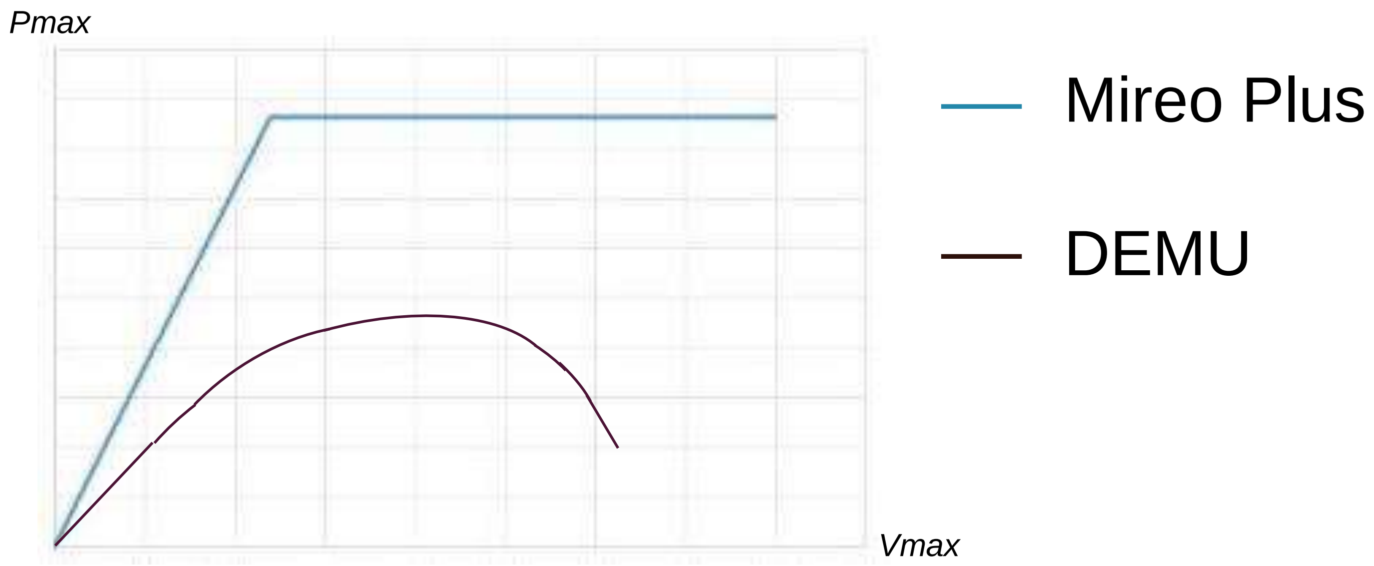
All Mireo advantages in one hybrid platform with all positive characteristics of the Mireo family: energy-saving, flexible interior, low maintenance and life cycle costs

Mireo Plus B: Battery solution for lines that are partially electrified; range: 80 – 120 km

Mireo Plus H: Hydrogen solution for long distances without catenary; range: 600 – 1,000 km

2-Teiler: 47 m, max. 130 seats

3-Teiler: 63 m, max. 180 seats



V_{max}: 160 km/h

P_{max}: 1.700 kW

High performance: 2 powered bogies to ensure reliable operation even under challenging conditions

SIEMENS

The first project of Mireo Plus is Ortenau network with battery hybrid drive

Contract award
April 2020

Vmax
140 km/h

Catenary-free operation
~80 km

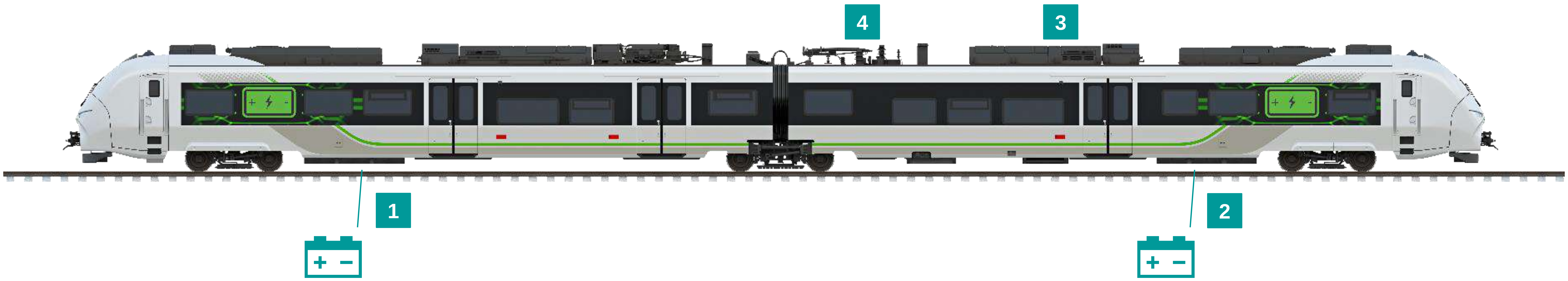
Level platform access
550 mm

SIEMENS

The Mireo Plus B meets demanding operational requirements without a continuous overhead catenary

- EMU performance
- High energy efficiency / low power consumption thanks to SiC
- Charging below overhead catenary and quick charge
- Low lifecycle costs

1. Flexible battery size – long ranges possible
2. LTO technology for long battery life
3. 160 km/h in both overhead catenary and battery operation
4. Overhead catenary operation at 15 kV/16.7 Hz or 25 kV/50 Hz



SIEMENS

The Mireo Plus H is applied in a research project with DB Regio

120
seats

Mireo Plus H
2-car

Project start
23.11.2020

Vmax
160 km/h

Range
600 km

Rapid refueling in max.
15 minutes

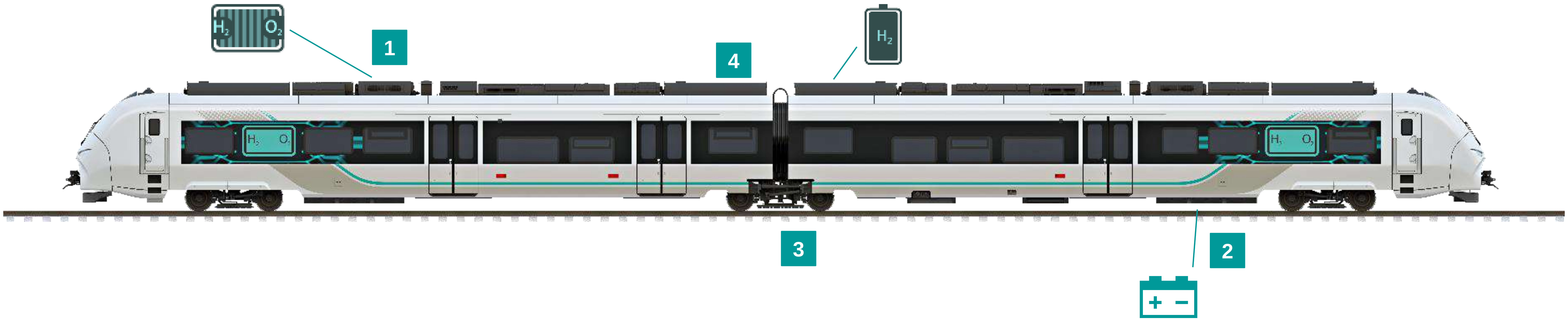
Start of trial operation
2024

1,7 MW
traction power

The Mireo Plus H meets demanding operational requirements without an overhead catenary

- EMU Performance
- High energy efficiency / low power consumption thanks to SiC
- Vmax 160 km/h
- Low lifecycle costs

1. Highly efficient fuel cell – long ranges possible
2. LTO technology for long battery life
3. Intelligent system for rapid refueling
4. Low power consumption, e.g. through use of waste heat from fuel cell for passenger air-conditioning



SIEMENS

Ambitious targets are achieved through innovative hybrid traction building blocks

HD8 Next Generation fuel cell

Higher power density

Longer lifetime, lower life cycle cost

Higher efficiency

H2 tanks

Modular concept

+10% H2 storage capacity

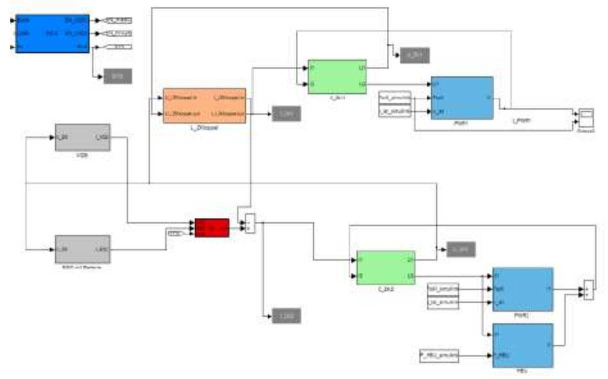
DC – DC converter

SiC technology (compact, light and low losses)

Hybrid control software

Optimized operation through predictive energy management

~ 5 – 15% energy savings

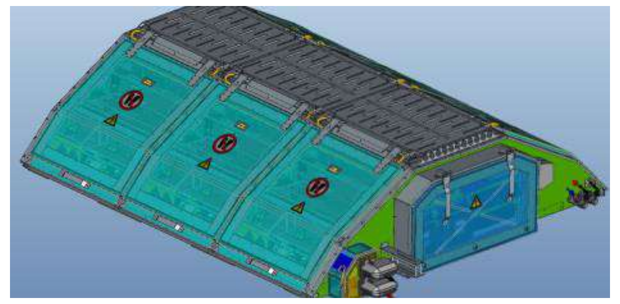


Powerful battery family

Safe chemical cells

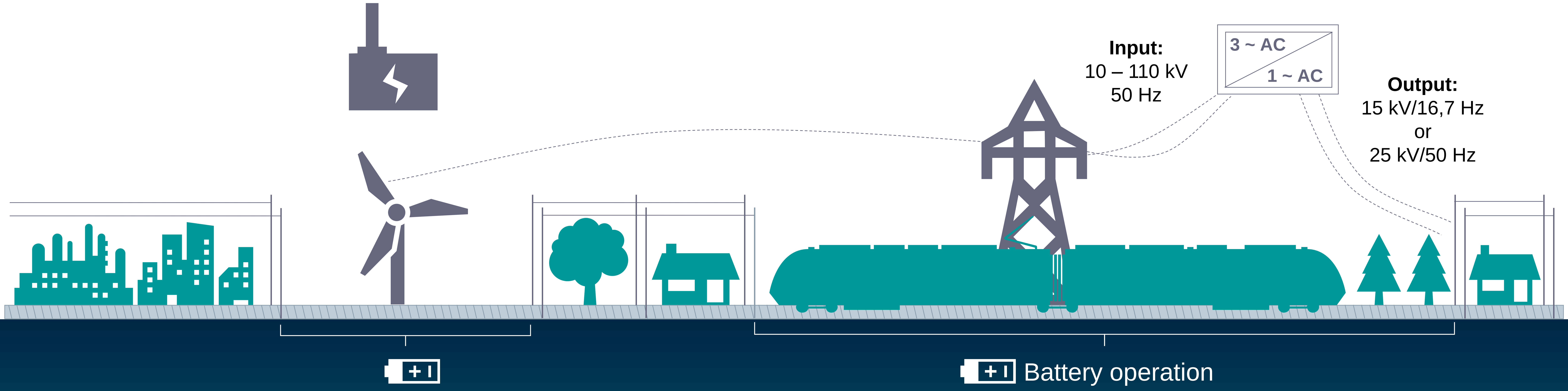
High-power charging

Long lifetime



SIEMENS

The Mireo Plus B makes the most of the existing infrastructure



1 Charging below **existing overhead catenary** (including during travel)

2 Charging at the **recharging section** at the intersection (including during travel)

3 Charging at the **recharging point** at the terminus (charging only while stationary)

SIEMENS

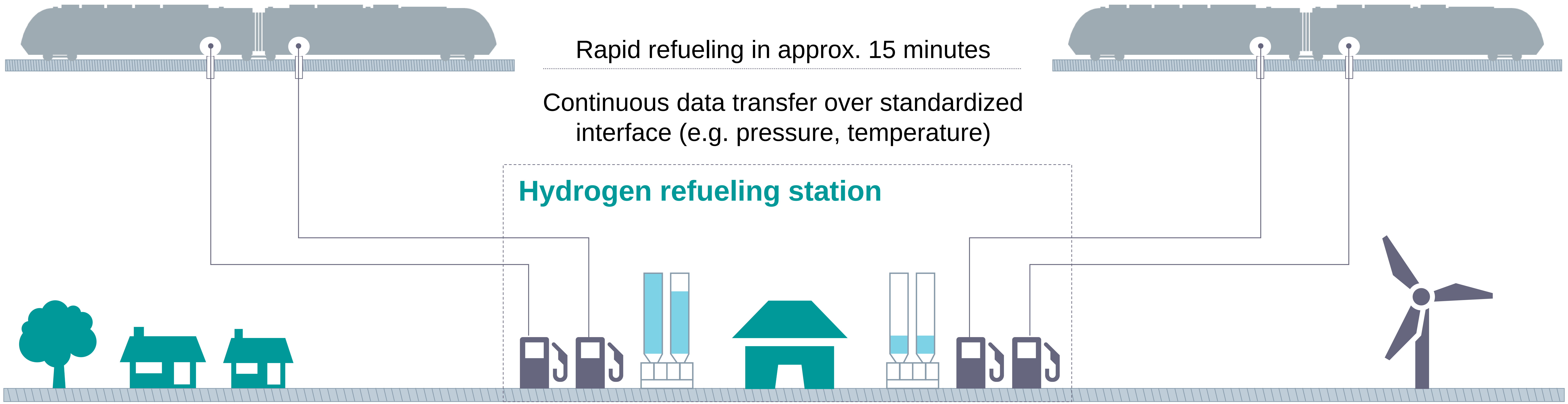
Suitable infrastructure is the prerequisite for the efficient use of the Mireo Plus H

Refueling process

1 Vehicle is connected one car at a time to the dispenser: **Start of the refueling process**

2 Hydrogen is pumped in: **Refueling process**

3 Rated pressure is reached at the hydrogen tank: **End of the refueling process**



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Case study

Proven in Austria

#years of experience in all weather conditions

Feasible in Belgium

comparable distances

comparable height differences (Charlerloi-Couvin)

or flat (e.g. Eeklo-Ronse)

comparable electrification ratio on most diesel lines

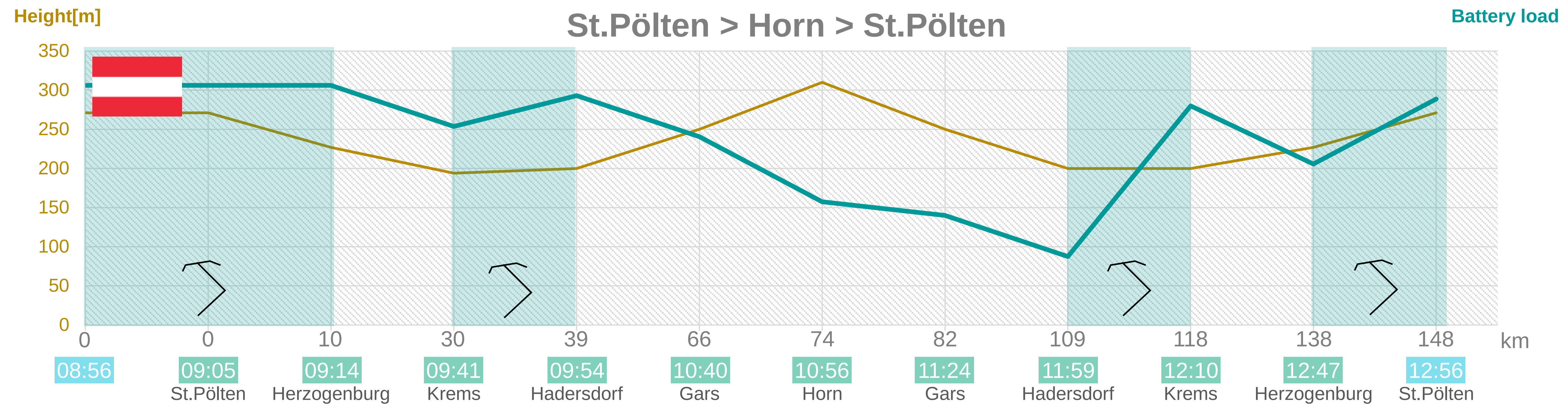
Infrastructure characteristics Belgium

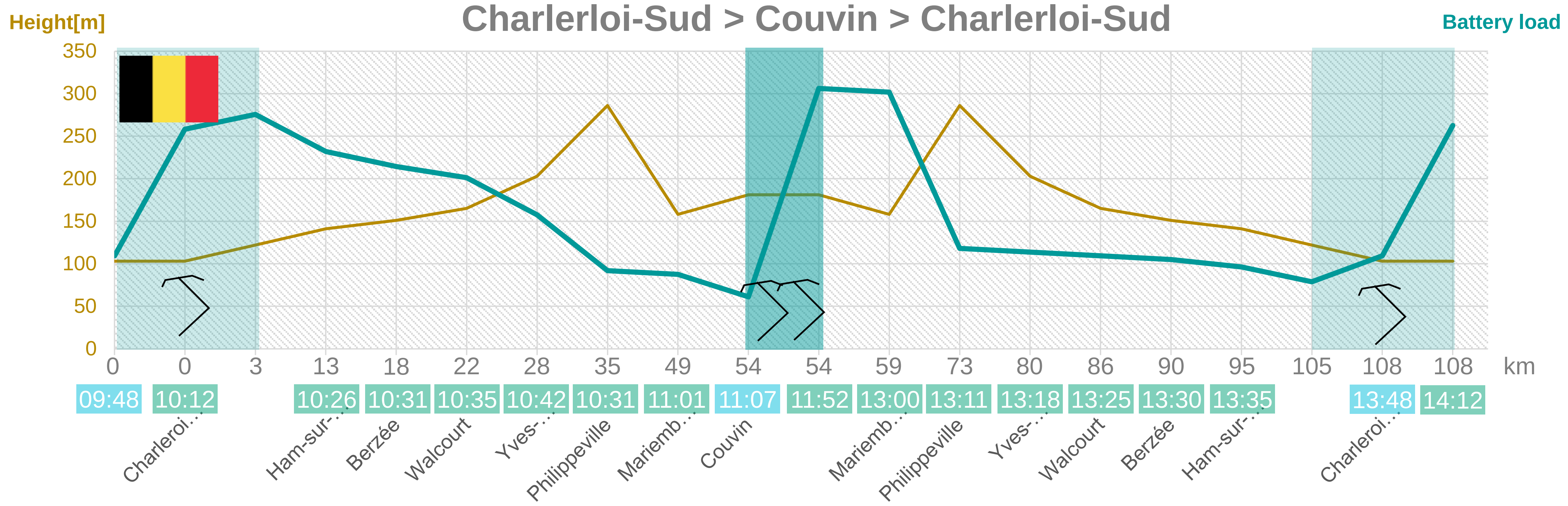
Catenary voltage 3kV DC

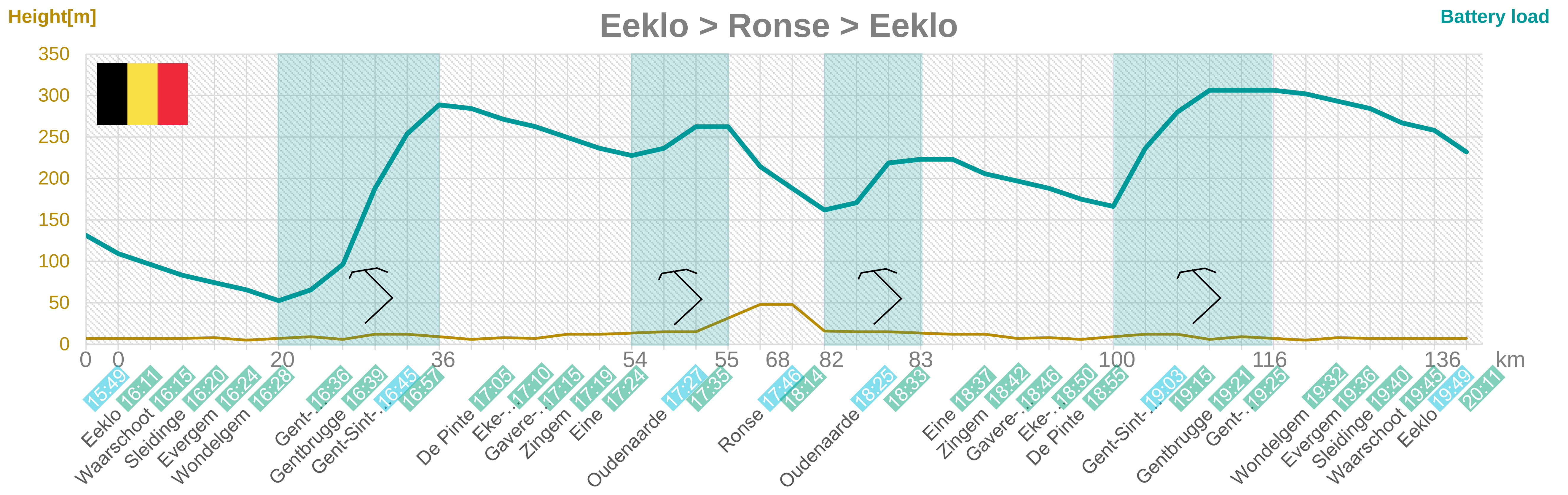
Maximum 200A during standstill

Maximum 2400A in motion

A charging possibility will be required in Couvin







09:48 Arrival time 10:12 Departure time

SIEMENS

Questions

Discussion

Katrin Seeger
Siemens Mobility - Head of Battery Technology
Commuter & Regional Trains

Thank you for your attention.

INTERNATIONAL UNION
OF RAILWAYS

ON-BOARD ENERGY STORAGE FOR CATERNARY FREE SECTIONS

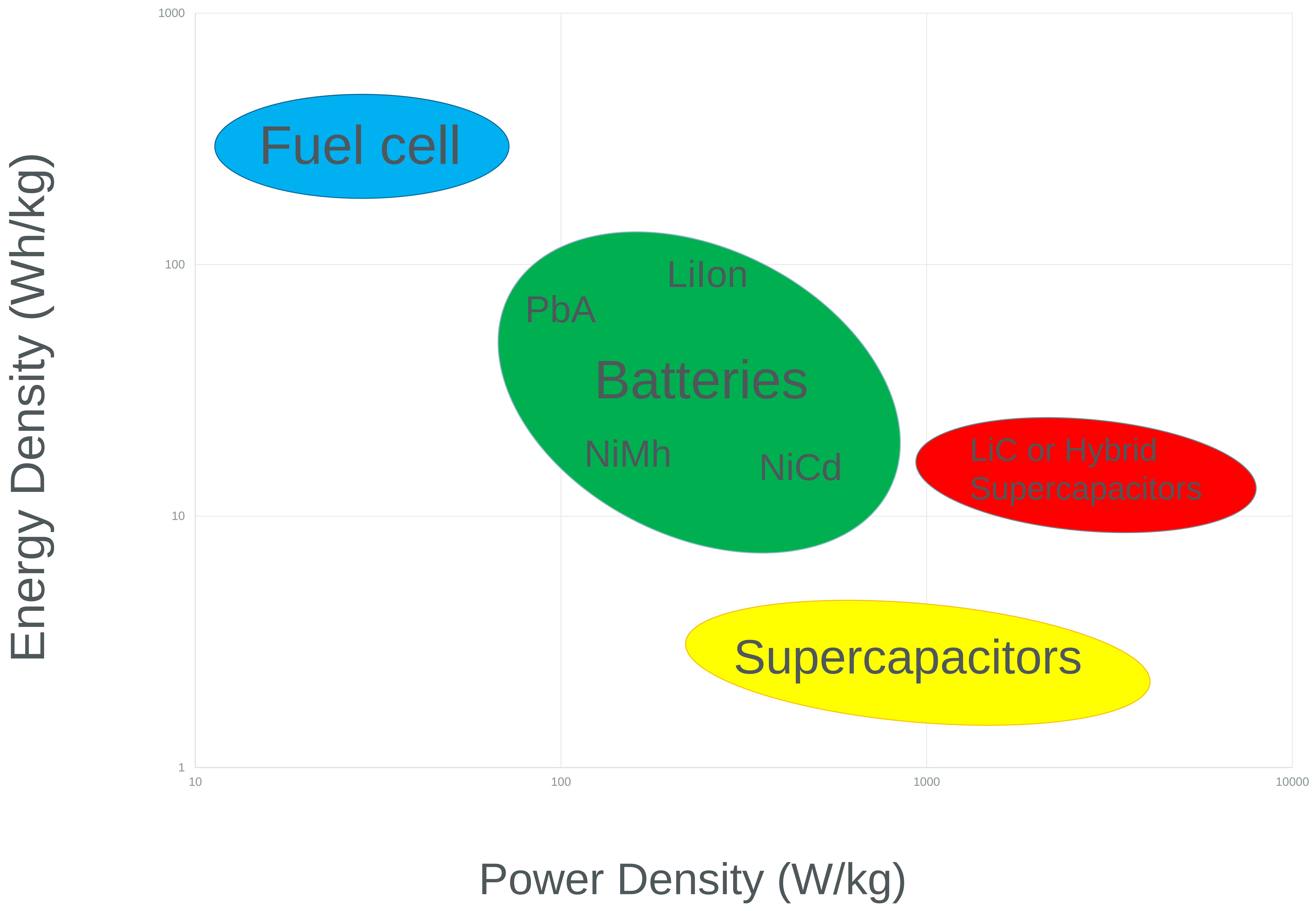
Powering Business Worldwide

Akos Labady
Sr. Field Application Engineer, Eaton Electrical/ELX

UIC online workshop, 19May2021

products for rolling stock and infrastructure

Electric Energy Storage Options - The Ragone-Plot

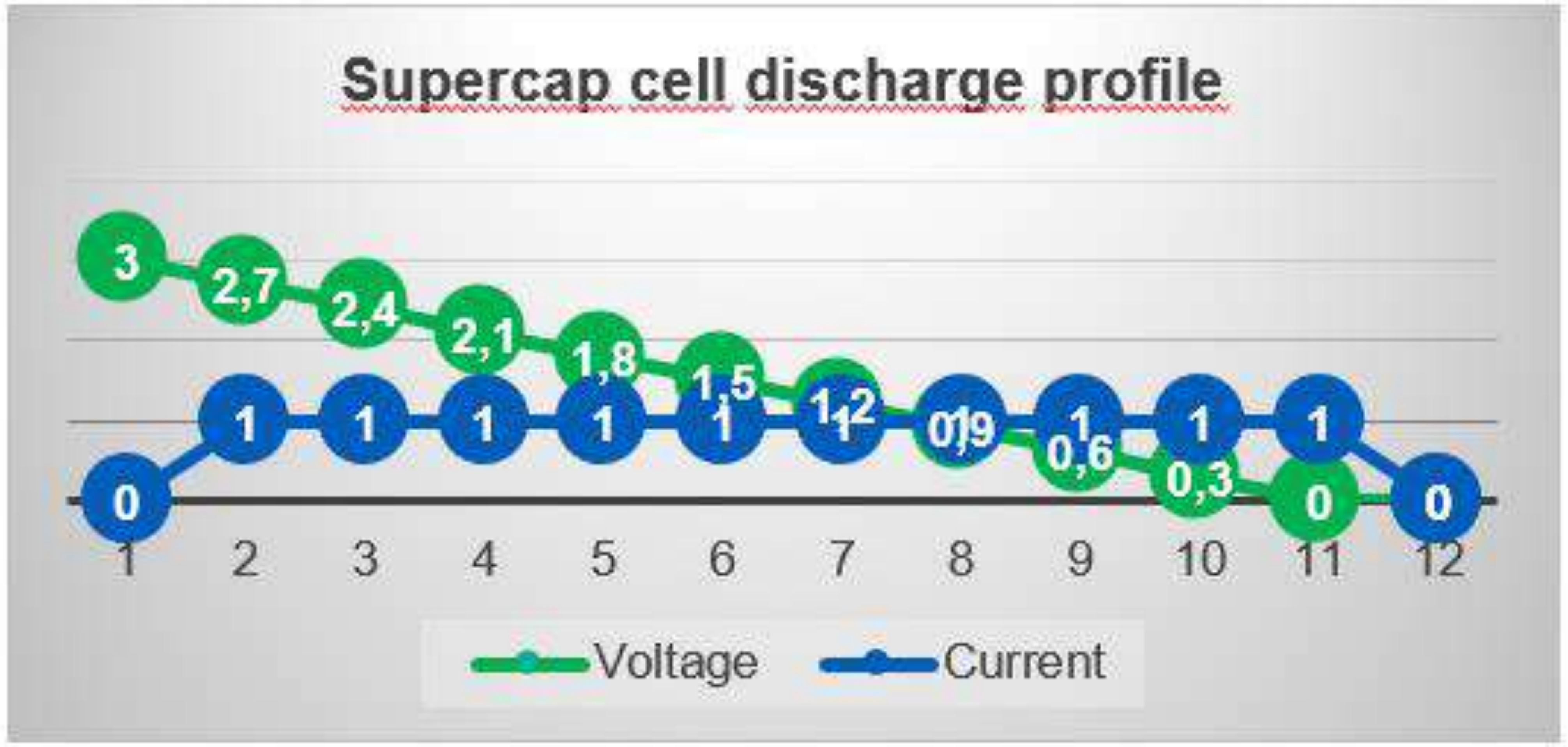


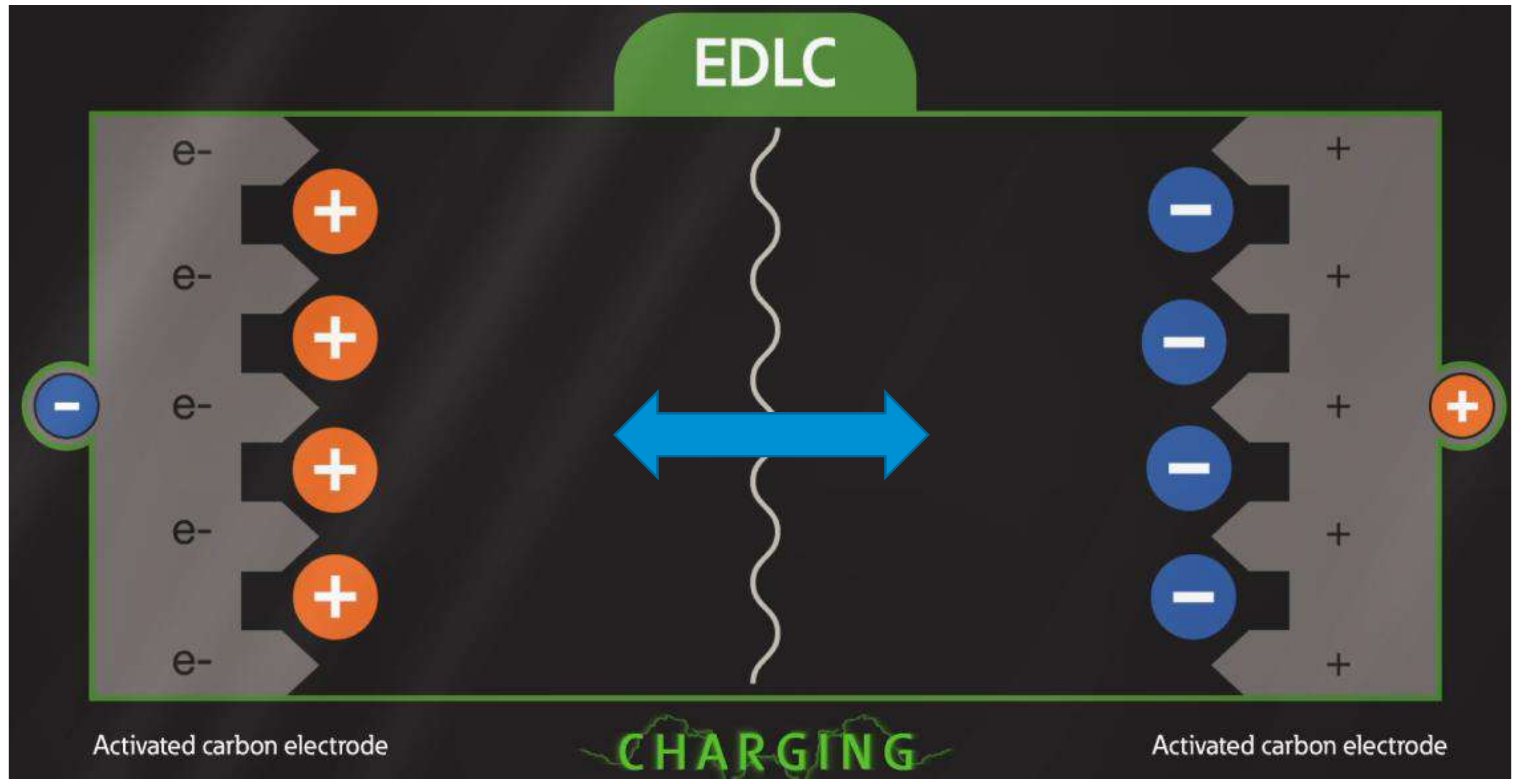
Eaton offerings for energy storage:

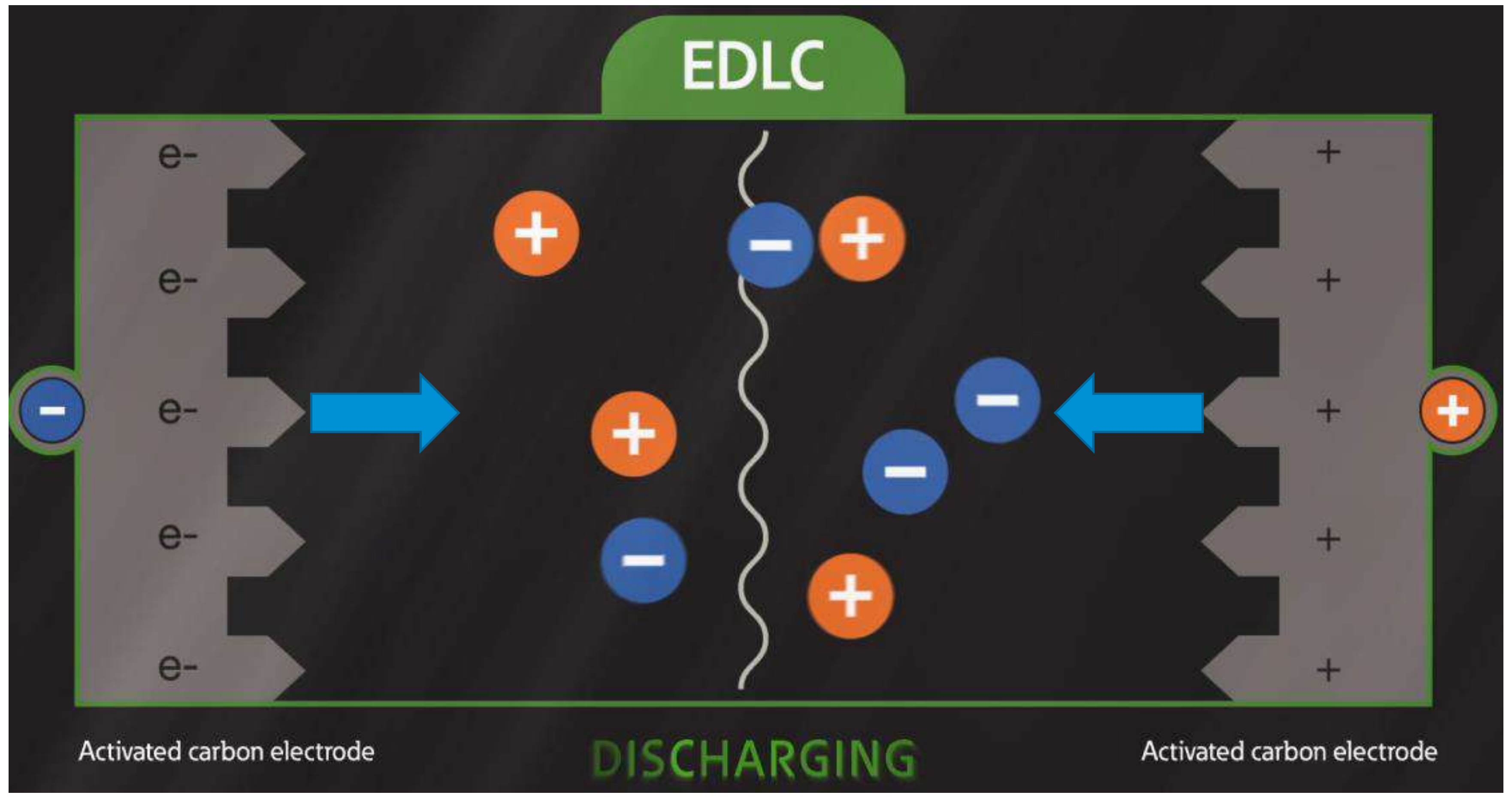
- LiIon based systems
- PbA based systems
- Supercapacitor based systems
- Hybrid supercapacitors

EDLC aka. Supercaps

- Supercaps are symetrical devices comprised by activated carbon electrodes at both anode and cathode sides
- Charging and discharging are electrostatic processes – no chemical reactions
- Cycle life is practically unlimited
- Charge and discharge can be done at the same speed and fashion in seconds
- Voltage drops linerarly by the energy delivered

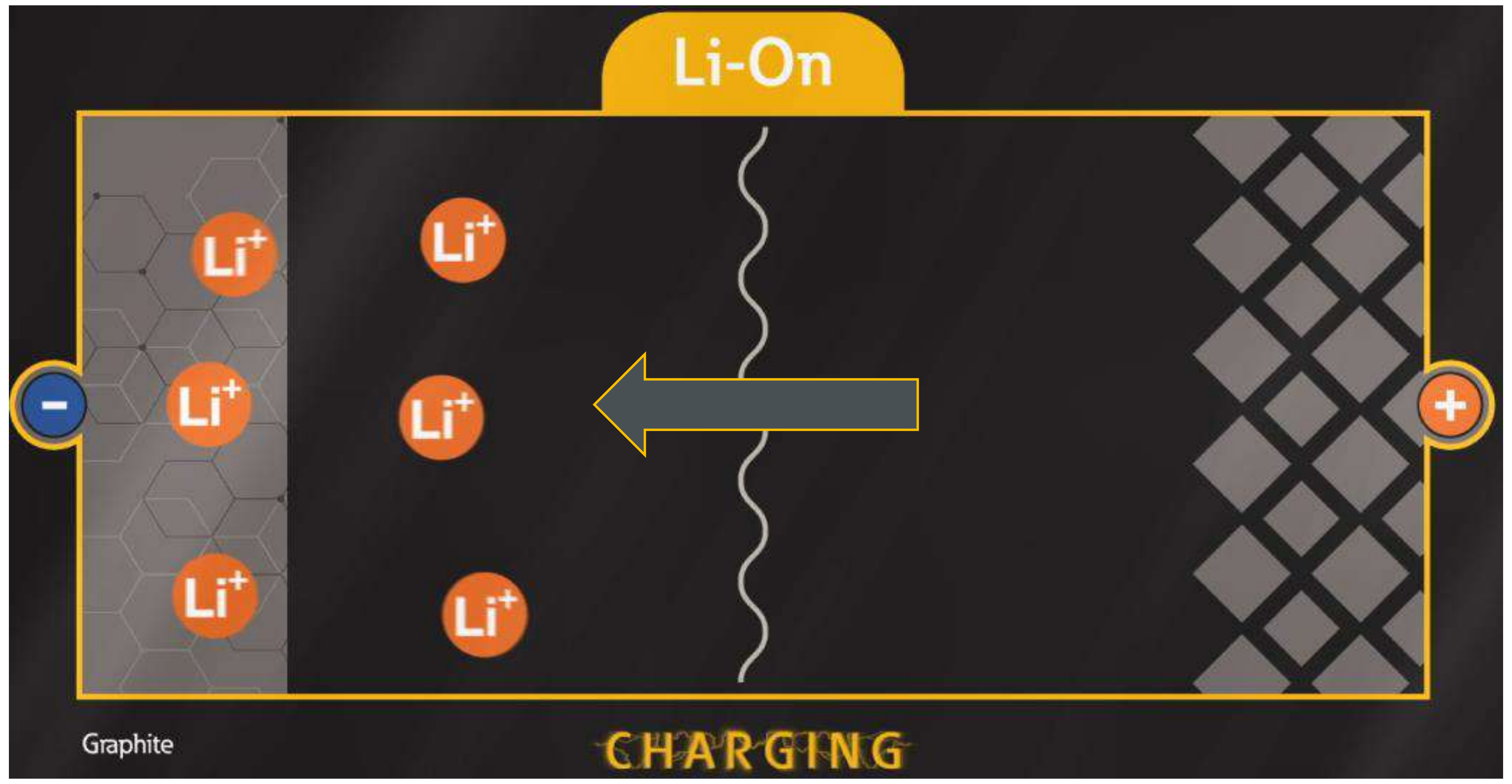


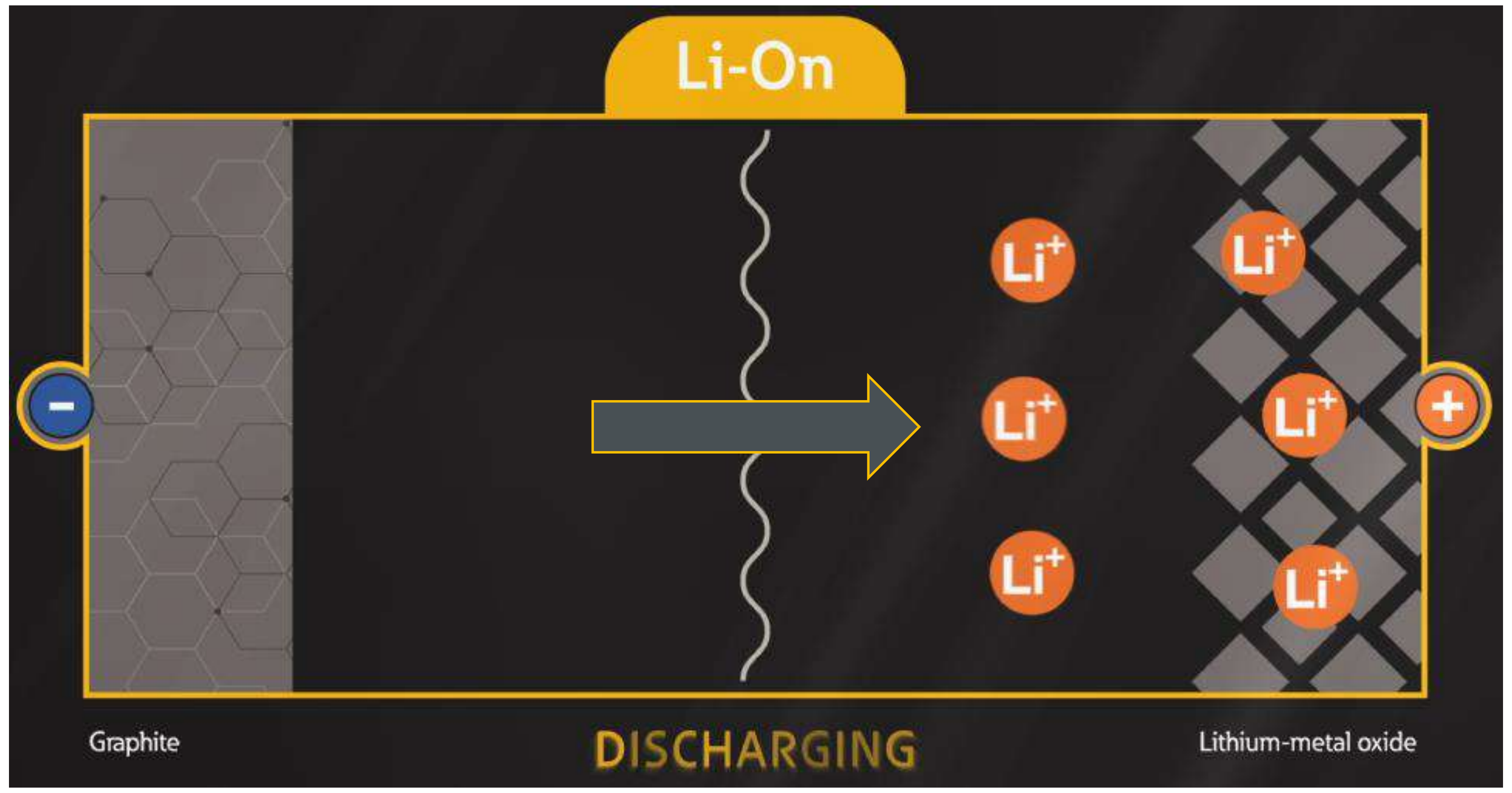


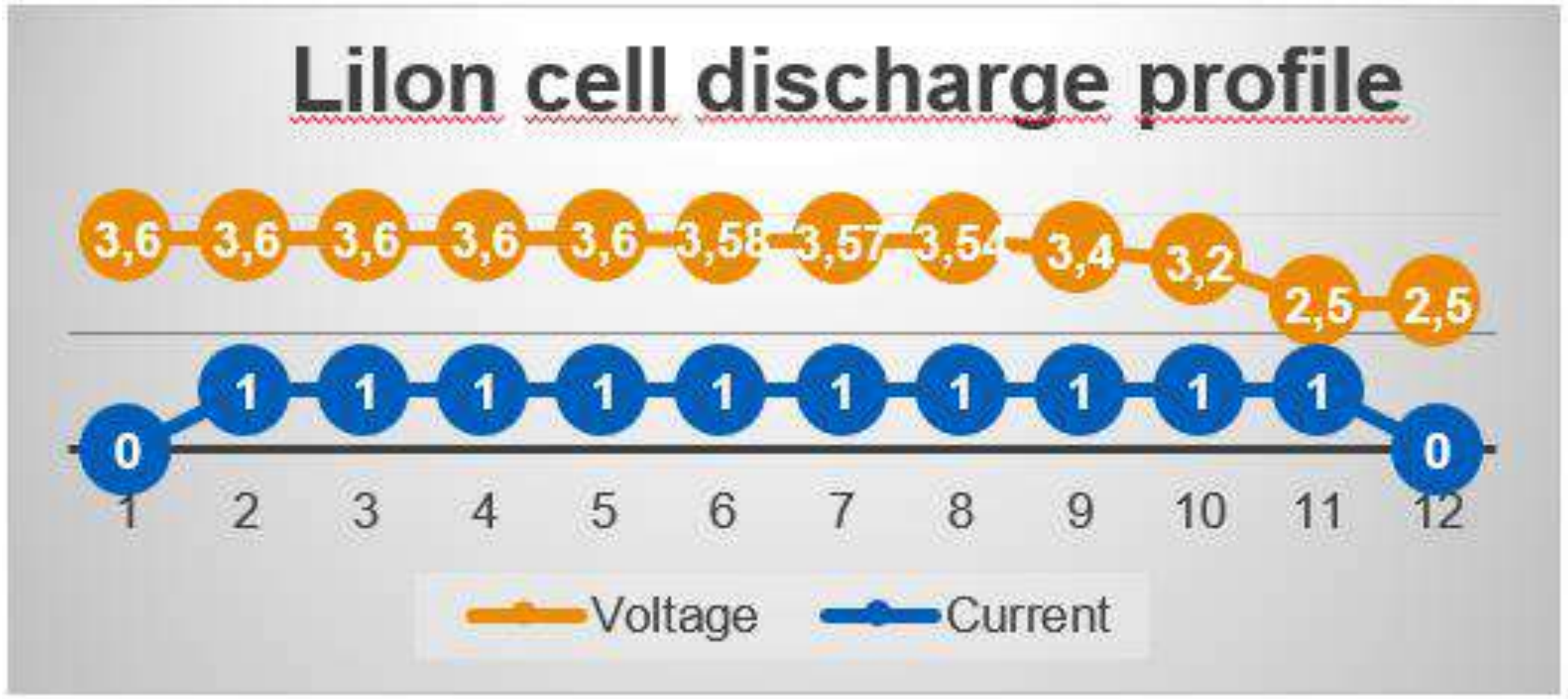


LiIon batteries

- LiIon batteries are assymetric devices comprising of graphite anodes and metal oxide cathodes (Co, Mn, PO4, Fe, Ni combinations)
- Charge and discharge are electrochemical processes
- Cylce life is limited due to degradation (electrolyte oxidation, Li oxide buildup on anode and cathode surface, structural damage etc.)
- Discharge profile is flat, delivering quasi constant voltage

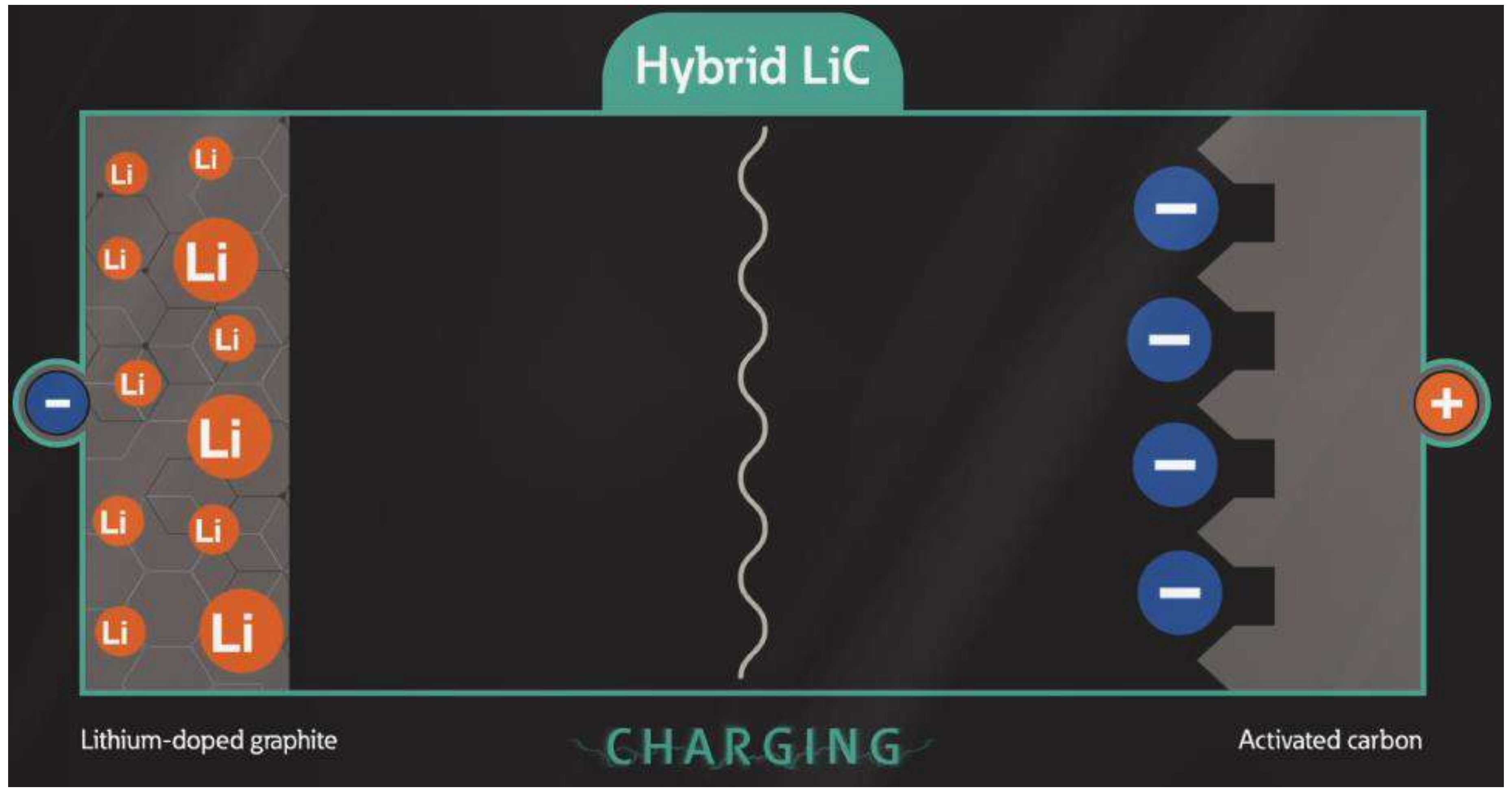


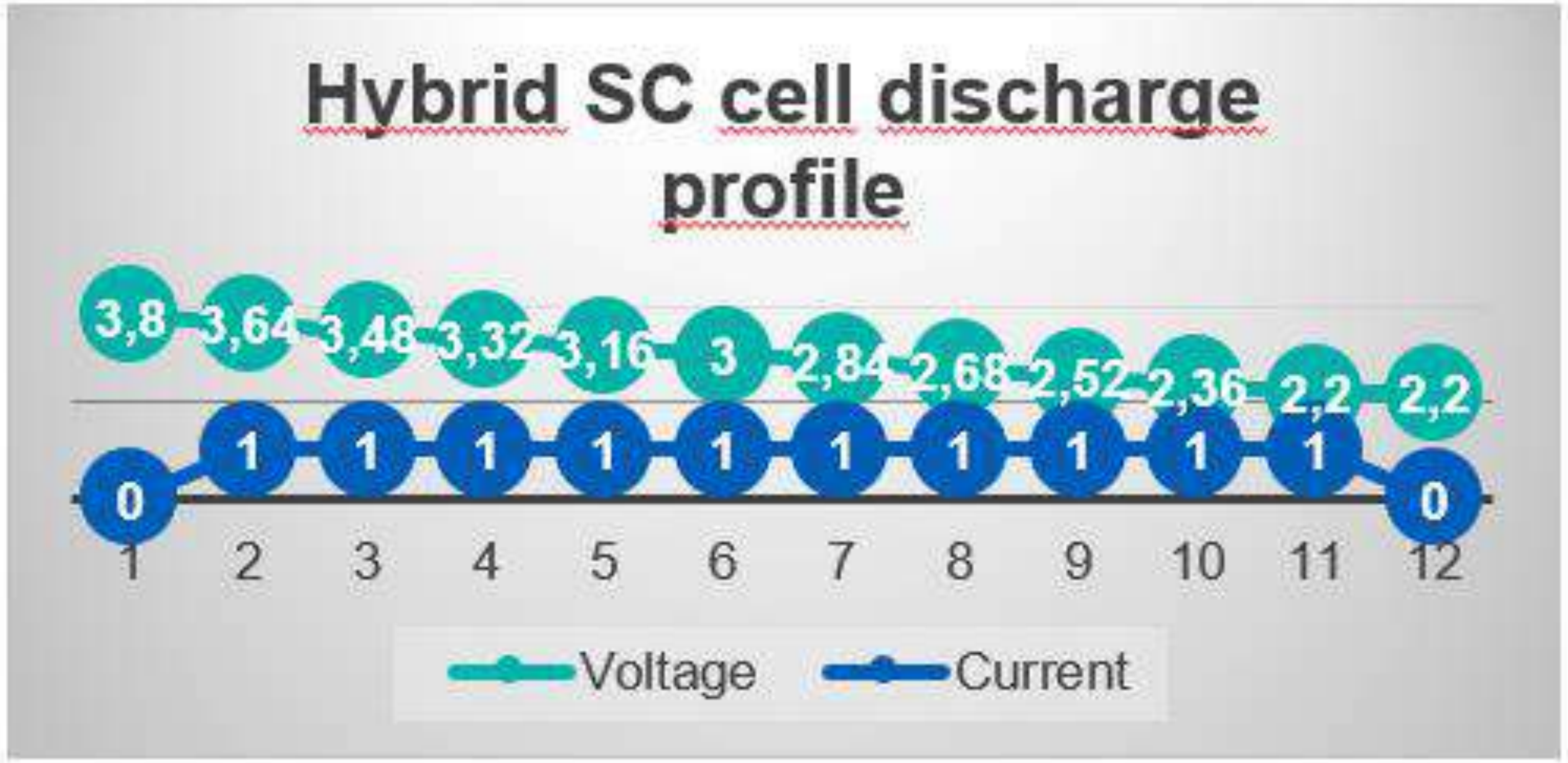


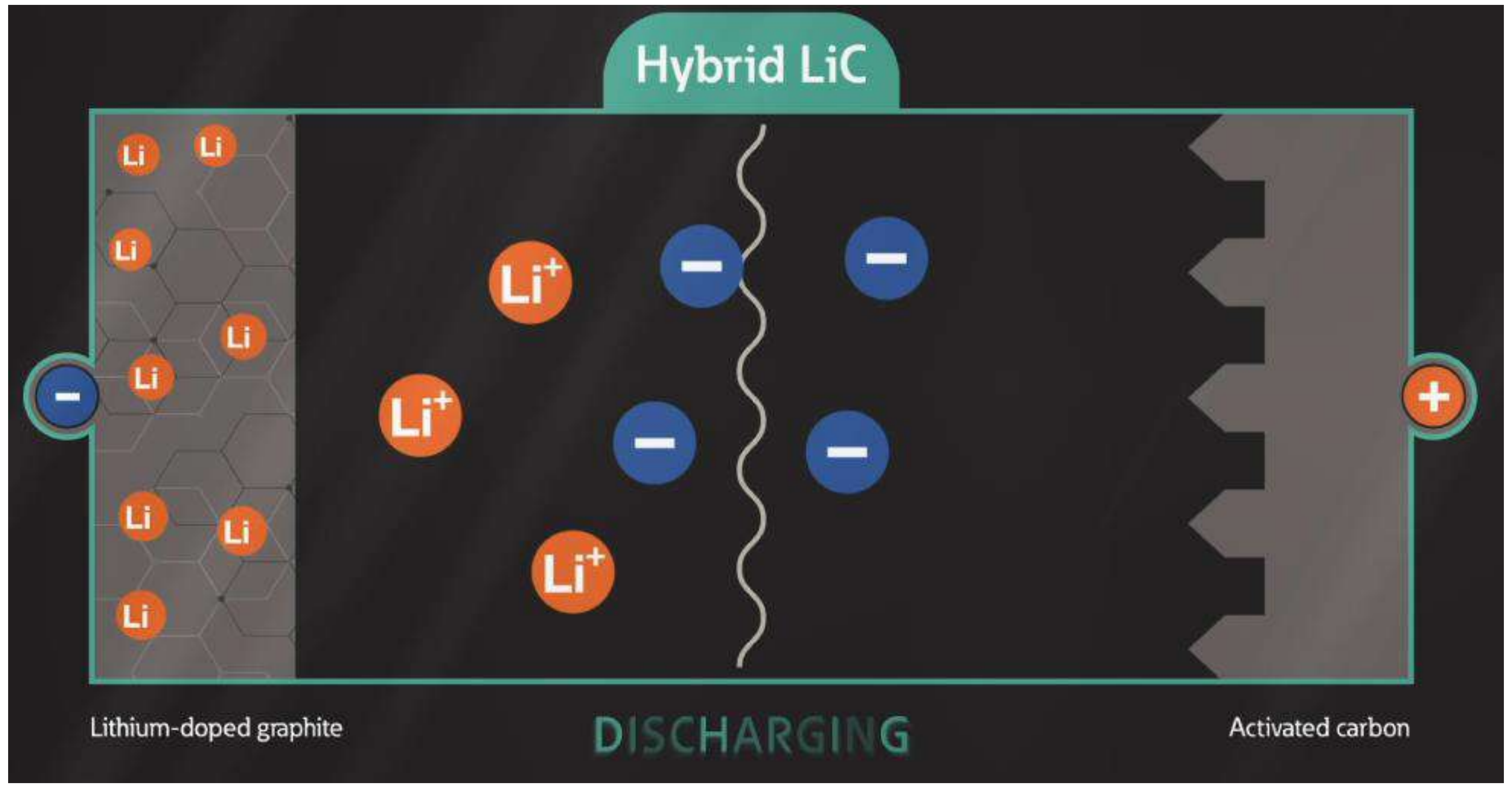


NEW - LiC aka. Hybrid Supercaps

- Hybrid supercaps are asymetric devices comprise of a Li doped graphite anode and activated carbon cathode
- The charge movement is done electrochemically mainly but in significantly lower depht as in case of the LiIon battery. This results a very high ~500.000x cycle life and very fast responsiveness to high C rate discharges
- As there are no metal oxides used the hybrid supercaps are not posing any risk of fire or thermal runaway







Technology Comparison

Li-ion Battery

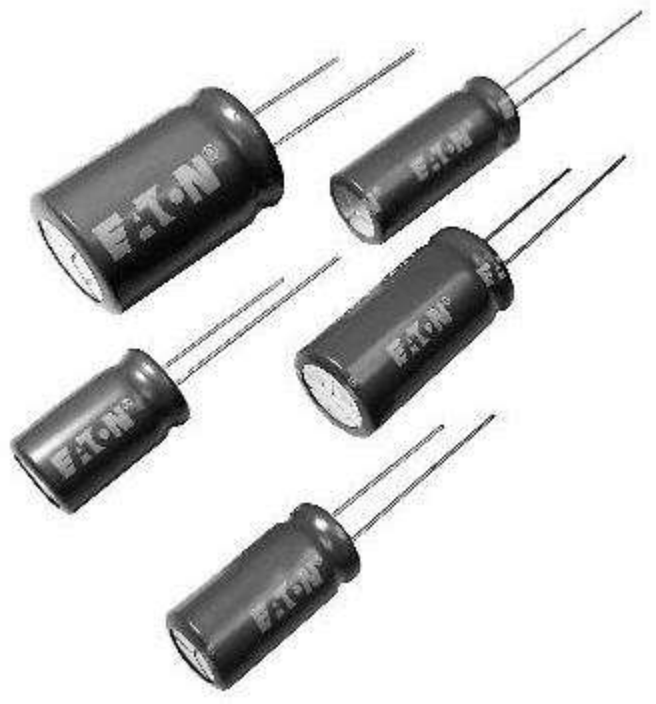
+Highest energy density
+Lower self discharge – years
+Cost per Wh

-High current recharge shortens life
-Higher internal resistance limits power
-Must manage thermal load
-Operating temperature range -10 to +40ºC
-Require sophisticated battery management system
-Must oversize to reach longer life times >5 years
-Sustainability – rare earth metals
-Safety to manage
-Cycle life: 3k-10k

Hybrid Supercapacitor

+High energy density provides fast recharge in minutes
+Long life time: 10 years at 20ºC
+Long cycle life: 500k (HS), 250k (HSL)
+Safety: no thermal runaway, short circuit does not cause fire
+Simple cell management and charging circuit
+-15C/+70C operating temperature
Low self discharge for longer life when paired to primary batteries – individual self discharge in months

–Cost per Wh



Example - overhead line free sectioned line

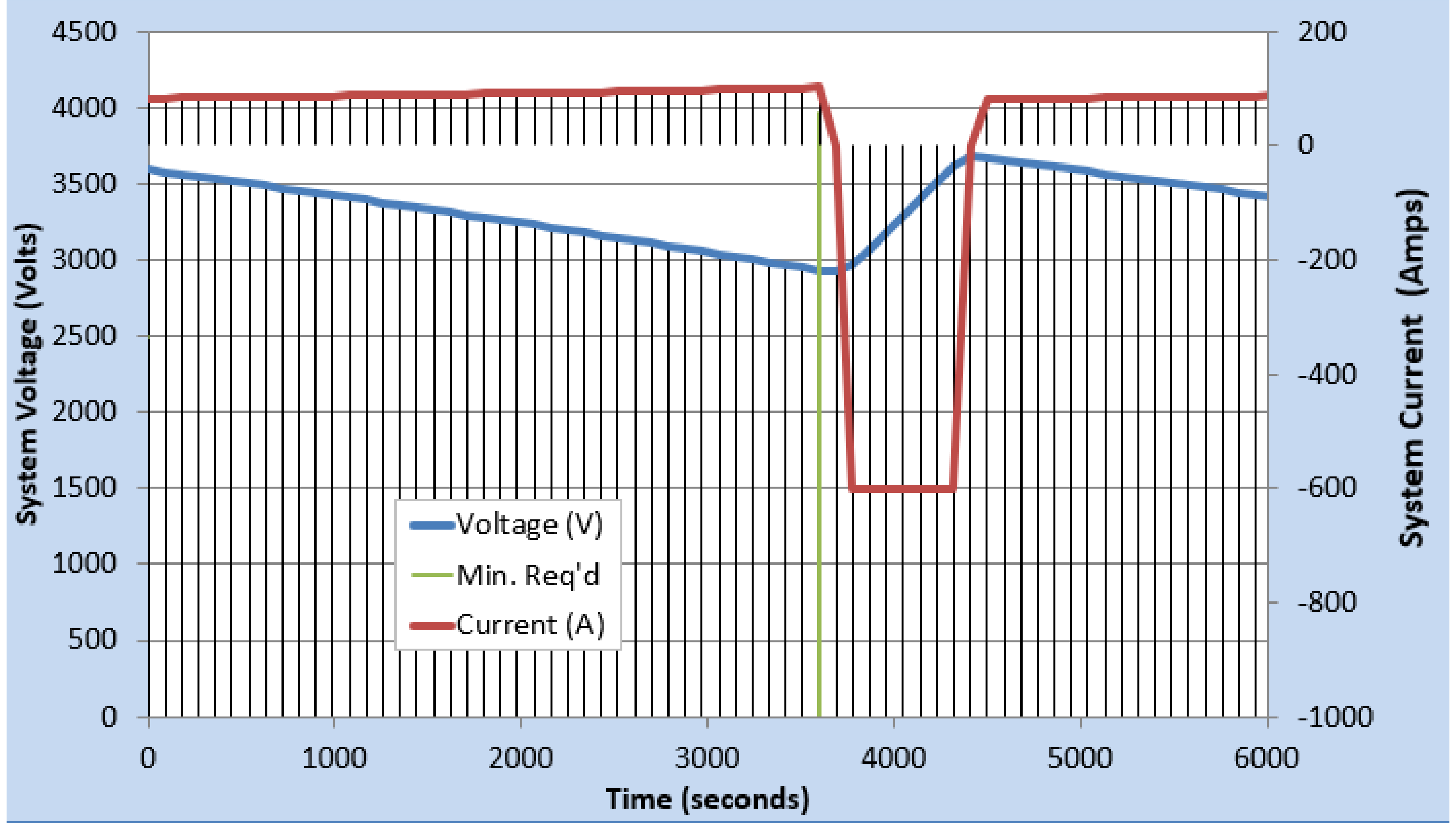
150ton train

3000VDC line

50km distance between charging lines

50km average speed on main line

300-500kWh stored energy on-board by LiIon batteries or hybrid supercapacitors



60min 300kW dishcarge followed by 10min 600A recharge

10min 1800kW charge

60min 300kW discharge

20min 900kW charge

Required energy storage per technology

Hybrid Supercapacitor (lithium doped graphite / activated carbon)

Charge voltage = 3800-4000VDC
Nominal voltage = 3600VDC
Min discharged voltage = 2500VDC
Installed capacity = 550kWh
Theoretical lifetime = 75MAh or 25million km assuming ideal cell management and moderate temperature level
Size = 36m3
Weight = 25-30tons

NMC (lithium / nickel manganese cobalt oxide)

Charge voltage = 3800-4000VDC
Nominal voltage = 3200VDC
Min discharged voltage = 2700VDC
Installed capacity = 2160kWh
Theoretical lifetime = 68MAh or 20million km assuming ideal cell management and moderate temperature level
Size = 16m3
Weight = 20-25tons

No actual product displayed

Advantageus Use Cases

Hybrid SUPERCAP

- Short distances to cover with stored energy **<50km** sections
- In case **high current** available for **charging**
- In case **safety** is critical – tunnels/subways
- In case **braking energy** is more to utilize (downhills)
- In case **higher acceleration** rates are appreciated (uphills, urban transport)
- When **wider temperature** either cold or hot is an issue

Li-Ion BATTERY

- Can cover **100+km** with one charge
- More **cost efficient** solution over 50km
- May be overnight charged to **save** the number of **charging sections** and extend battery life
- **Available** solution as per 2021

Questions

Discussion

Akos Labady
Sr. Field Application Engineer, Eaton Electrical/ELX

Thank you for your attention.

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Stay in touch with UIC:

www.uic.org

#UICrail

Slides and recording to be made available on the event page
https://uic.org/events/battery-trains

Call for speakers is open for a workshop on stationary energy storage systems, please contact stefanos@uic.org

Thank you for your attention.