Electric Vehicles & the Grid: From Problem to Opportunity

11:00-12:45

Wed, 27 September 2023

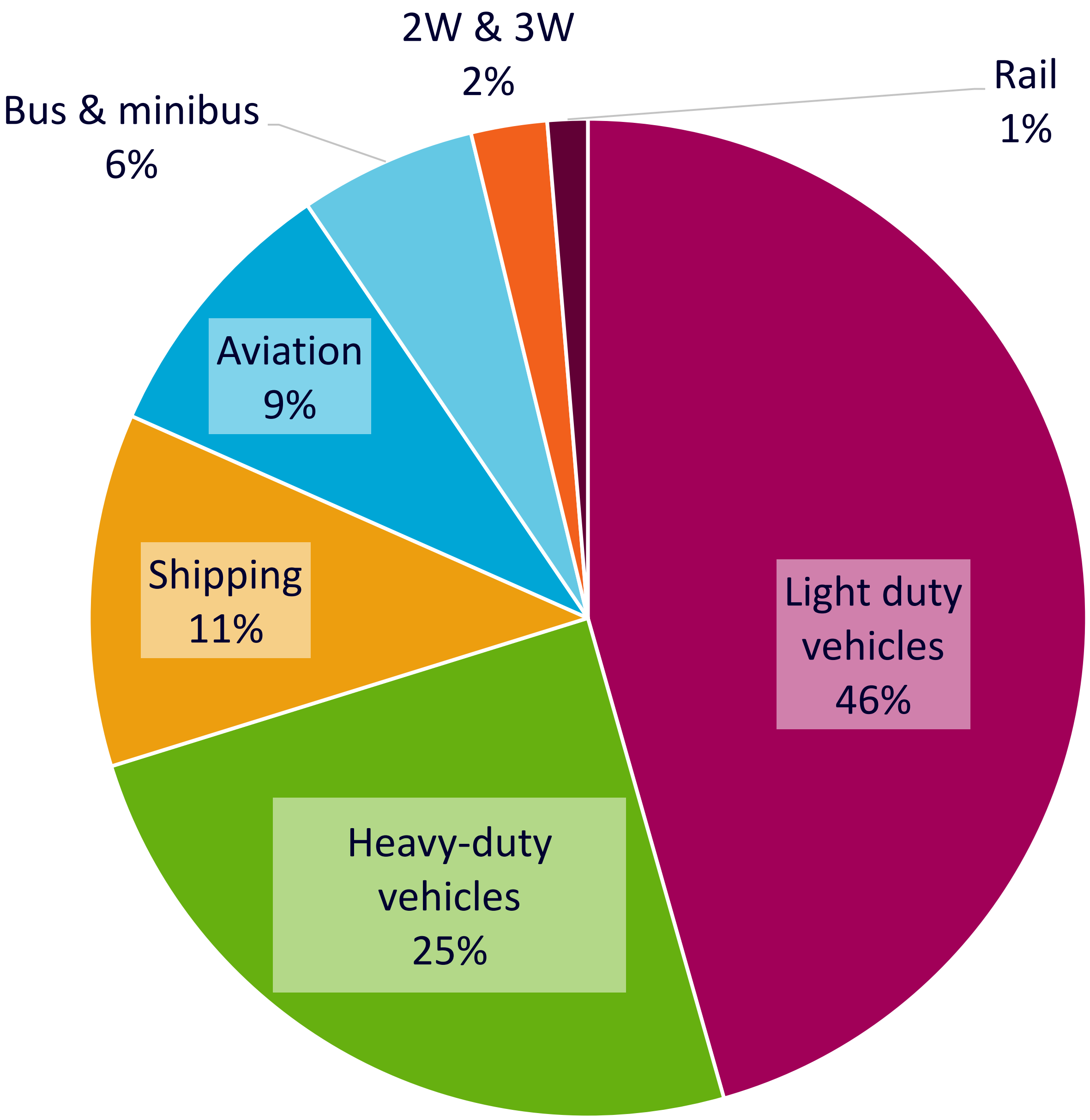
Theater Hall, Delft X, TU Delft

Electric vehicles & the Grid: From Problem to Opportunity

Time	Speaker	Topic
11:05	**Sebastian Rivera, Assistant professor, DCES**	Power electronics for Energy hubs for EV charging
11:20	**Gerd Kortuem, Full professor, IDE**	EV charging: Human aspects & responsible AI
11:35	**Gautham Ram, Assistant professor, DCES**	Vehicle to grid: Technology trends & challenges
11:50	**David Shipworth, Professor, UCL Energy Institute**	Vehicle-to-grid vs vehicle-to-home from an end-user perspective
12:05	**Pedro Vergara, Assistant professor, IEPG**	Smart charging at scale (ROBUST)
12:20	**Jianning Dong, Assistant professor, DCES**	High-efficient wireless charging of EVs
12:35	**All speakers**	Audience questions with speakers panel

Transport emissions

- Transport emissions = 7.2 Gt CO_2
- ~17% of all emissions



2020 Transport emissions (IEA)

Source: https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-transport-by-subsector-2000-2030;
Trucks include road freight vehicles with a gross vehicle weight of more than 3.5;

59 Gt CO_2e = Net emissions 2019 - CLIMATE CHANGE 2023 - Synthesis Report, IPCC

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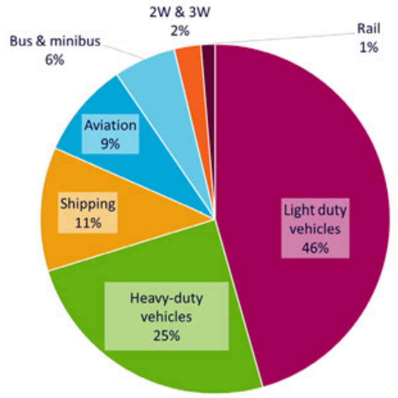
Take the bike, bus & train

- Electric cars are not the only solution
- Bike > Train, Bus, tram > (Electric) car



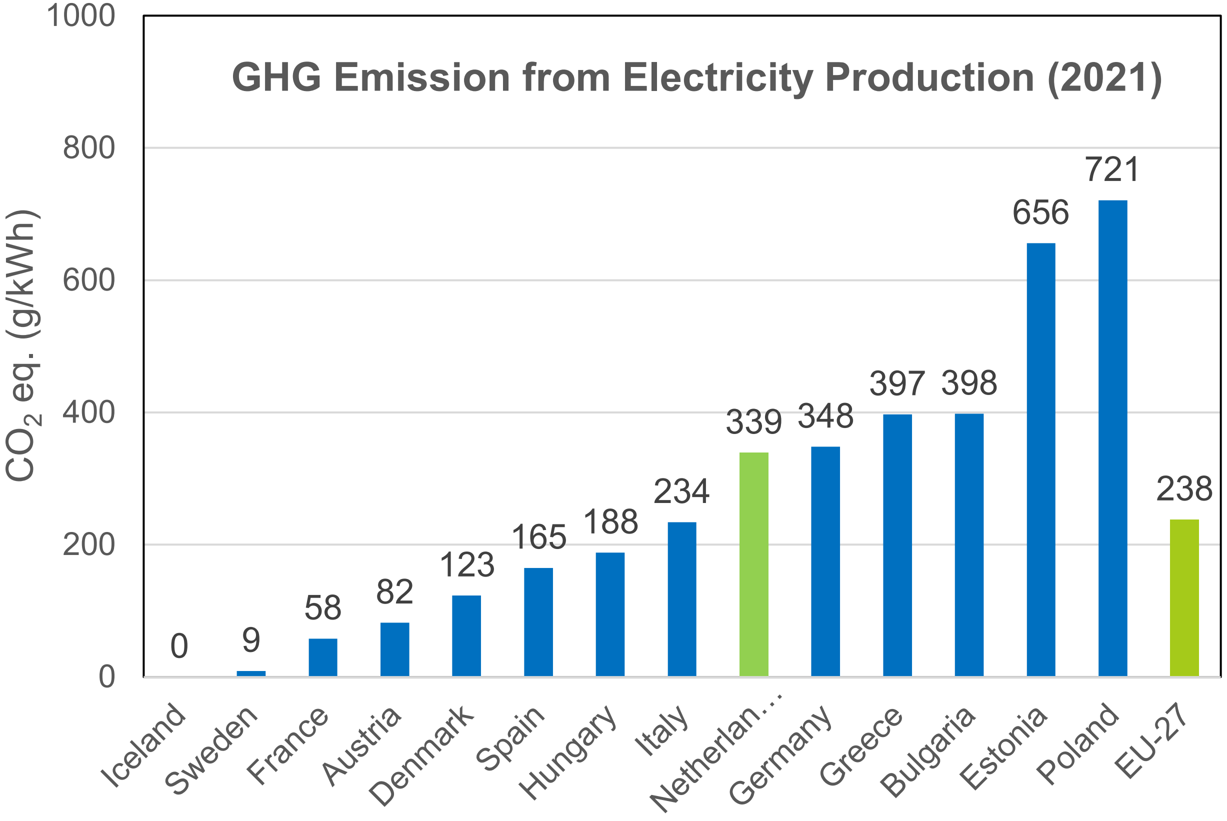
2020 Transport emissions (IEA)

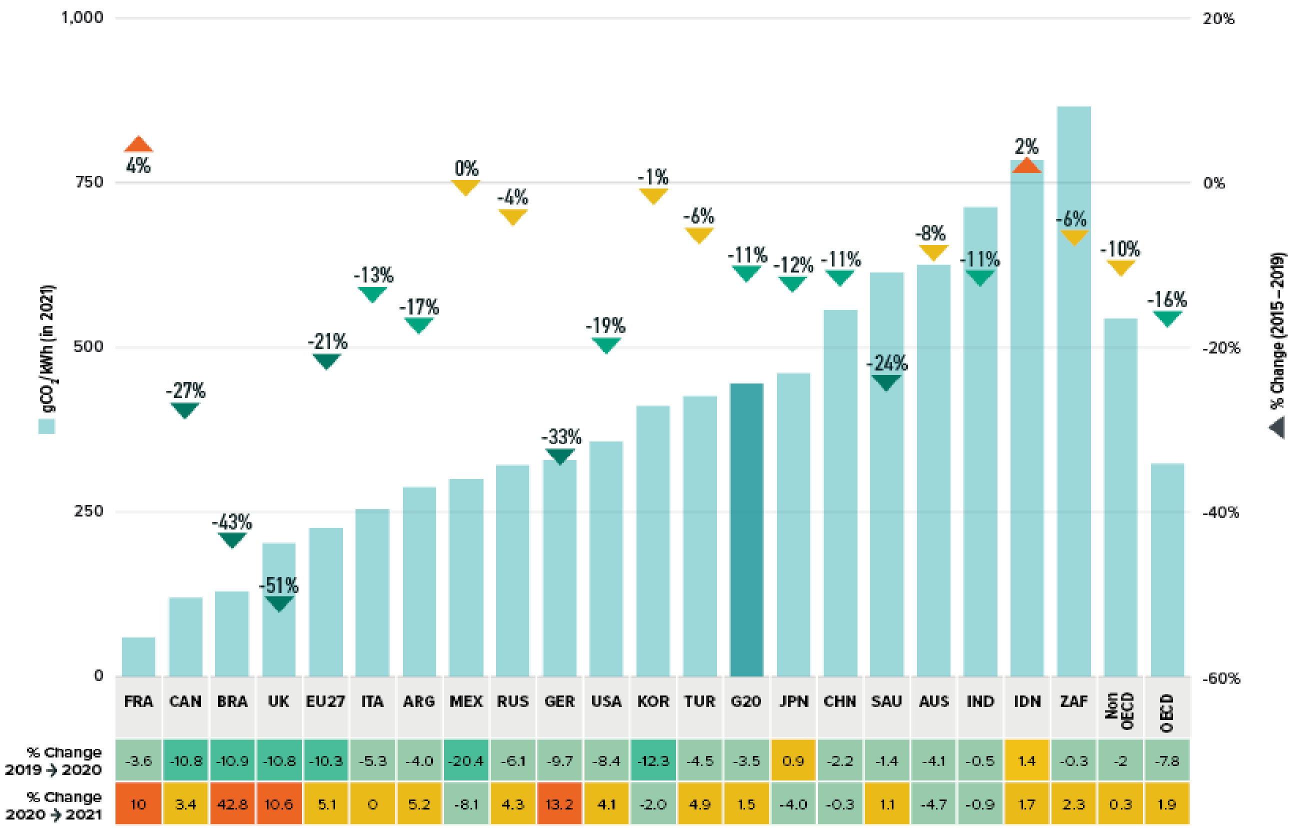
< 5km

< 500 km

Mobility & Energy transition need to go hand-in-hand

- Electricity generation mix (Note: May not account for emissions due to production of fuel source)





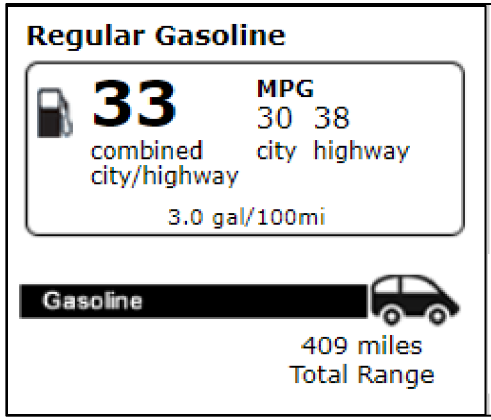
1 kWh ~= 6 km EV range

Source: CO_2 emission intensity (1990-2021), European Environment Agency (EEA), https://www.climate-transparency.org, Enerdata 2020-22

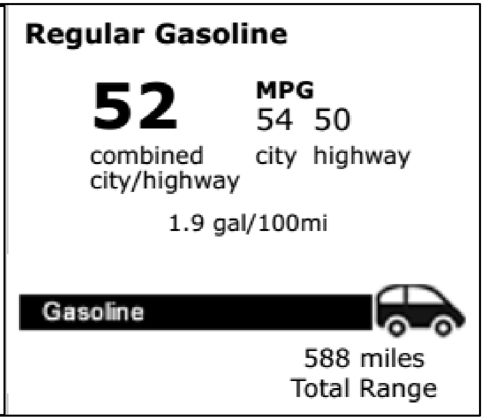
(Plug in) hybrids have a key role

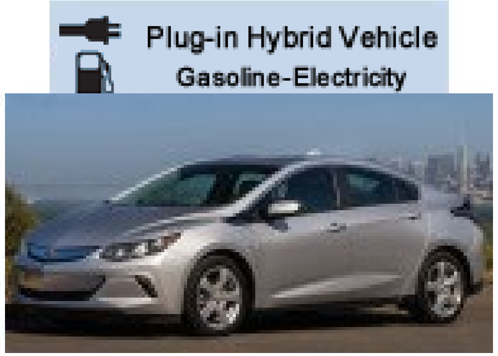
- Go for fully electric cars in the near term (1-5y) in your country if
  - 1) build fast charging infrastructure, 2) significantly decarbonize its electricity grid, 3) bring affordable EVs in the market
- If not, plug-in hybrids can reduce emissions by 1.5-4x in near term (1-10y)

Honda Civic

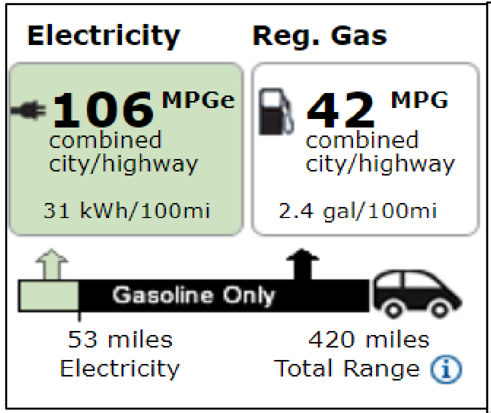


Toyota Prius (4.4kWh)

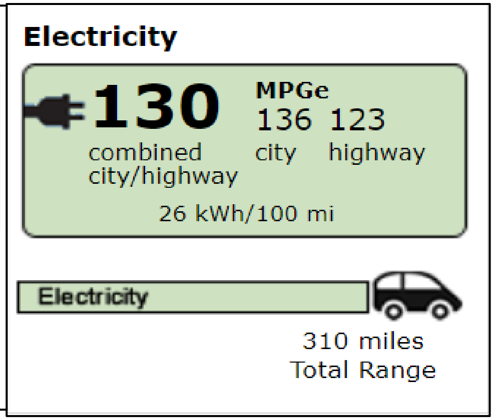




Chevrolet Volt(18.4 kWh)



Tesla Model 3 (75 kWh)



Source: EPA, Dept. Of Energy, US - fueleconomy.gov

Power Electronics for Energy hubs for EV charging

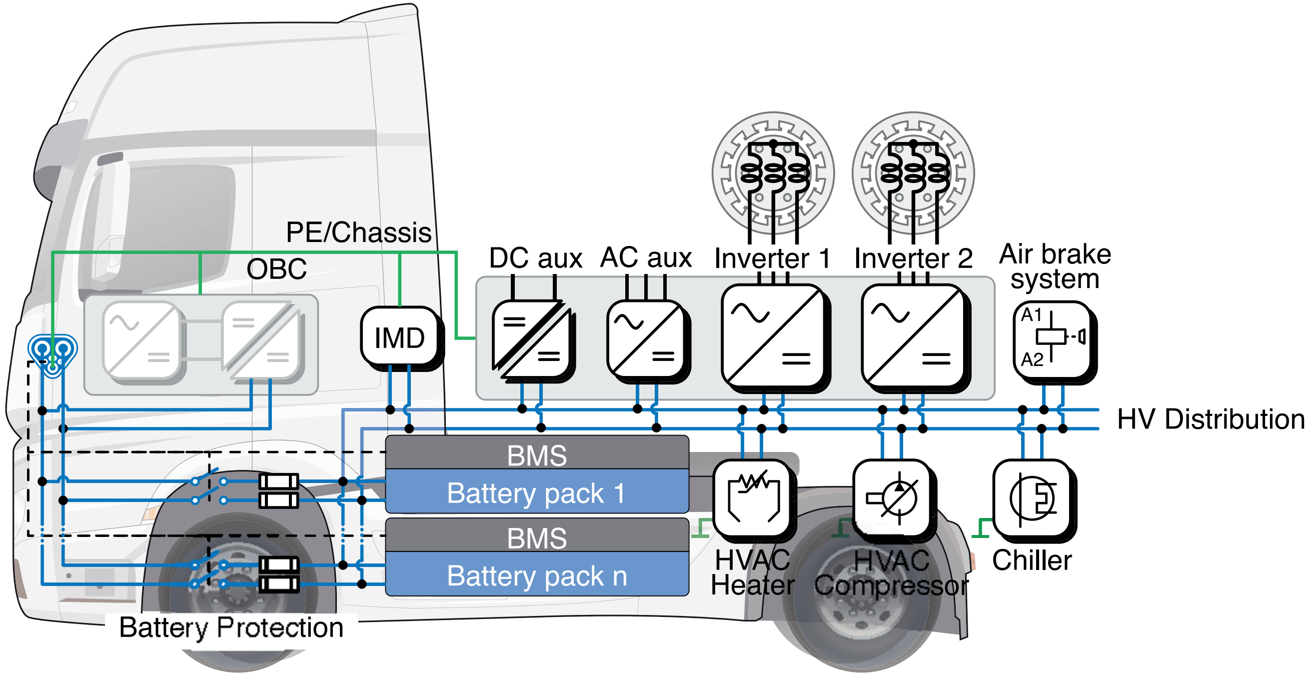
Dr. Sebastián Rivera, DCE&S

TU Delft

Presentation Outline

DCE&S
DC systems, Energy conversion & Storage

- Charging Systems for Medium- and Heavy-Duty EVs
  - EV Charging Infrastructure.
  - Heavy-duty EV Charging Standards
  - DC Charging options for Heavy Duty EVs
  - Commercially Available High-Power Chargers
  - Challenges
- Energy Hubs
  - Energy Hub Concept.
  - EHs for HD Chargers.
  - Dual purpose of EH-based Charging infrastructure
- Ongoing Research
  - Highly-Efficient and versatile Multiport PEBBs.
  - Modular structure for +MW vehicles (beyond MCS).
  - Energy Hubs for the Railway System
- Conclussions and Outlook



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Charging Systems for Medium- and Heavy-Duty EVs

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EV Charging Infrastructure: AC and DC Charging

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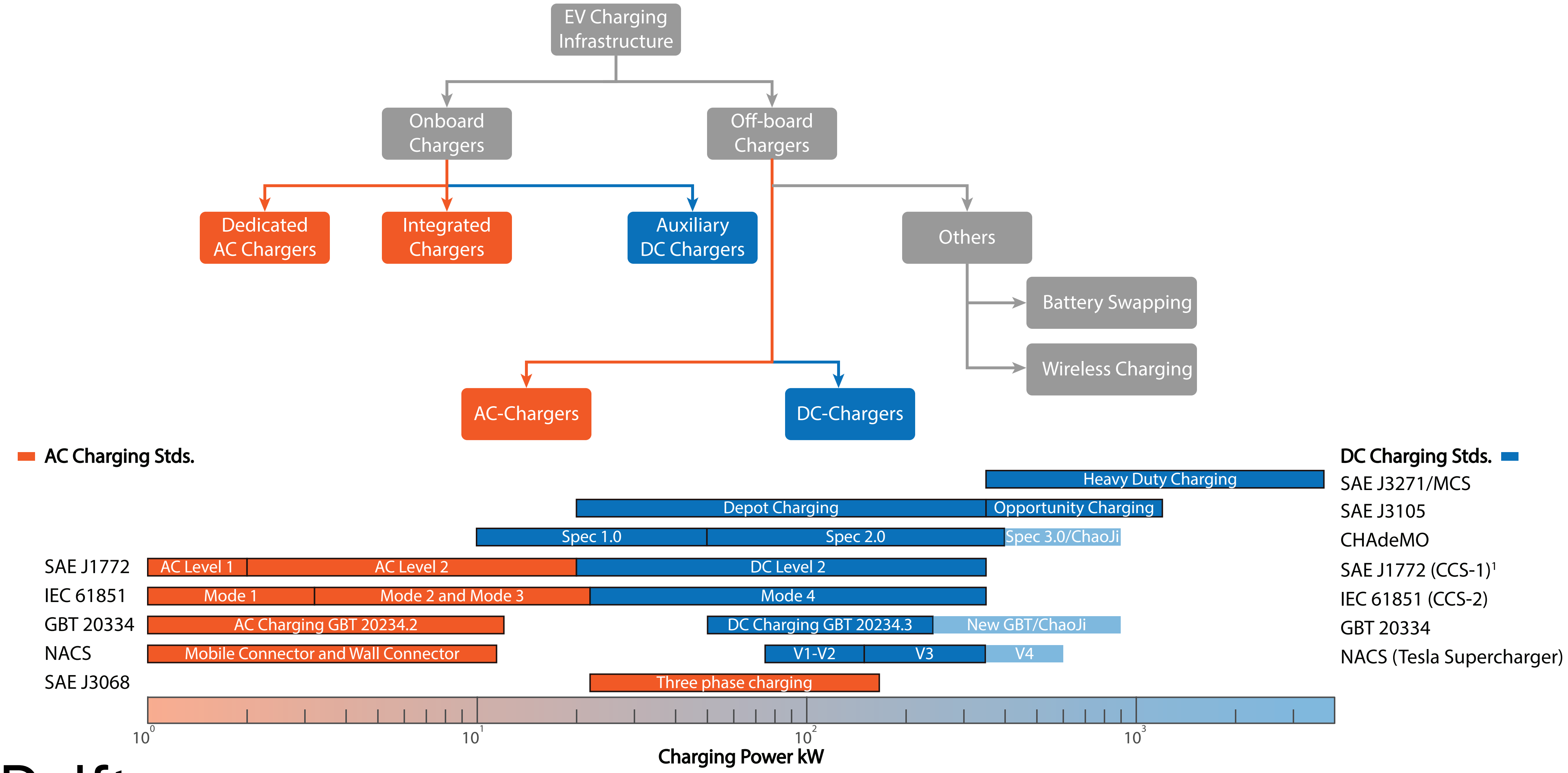

Heavy-duty EV Charging

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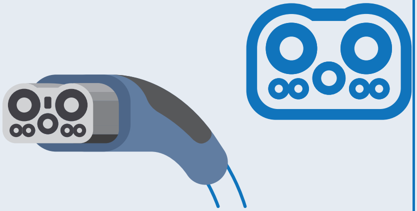
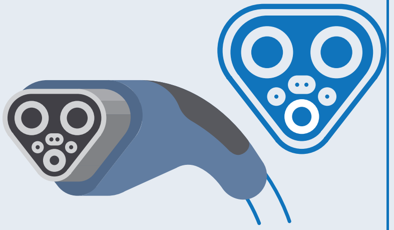
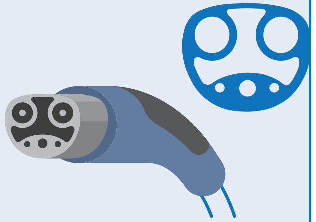
- Charging standards above 1 MW

	CHAdeMO/ChaoJi	MCS	NACS
Max Power[1] Typ Power[2]	900 kW TBD	3750 kW 1000 kW	1000 kW
Output voltage	50 - 1500 V	500 - 1250 V	500 V / 1000 V
Maximum current	600 A	3000 A	900 A
Comms.	CAN	TCP/IP (differential PLC)	CAN
Region	China, Japan	Europe, US	Global
Related standards	• IEC61851-23,-24 • IEC62196-3 • JEVS G105-1993	• IEC61851-23-3,-24 • IEC63379, SAEJ3271 • ISO 15118 - 20	• IEC62196-3 • NACS
V2X	Yes	Under development	Under development
Plug type			

EV Charging Infrastructure: DC Charging of HD EVs

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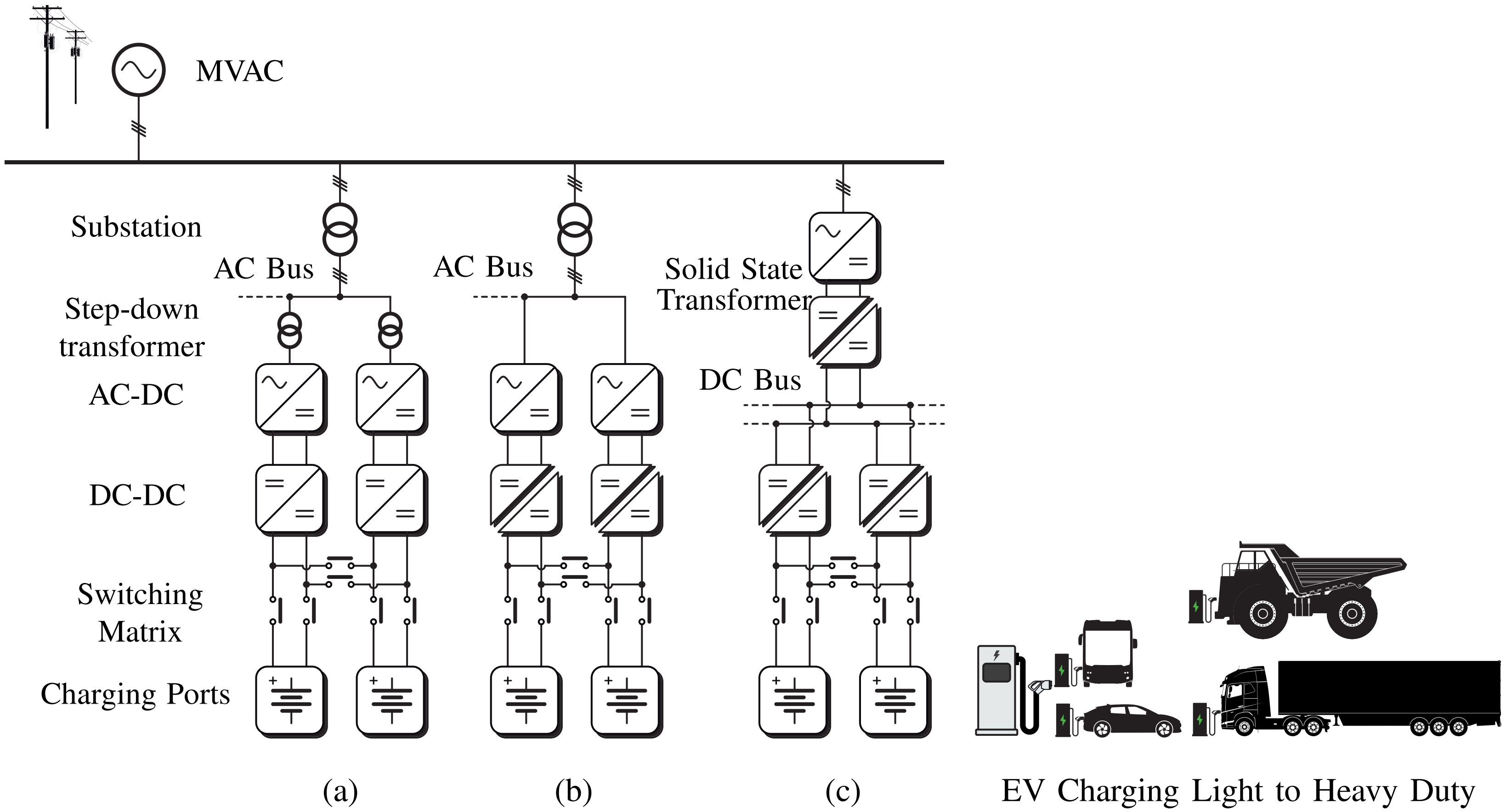
- DC Charging options for Heavy Duty EVs



State-of-the-art High-power Chargers

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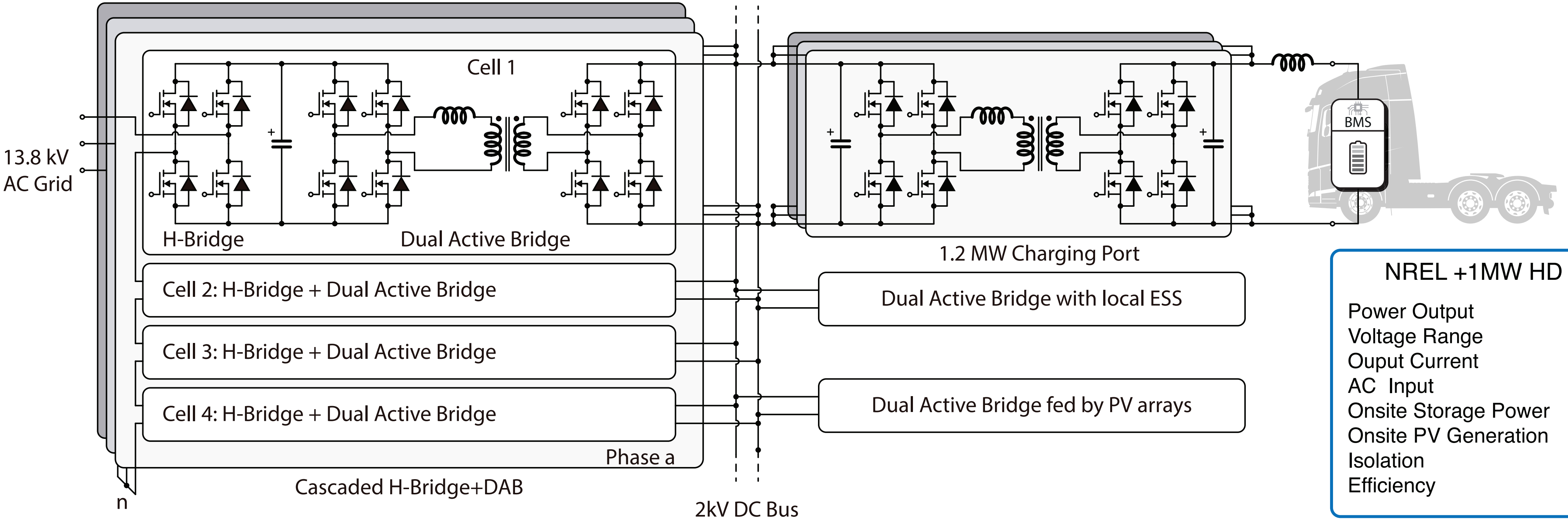
- High-power chargers in the market
  - Commercially available chargers reach up to 600 kW
  - Modular structure using 20-50 kW PEBB
  - Similar approach is not suitable for +MW Chargers (+100 of modules)
  - Higher power blocks are required.
  - Several challenges arise: heavier, magnetics design, power

EV Charging Infrastructure: DC Charging of HD EVs

- DC Charging options for Heavy Duty Evs: Practical demonstrator NREL



NREL +1MW HD EV Charger	
Power Output	400kW -1.2 MW
Voltage Range	220 - 1500 V
Ouput Current	800 A
AC Input	13.8 kV
Onsite Storage Power	400 kW
Onsite PV Generation	400 kW
Isolation	HF
Efficiency	98%

EV Charging Infrastructure: Challenges

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- Main challenges for +MW charging
  - Conventional discretization of power modules may not be suitable.
  - Increasing the power rating of PEBBs challenges the design of magnetics.
  - Substantial increase the stress on the electric power grid.

- Regional Challenges
  - EU prioritized the decarbonization of the HD vehicle sector.
  - Two TEN-T corridors have a key node in the Gerland Province.
  - Urban logistics will exponentially increase the demand for HD chargers.
  - Most of EU logistic routes have distances below 500 km.

Energy Hubs for EV Charging

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Energy Hub Concept: Transportation Decarbonization

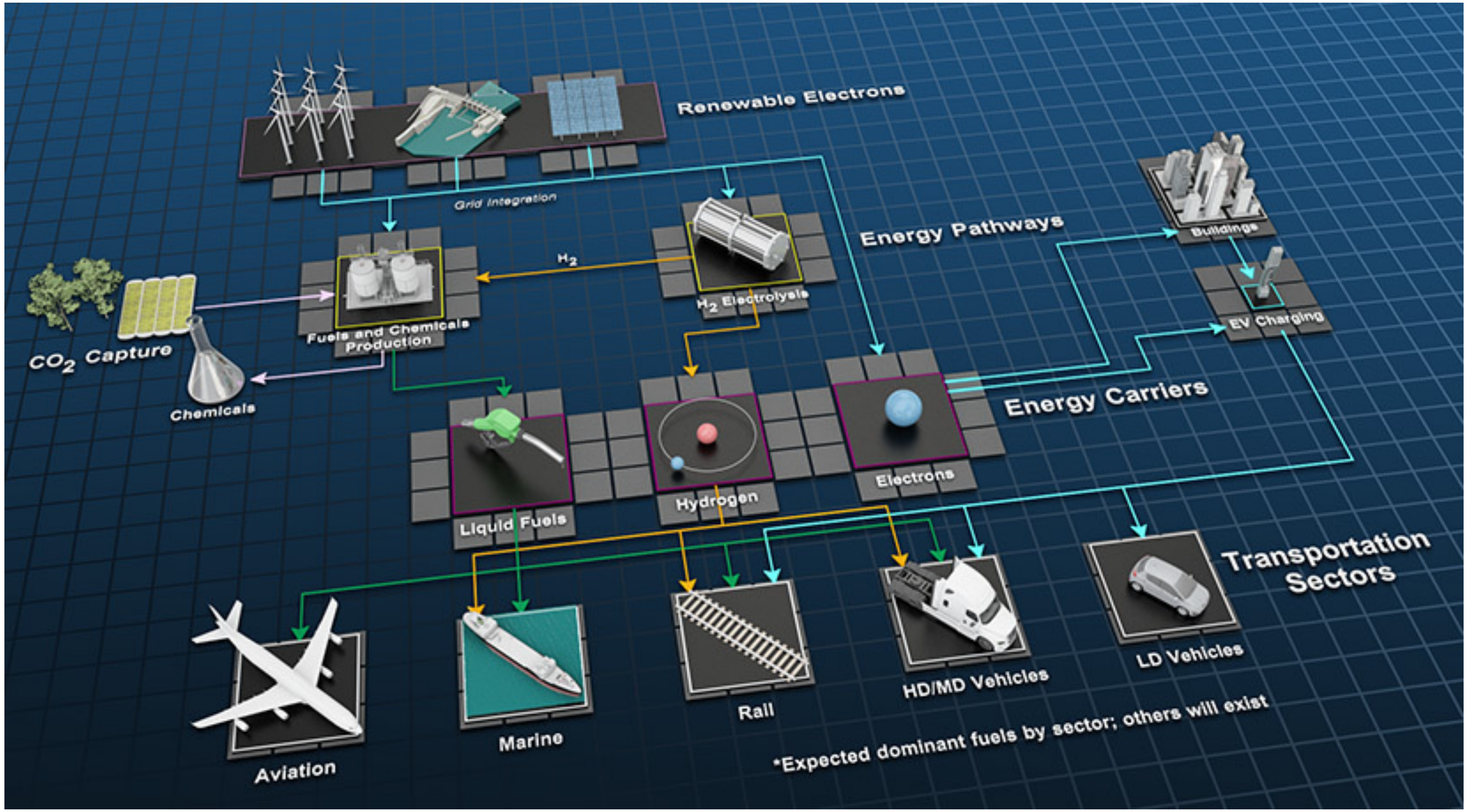
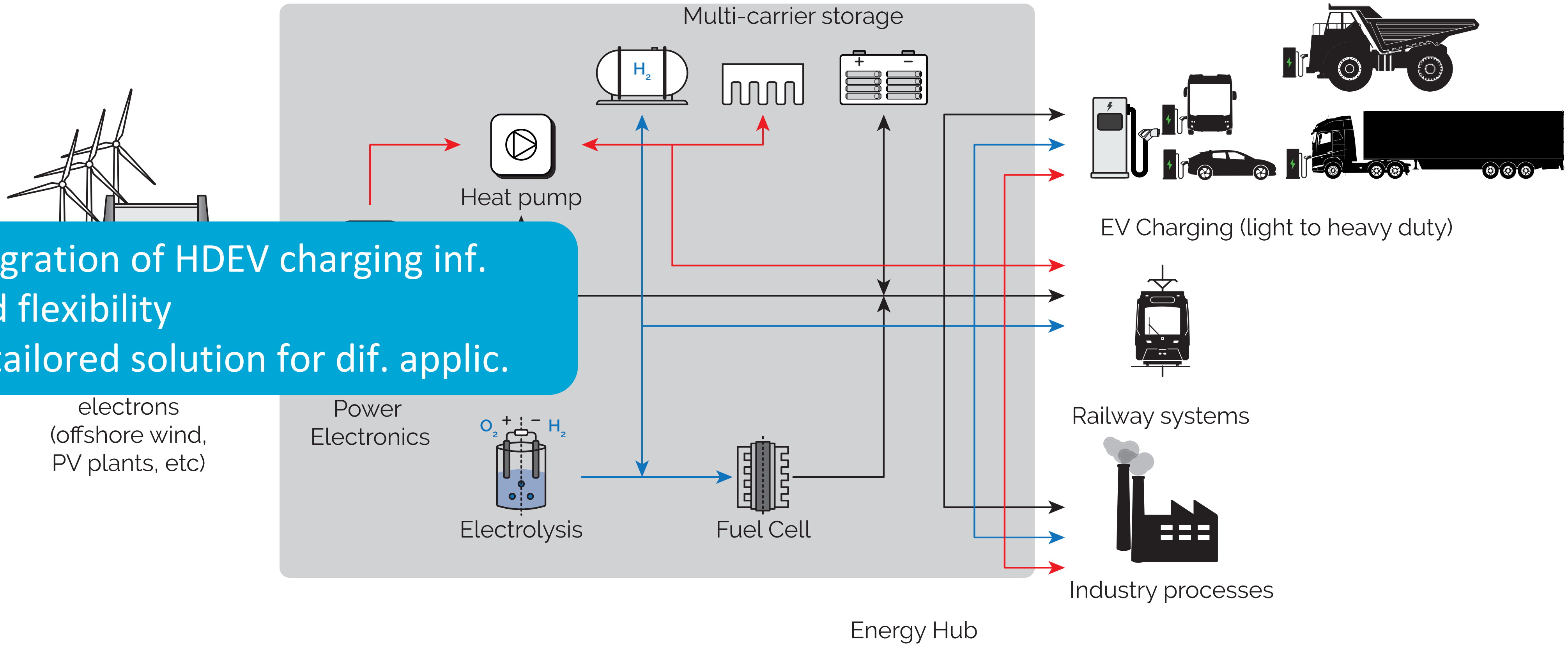


Image: NREL

Energy Hub Concept

- Energy hubs create multiport pathways for different energy carriers to enable the modernization of the electric system and further electrification of industry processes as energy prosumers (bidirectionality).



Seamless integration of HDEV charging inf.
Enhanced grid flexibility
Scalable and tailored solution for dif. applic.

EV Infrastructure as a Versatile Grid Asset

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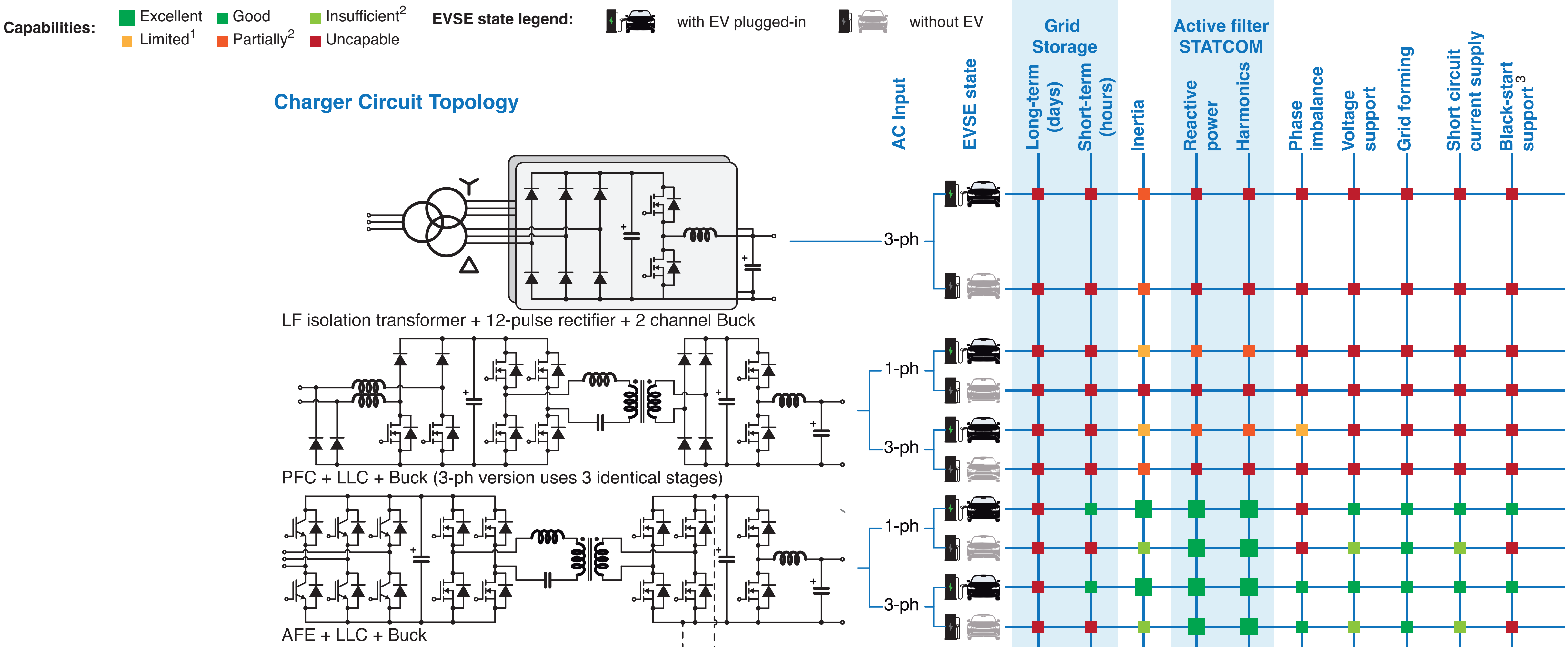

EV Infrastructure as a Versatile Grid Asset

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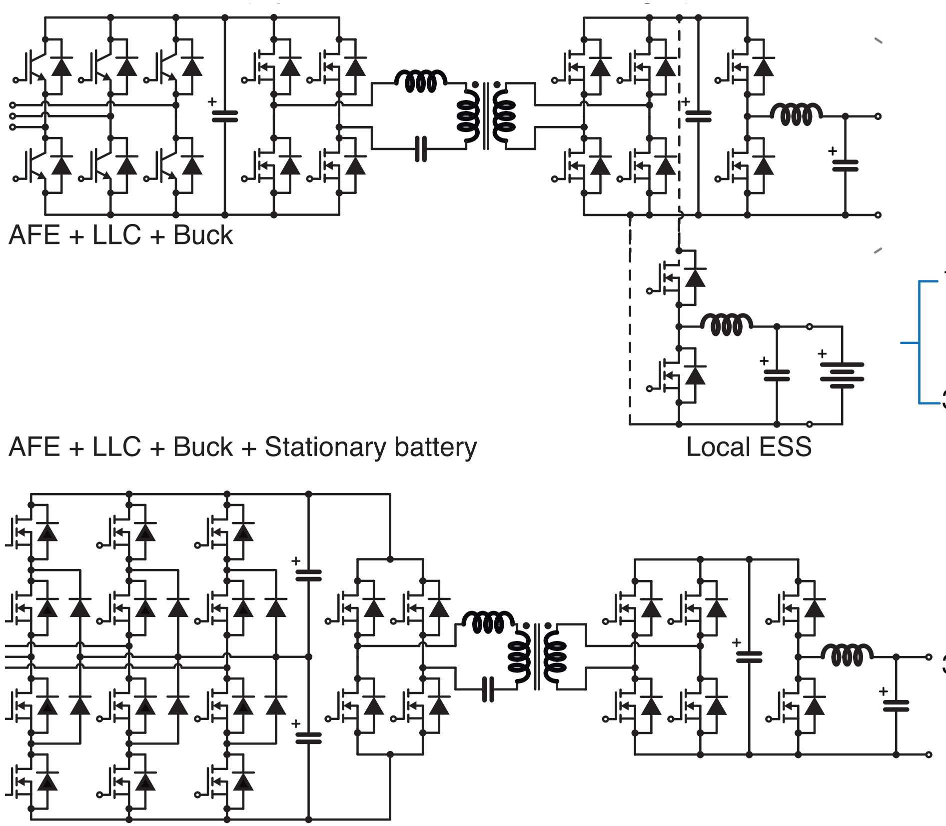
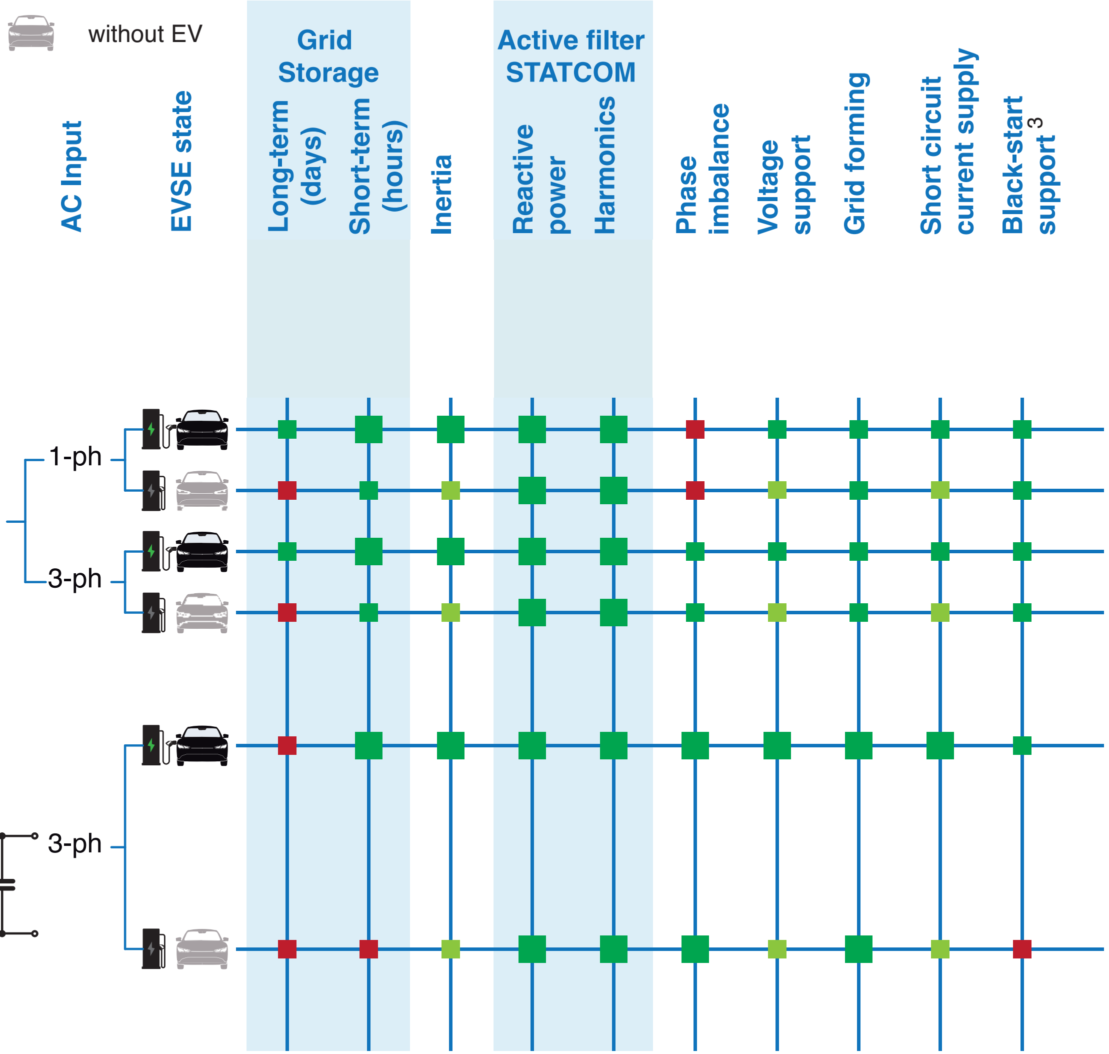
Capabilities: Excellent, Good, Insufficient[2], Limited[1], Partially[2], Uncapable

EVSE state legend: with EV plugged-in, without EV

Charger Circuit Topology





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Ongoing Research Projects

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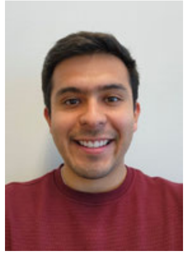
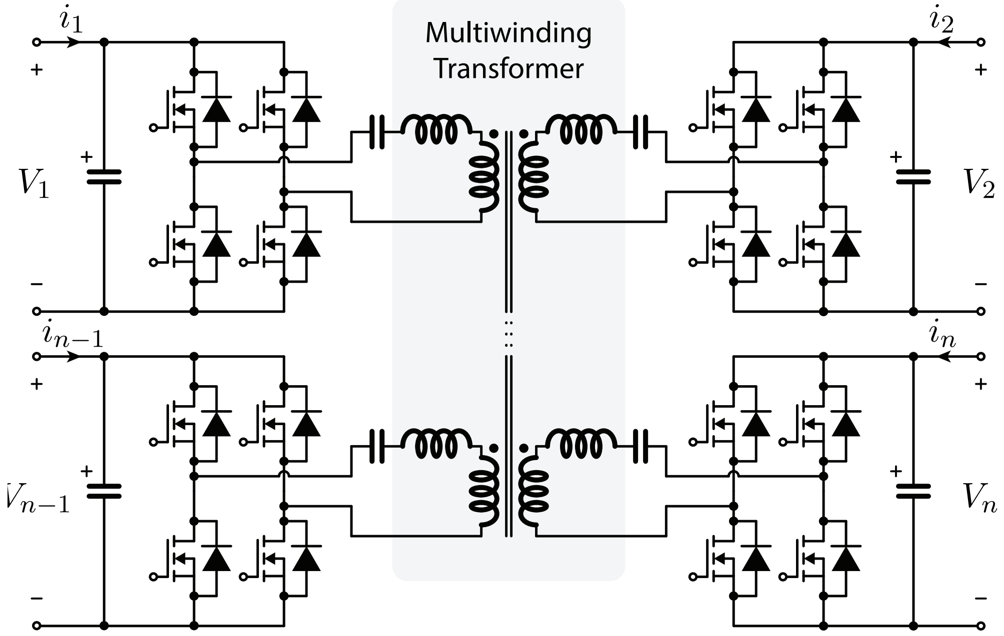
Energy Hubs for Heavy Duty EV Charging

- To design, develop and demonstrate versatile multiport PEEBs for interfacing HD chargers (above 1 MW).
- To coordinate and control several energy sources, storage and loads.
- Alleviate the impacts of high-power EV charging on the grid.
- 100 kW demonstrator under development.



PhD candidate Felipe Calderon Rivera



Aimed for Megawatt Charging System (MCS) Standard

Modular high-power fast charging system for HDEVs

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- To to develop a scalable highly-efficient modular heavy duty EV charging system aiming to the 4-40 MW range.
- Systematic assessment for developing conductive and inductive solutions.
- To propose and identify optimal power size of PEBBs.
- 100 kW demonstrator under development with tailored magnetic design.

PhD candidate
Heshi Guan

Image: Hitachi Energy

Image: Kempower

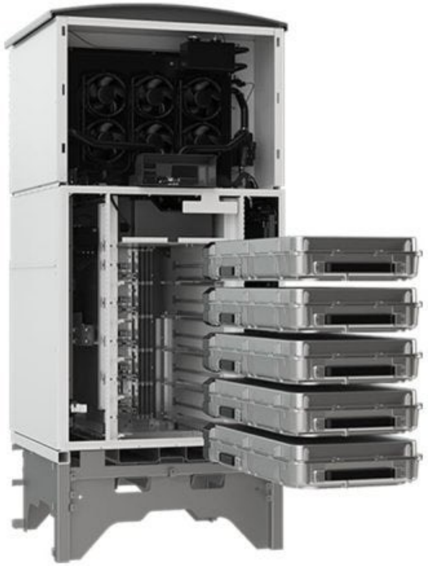

Image: ChargePoint

Energy Hubs for the Railway System

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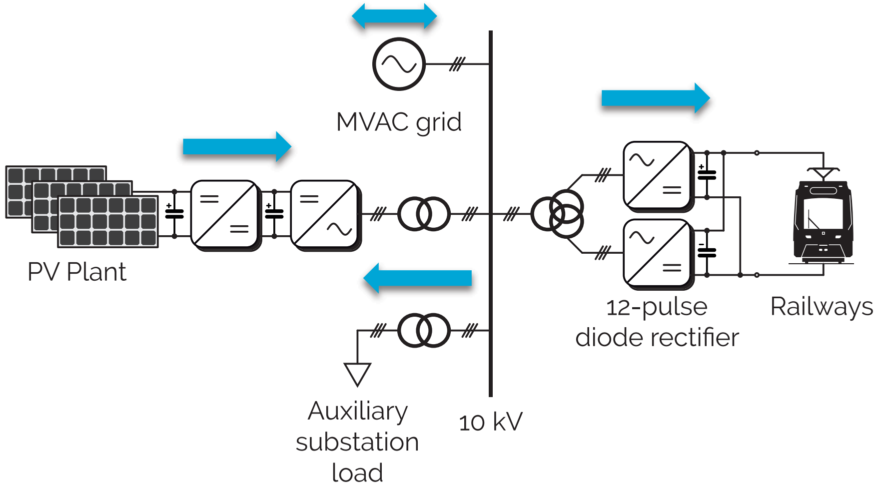
- DC powered railway infrastructure in the Netherlands can reach its full potential. More train lines can be added without compromising nor saturating the electric grid.
- Energy efficient power processing hubs will maximize energy from braking besides integrating energy systems based in different carriers.

PhD candidate
Julián Rojas

New fast IC train Amsterdam - Rotterdam - Breda

Simplified topology of the railway network



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Conclusions and Outlook

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- +MW charging entails several challenges, opening new opportunities for researchers.
- Tenfold increase in the output power requires novel approaches for the size of converter modules.
- Grid integration of HD charging infrastructure will further stress electric grid, specially in densely populated areas in the NL.
- Energy Hubs for HD EVs open new possibilities to maximize grid utilization and even provide additional functionalities that will support the power grid modernization. Their versatility can be used in the electrification of other sectors.
- HD EV Charging infrastructure can serve as a great opportunity to showcase the benefits of DC distribution at different levels.

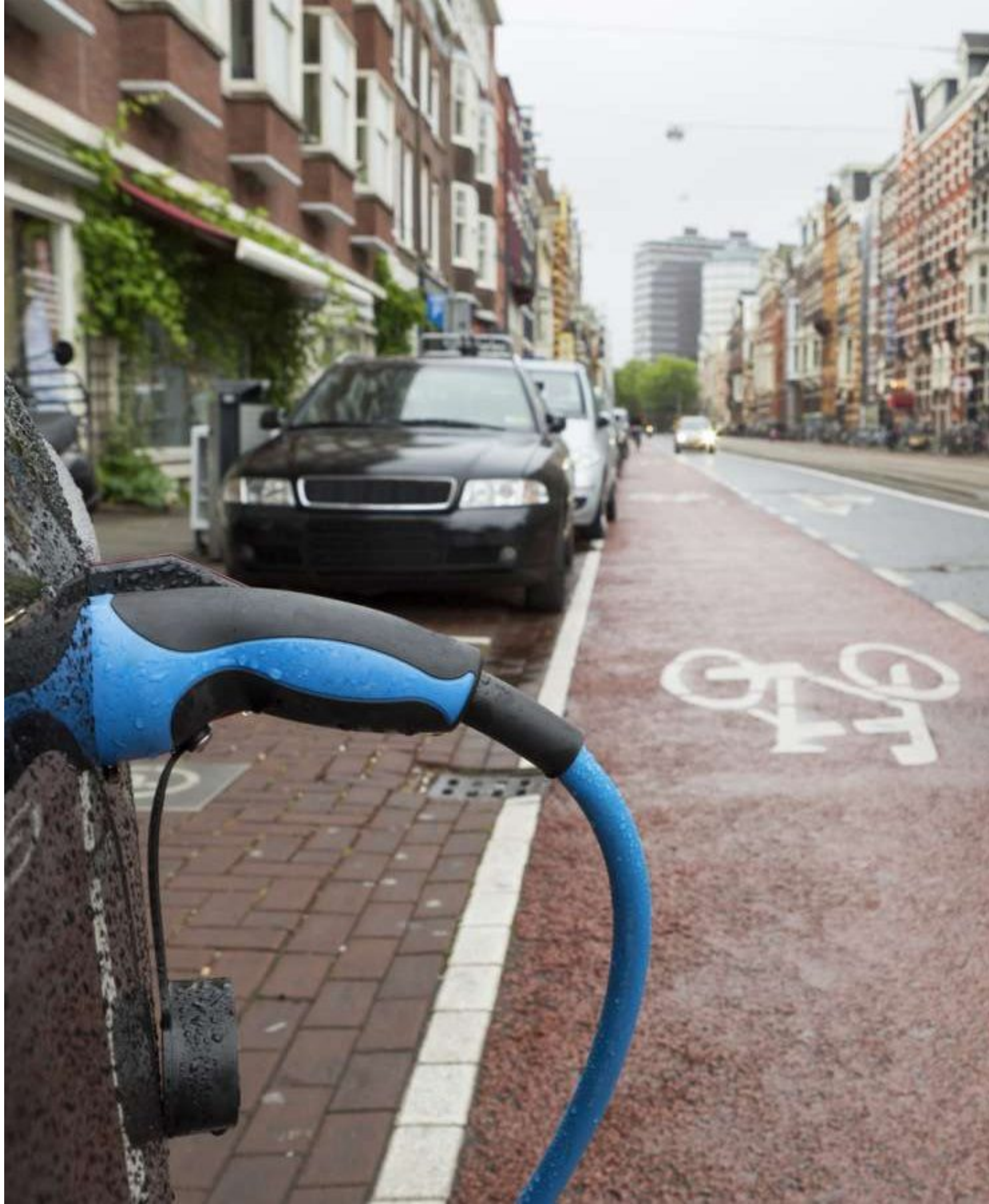
Bedankt voor uw aandacht

Dr. Sebastián Rivera, DCE&S

DCE&S
DC systems, Energy conversion & Storage
TU Delft

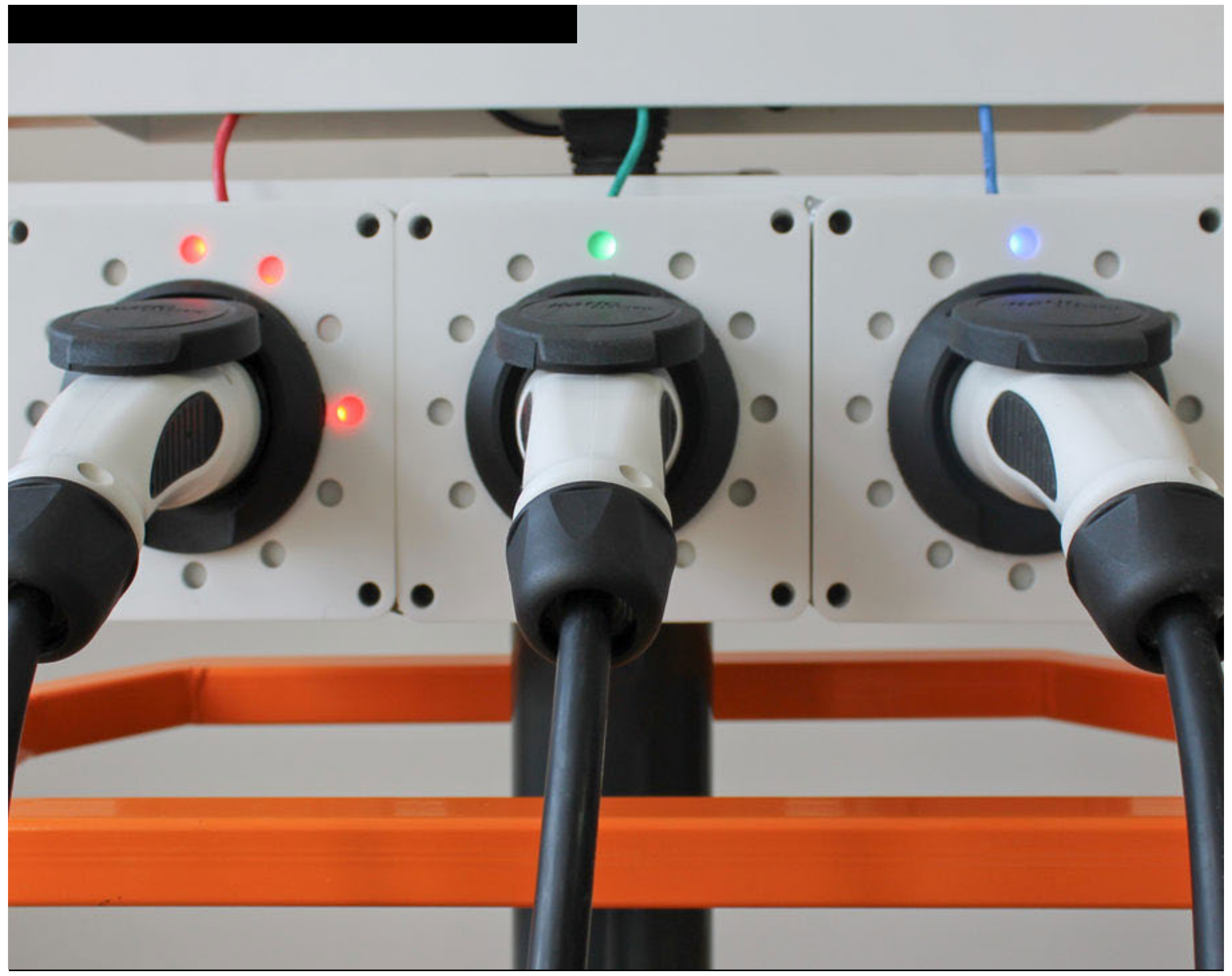
Designing a Smart Electric Vehicle Charge Point for **Algorithmic Transparency**

Gerd Kortuem | Kars Alfrink
Industrial Design Engineering | TU Delft
27 Sept 2023



Transparent charging station

Credit: The Incredible Machine, Alliander, ElaadNL, TUD, AMS Responsible Sensing Lab



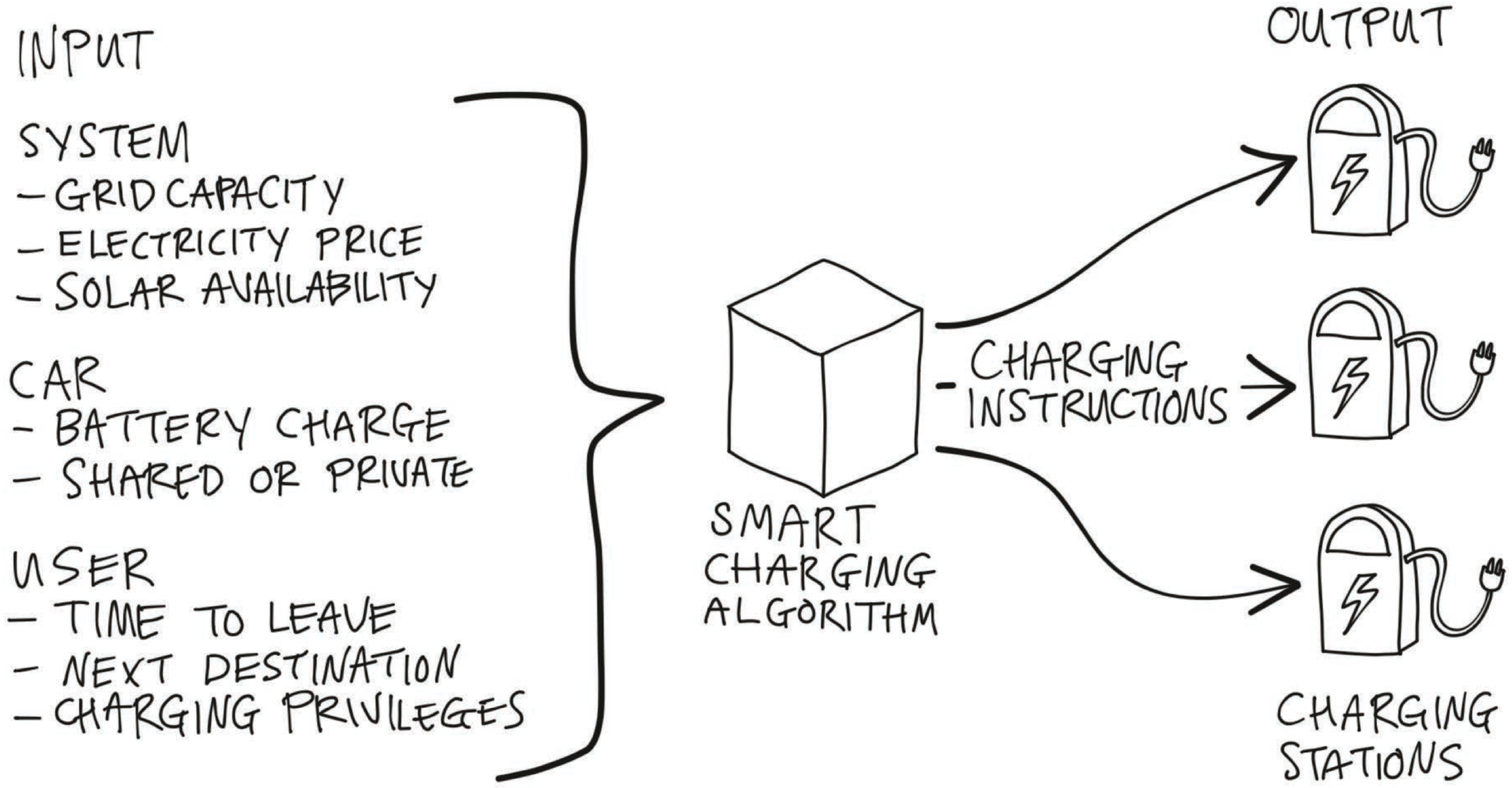
A speculative design artefact & research instrument for investigating **Algorithmic Transparency**

Intelligent EV Charging

Optimizing energy distribution

Aligning demand & supply

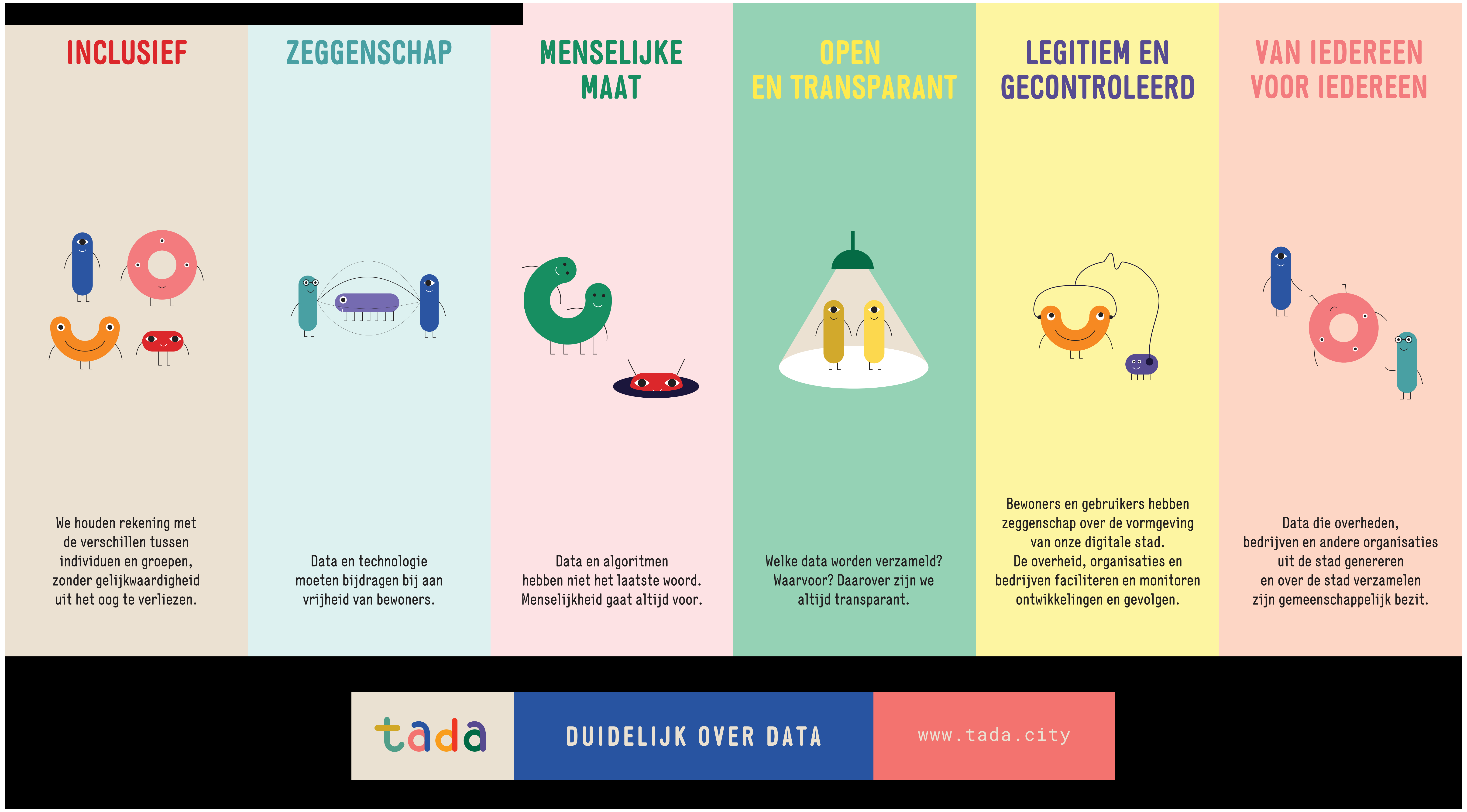
Algorithms will become increasingly sophisticated



Intelligent & Inclusive EV Charging

Unpredictable charging experience
Perceived unfairness of decisions
Systematic bias

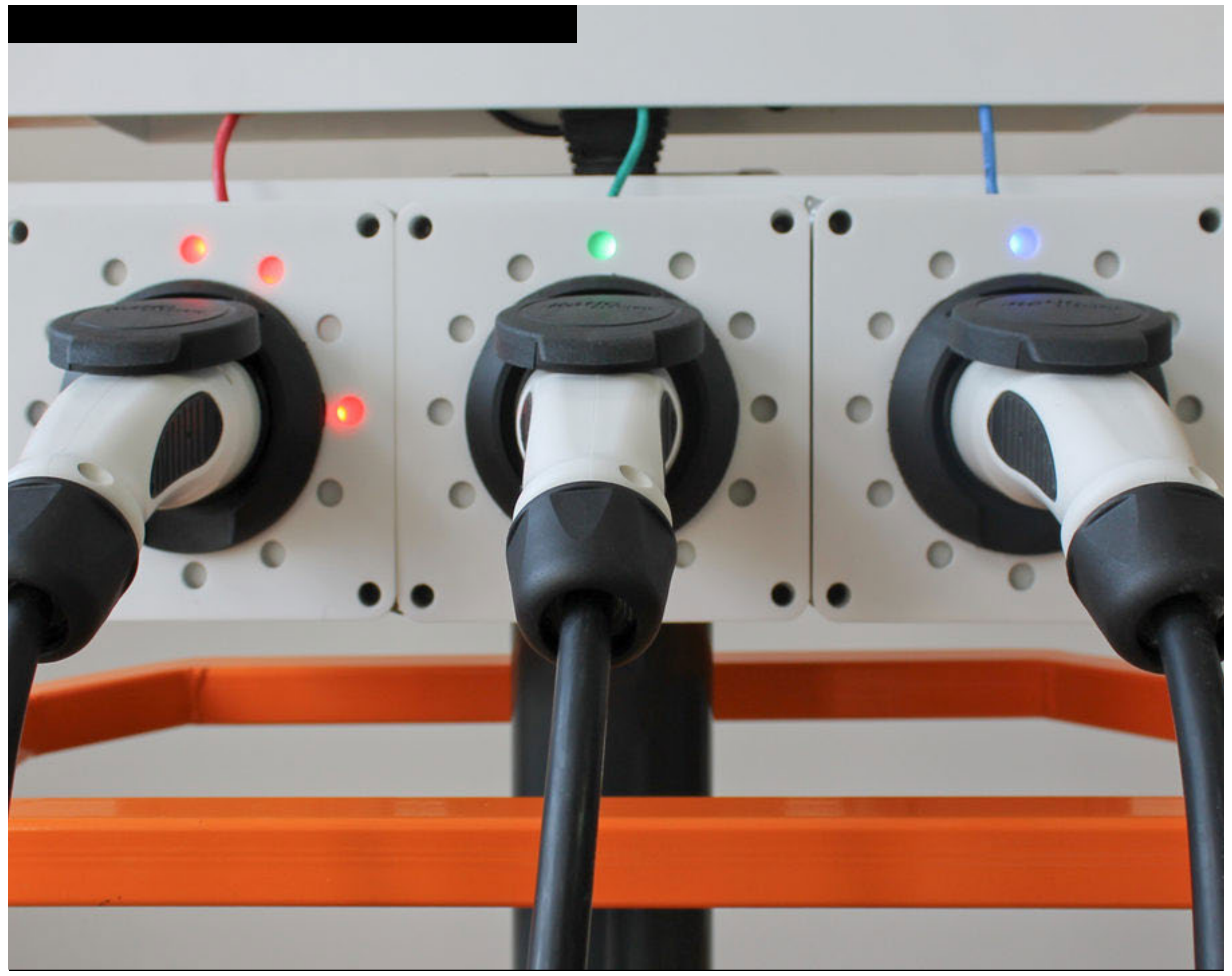
Public values

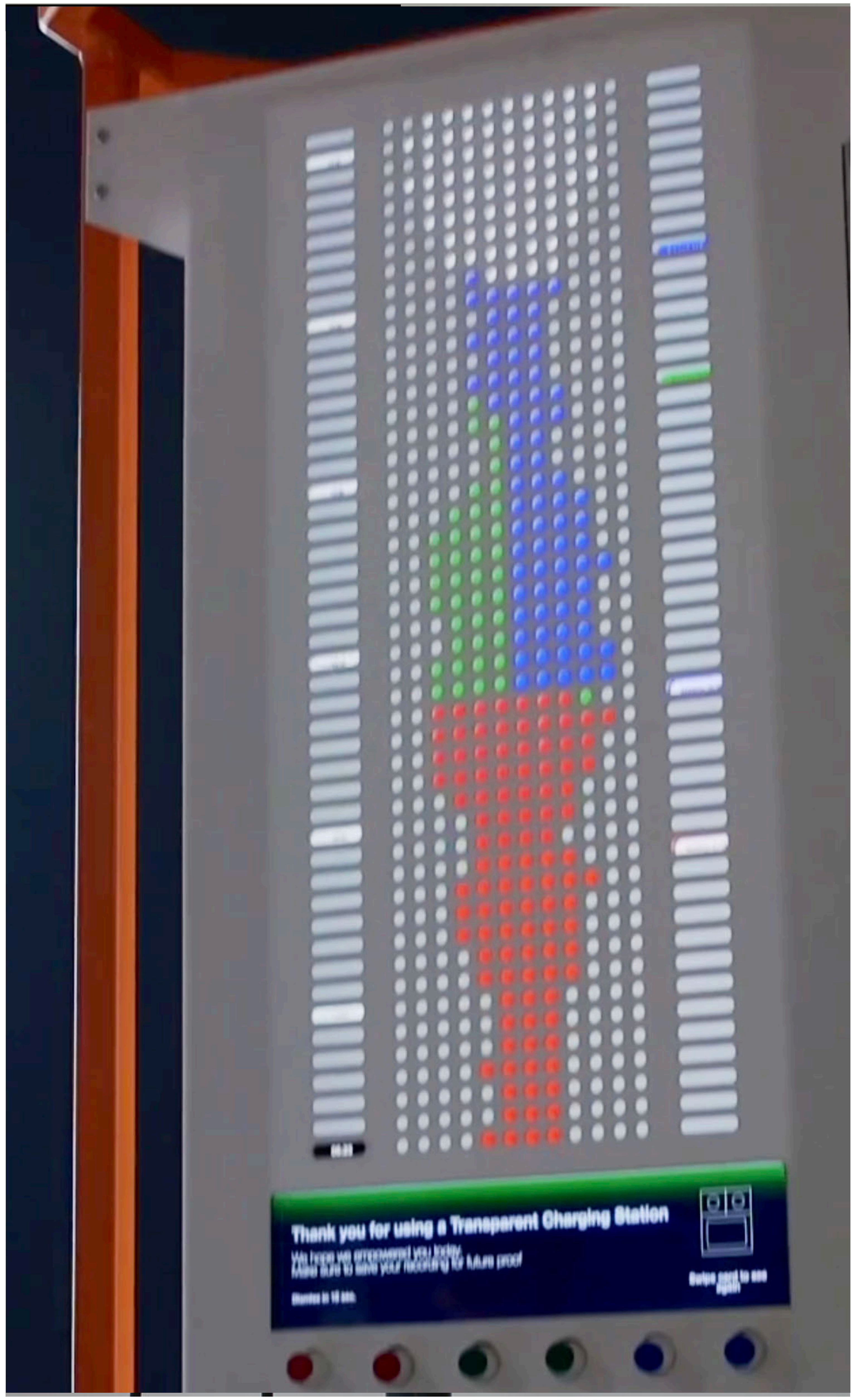


Experience

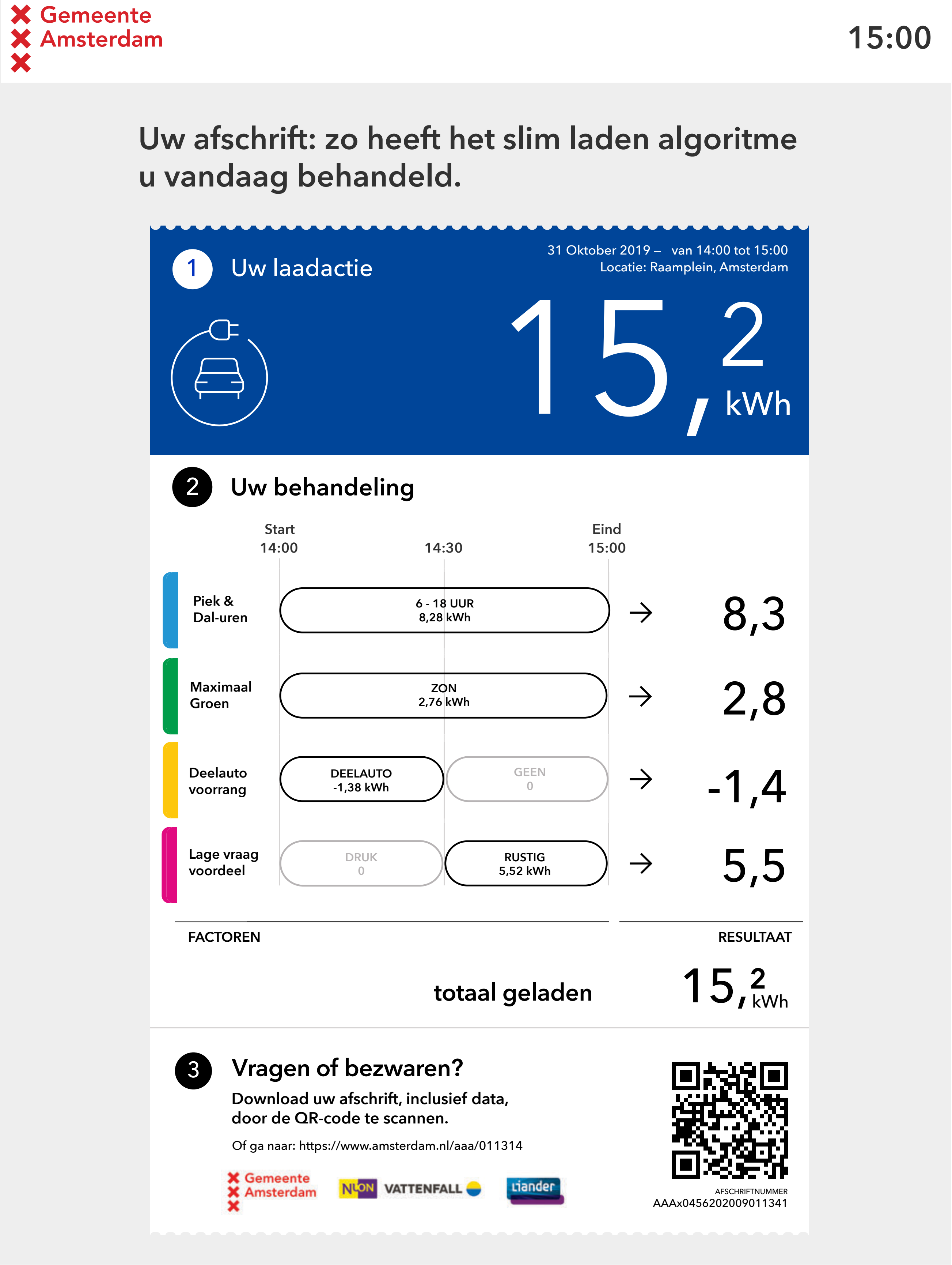
Transparent charging station version 1

Credit: The Incredible Machine



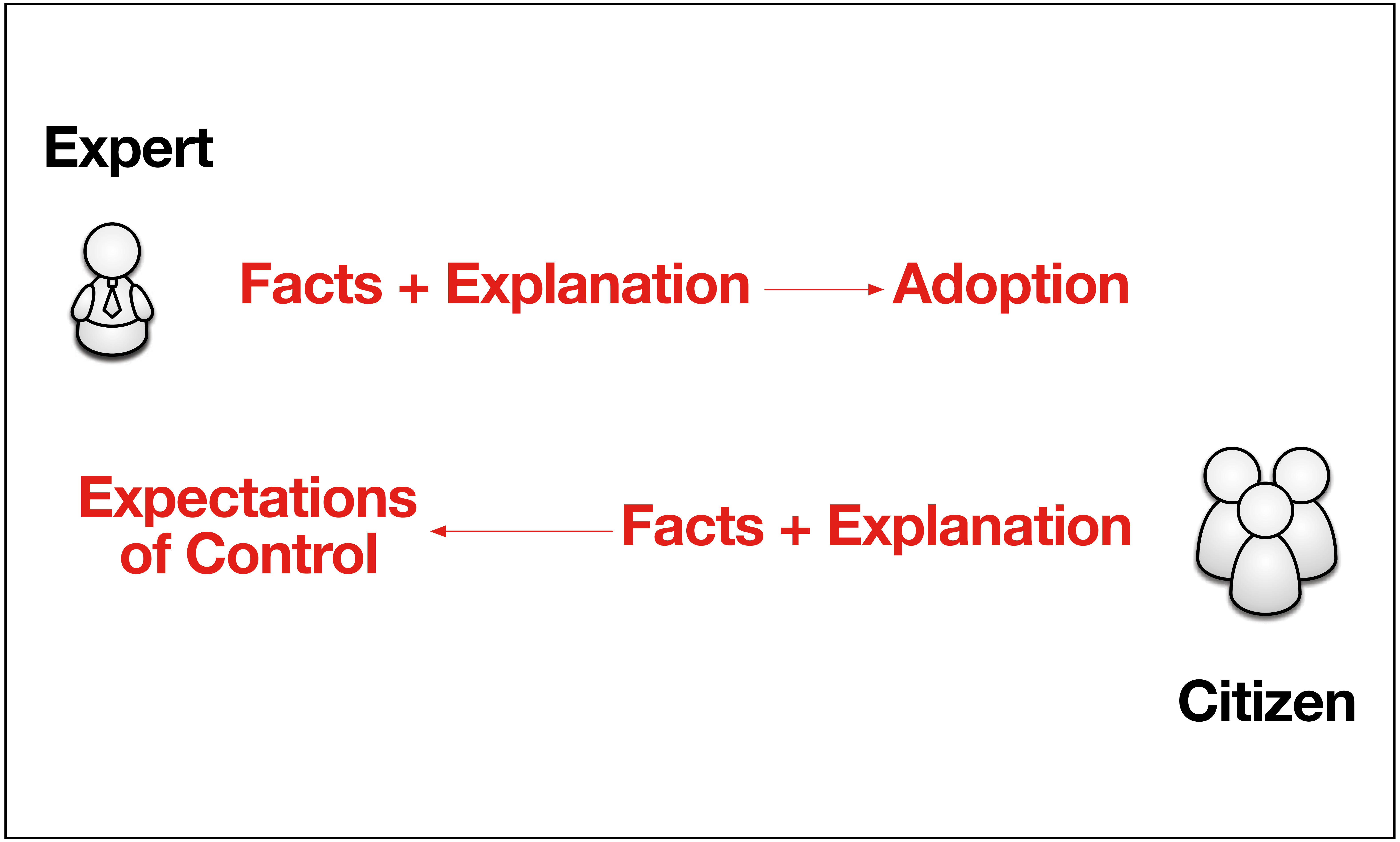


Transparent charging station version 2



Alfrink, K., Keller, I., Doorn, N., & Kortuem, G. (2022). Tensions in transparent urban AI: designing a smart electric vehicle charge point.

Findings



Alfrink, K., Keller, I., Doorn, N., & Kortuem, G. (2023). Tensions in transparent urban AI: designing a smart electric vehicle charge point. AI & SOCIETY, 38(3).

Findings — Citizens

- Algorithms are convenient
- Transparency is burdensome
- Transparency suggests (but does not afford) control

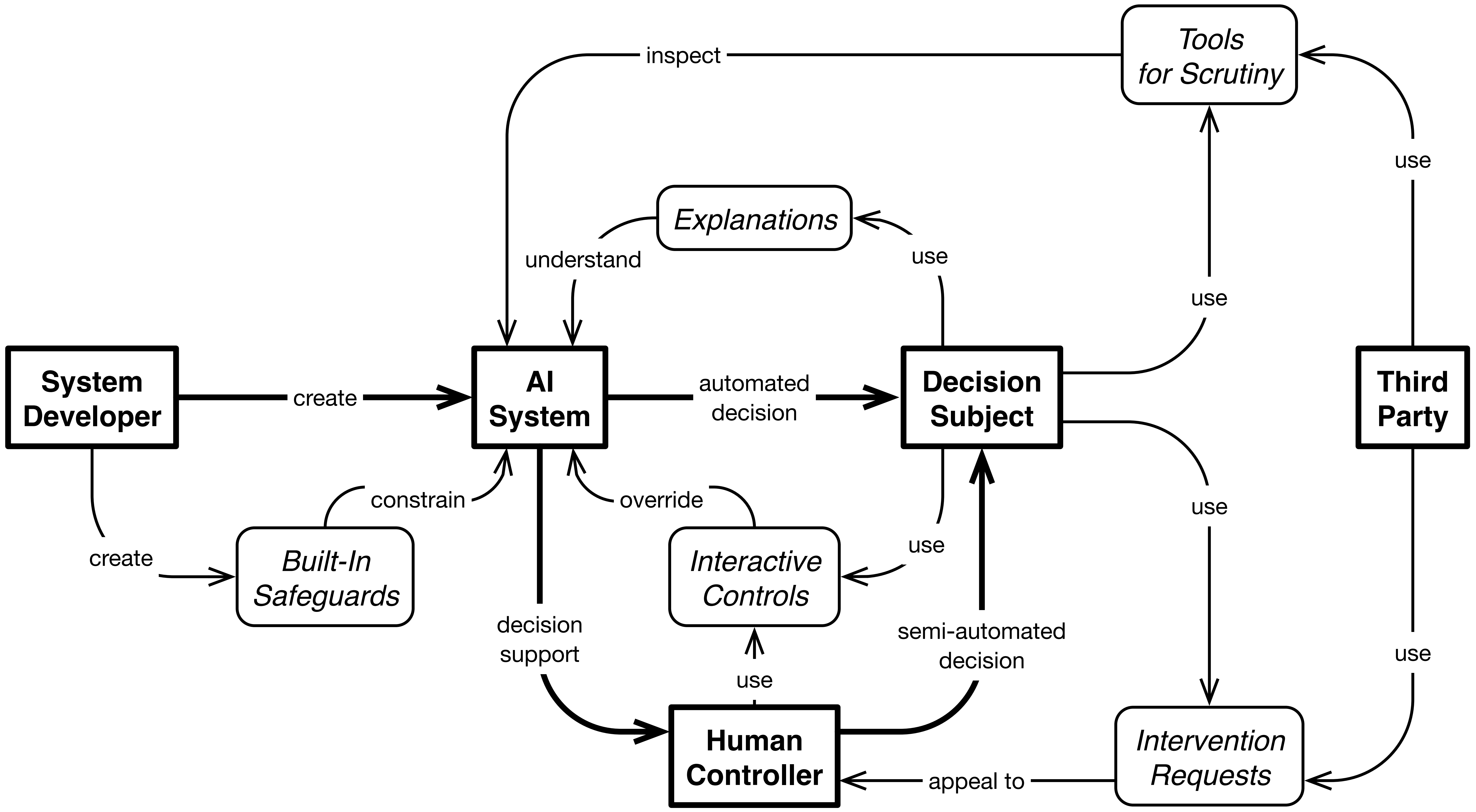
New concerns: Algorithmic anxiety and coping mechanisms

- “How does the algorithm judge me?”
- “What do I need to do to ‘please’ the algorithm?”
- “How can I outwit the algorithm?”
- Intentions of “gaming” & vehicles moving to other parts of the city because there’s good charging there

Alfrink, K., Keller, I., Doorn, N., & Kortuem, G. (2023). Tensions in transparent urban AI: designing a smart electric vehicle charge point. AI & SOCIETY, 38(3).

Beyond individual experience - towards societal control

Intelligent Algorithms Embed and Make Policy



Alfrink, K., Keller, I., Kortuem, G., & Doorn, N. (2022). Contestable AI by Design: Towards a Framework.

Type of Objection	Example	Concerns
Existence	“Charging shouldn’t be made smart at all.”	Who made the policy, and why? Who should determine policy?
Policy	“Shared cards get priority. I don’t drive a shared car so I think this is nonsense.”	Who made the policy, who can change it, how can I contact them?
Faulty outcome	“I charged a shared car but I did not receive the priority I am entitled to.”	What was the intended outcome? What is the actual outcome? Why did this change?
Unfair outcome	“I work shifts and the system assumes office hours so I am always screwed.”	What are the assumptions behind the policy? Who else is adversely affected?

Contestable by Design

Built-in safeguards

External adversarial system • Formal constraints

Interactive controls

Negotiate, correct, or override machine decision • Feedback loop back to training • Supplement local contextual data

Explanations

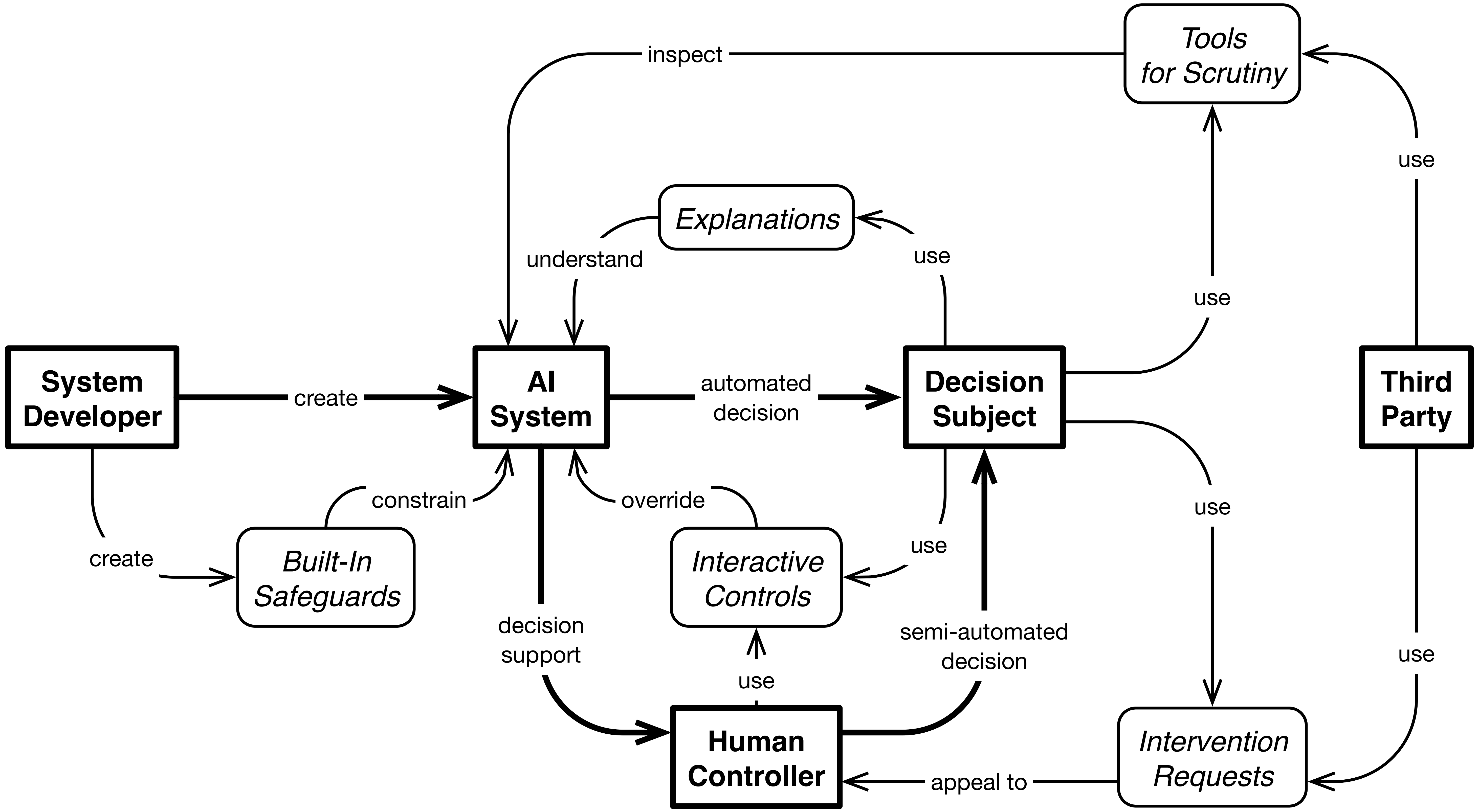
Traceable decision chains • Behavioral explanations • Sandboxing • Local approximations • Justifications

Intervention requests

Human review • Supportive, synchronous channels • Third party representation • Collective action • Dialectical exchange

Tools for scrutiny

Norms linked to implementation • Documentation • Formal proofs • Comparative measures • Opaque assurances



Alfrink, K., Keller, I., Kortuem, G., & Doorn, N. (2022). Contestable AI by Design: Towards a Framework.

Final Reflection

Speculative design on transparency inspired **empirical research** which informed a new **research programme on contestable AI**

Credits:
Marcel Schouwenaar, The Incredible Machine
Thijs Turel, AMS Responsible Sensing Lab
Kars Alfrink, IDE
Neelke Dorn, TPM
Alliander, ElaadNL

Vehicle to Grid (V2G) Technology trends & challenges

Dr. Gautham Ram

Assistant Professor (TU Delft)

Contributors – Ibrahim Diab, Yunhe Yu, Wiljan Vermeer, Dennis v.d.Meer, Johan Kaptein, Siddhesh Shinde, Menno Kardolus, Jos Schijffelen, Mike v.d.Heuvel, Peter van Duijsen, Pavol Bauer

Electrical Sustainable Energy (ESE) Department

DC systems, Energy conversion & Storage Group

Design and control of components for charging of electric vehicles and integration into future grids

Research themes

Power electronics for EV charging	Smart charging, V2G & grid integration	Battery modelling & ageing	Electrification of Heavy-Duty vehicles

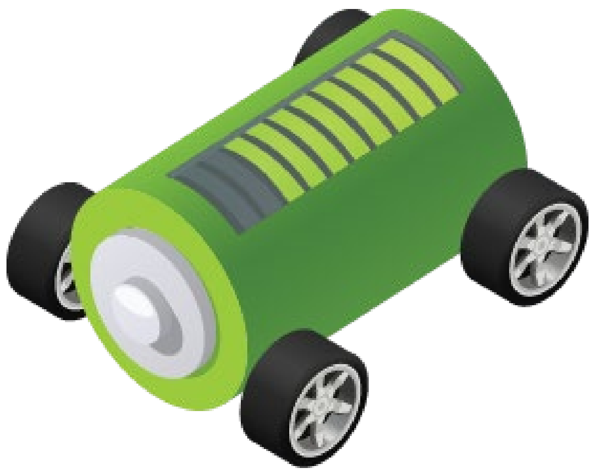
Gautham Ram

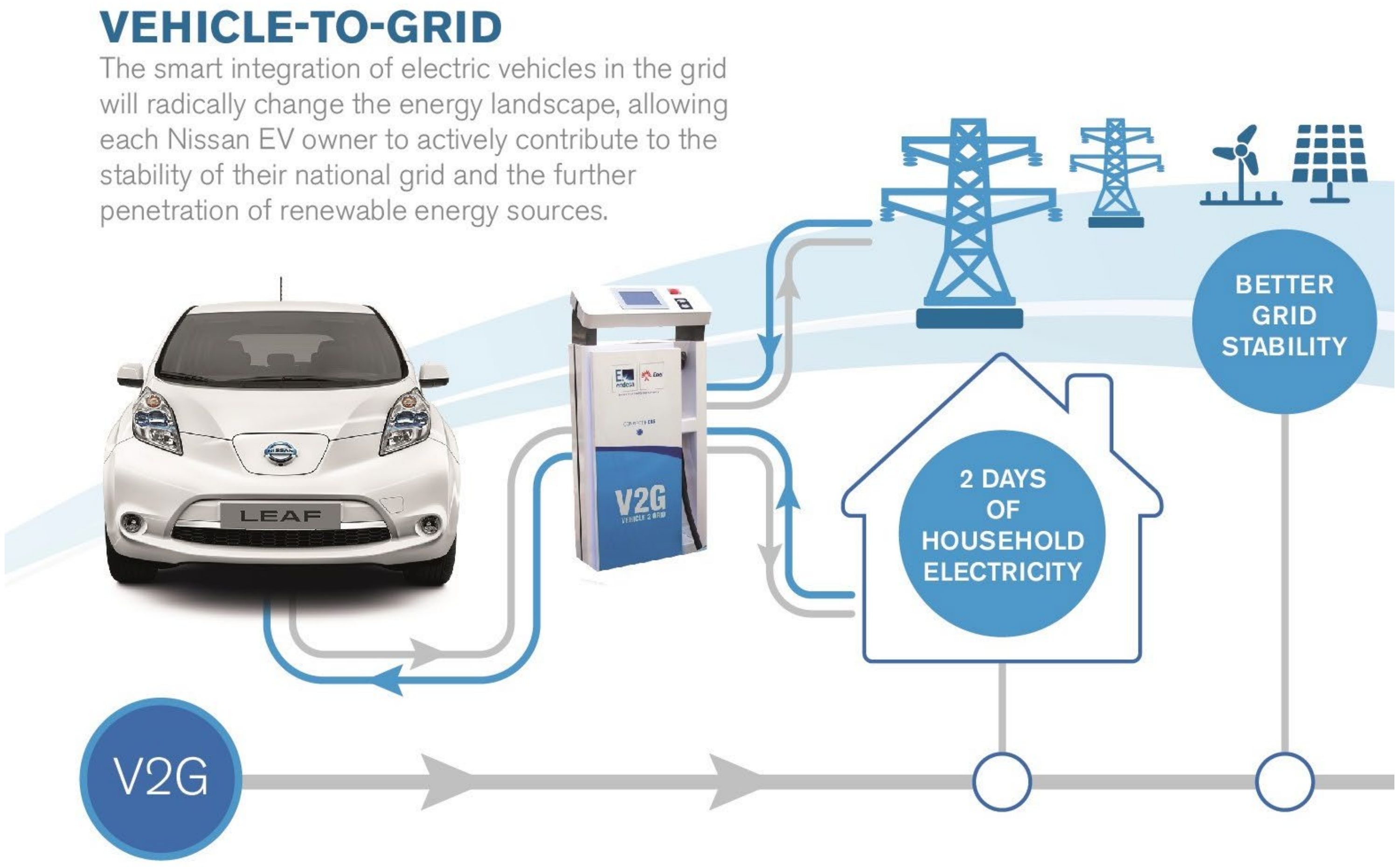
DCE&S

DC systems, Energy conversion & Storage

What is V2G?

- EV is a big battery on wheels (50-100kWh, 95% Stationery)
- In numbers: 10kW power * 7M car = 70 GW power capacity
- → Software Vs hardware (e.g., Generators, transformers)
- → Decentral Vs Central





Source: Nissan, http://www.amsterdamvehicle2grid.nl

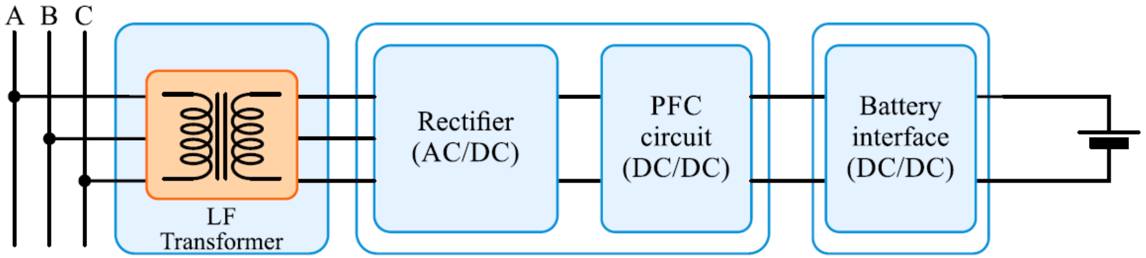
Trend 1: Compact V2G chargers

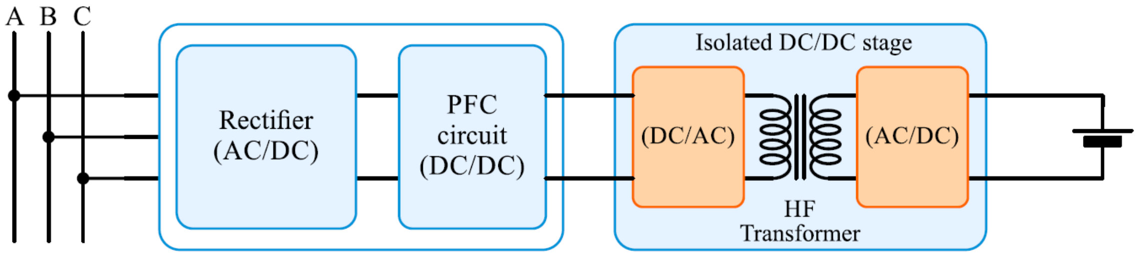
- 10kW (Magnumcap)
- 60x36x162 cm
- 260 kg

- 6kW (OVO)
- 52x23x69 cm
- 27 kg

- 7.4 kW (Wallbox Quasar)
- 35x35x15 cm
- 20 kg

- 20kW (Fermata FE-20)
- 94 x 76 x 28 cm
- 57 kg





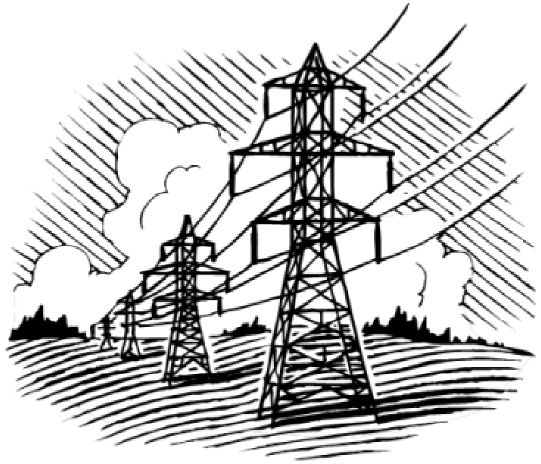
1. High frequency isolation
2. Soft-switching topologies
3. Silicon carbide wide bandgap devices

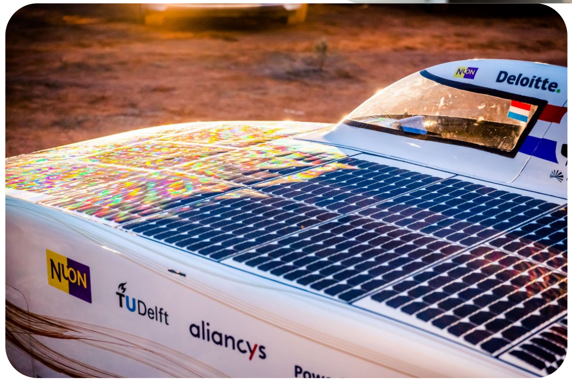
→ Higher power (~20kW) & Higher efficiency

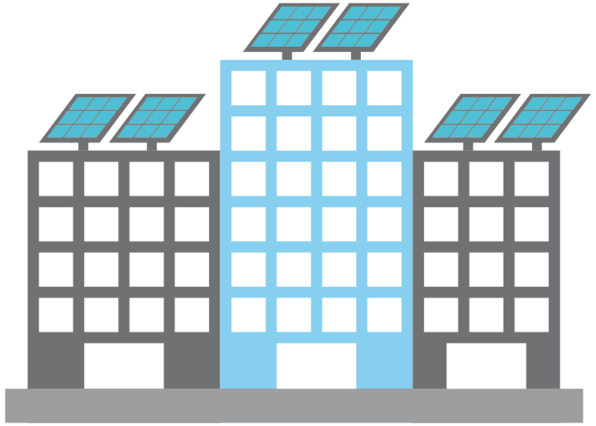
Image : Magnumcap, OVO, fermata, Quasar, DOI: 10.1109/TTE.2019.2958709

Trend 2: Using EV as storage for PV

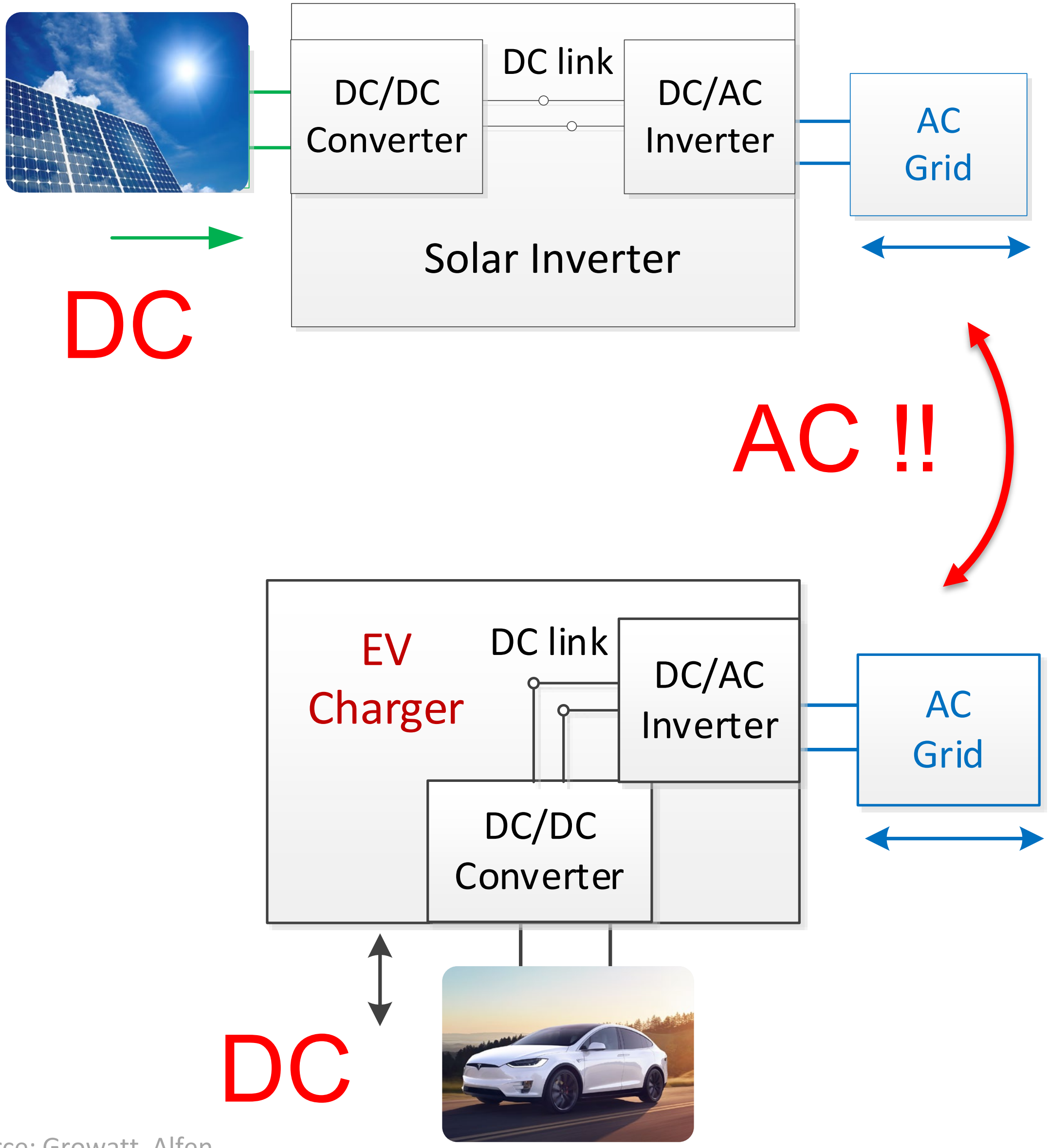
1. Zero net emissions
2. Both are direct current (DC)
3. EV as storage for PV (V2G)
4. Reduced EV-PV grid impact
5. Proximity (Onboard or rooftop PV)
6. Generation in summer & in day
   - Workplace charging ☺

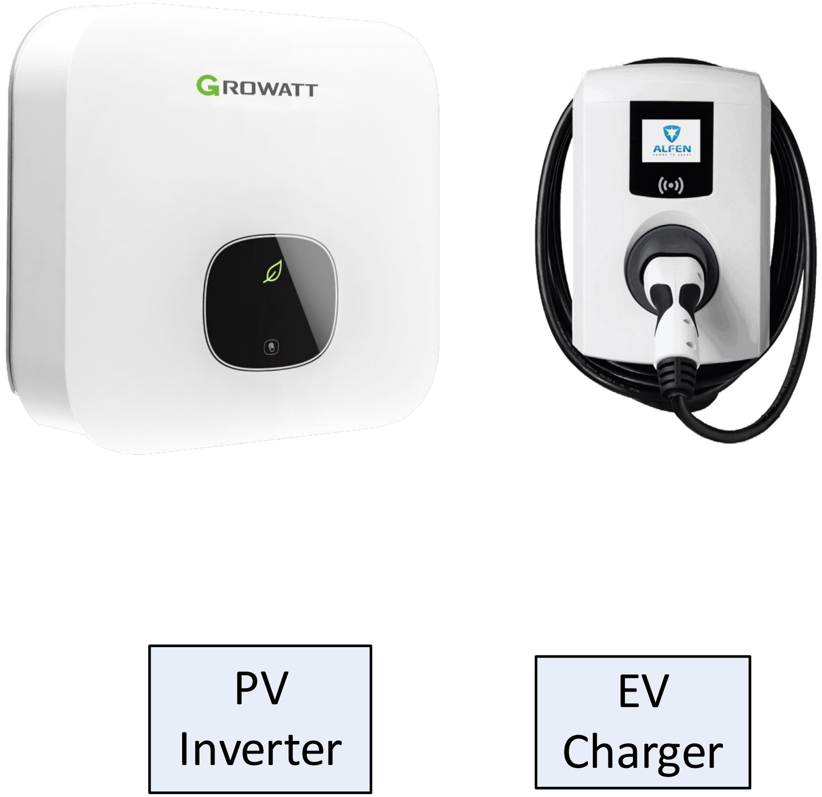




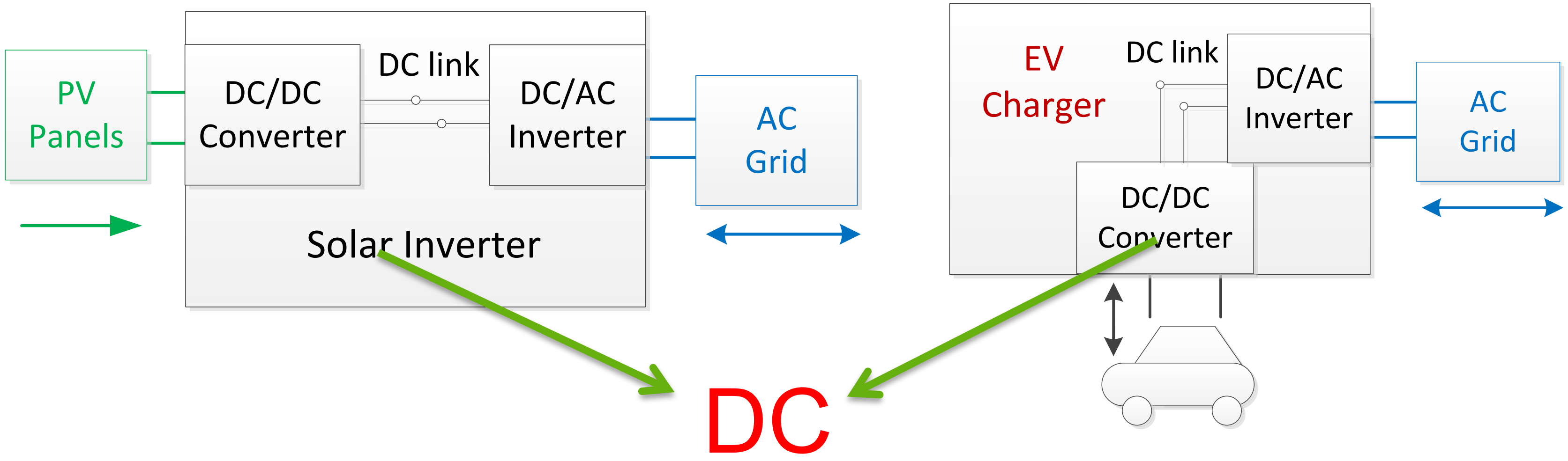


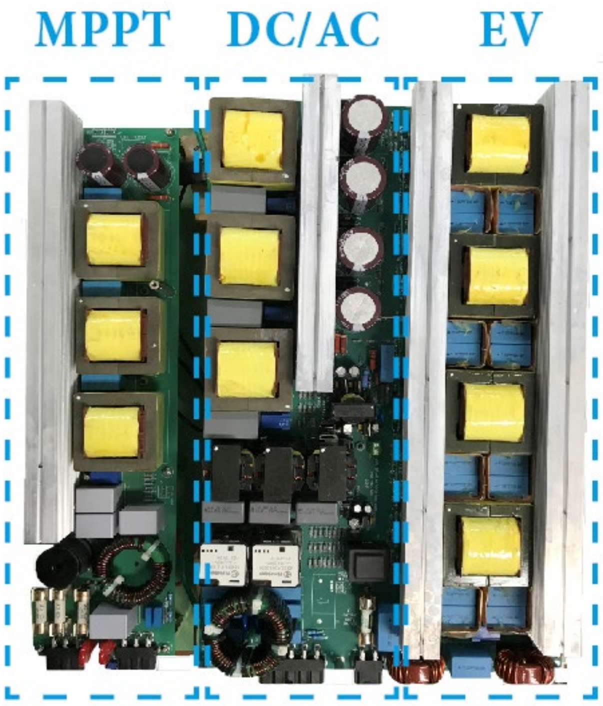
Charging EV from PV (Today): AC

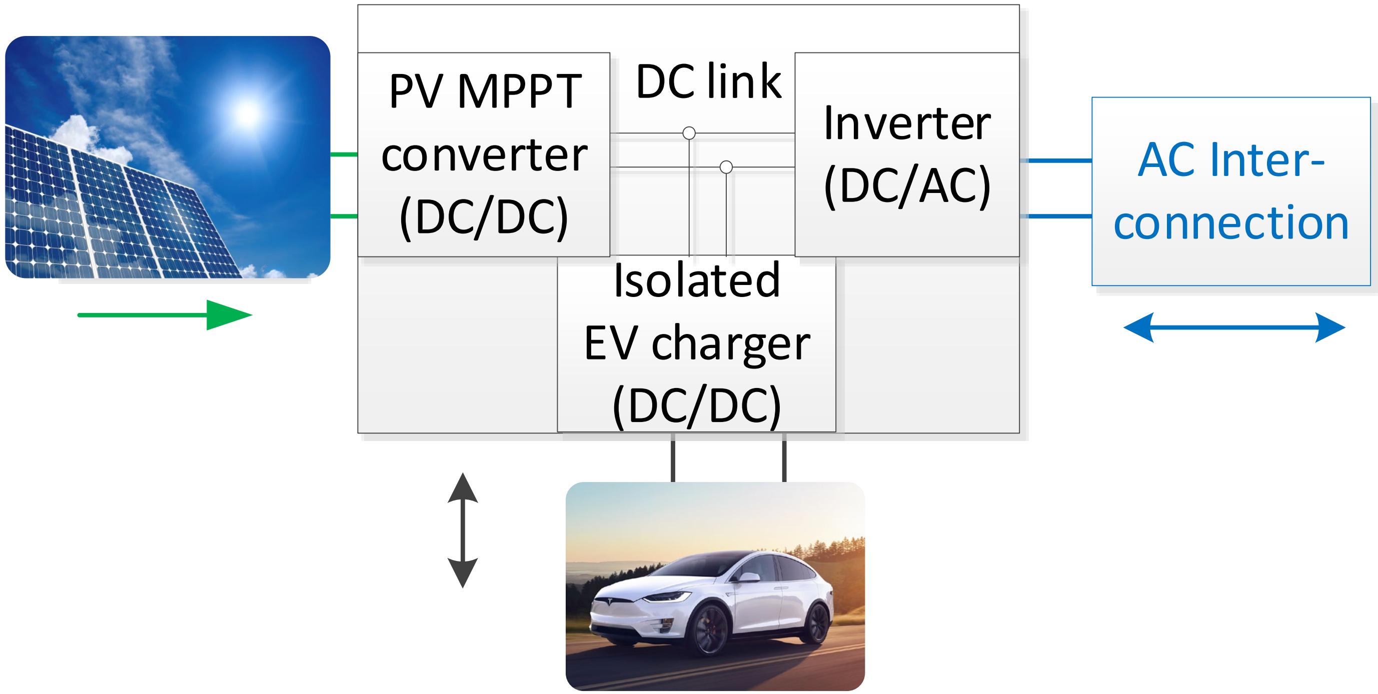




Integrated DC solution





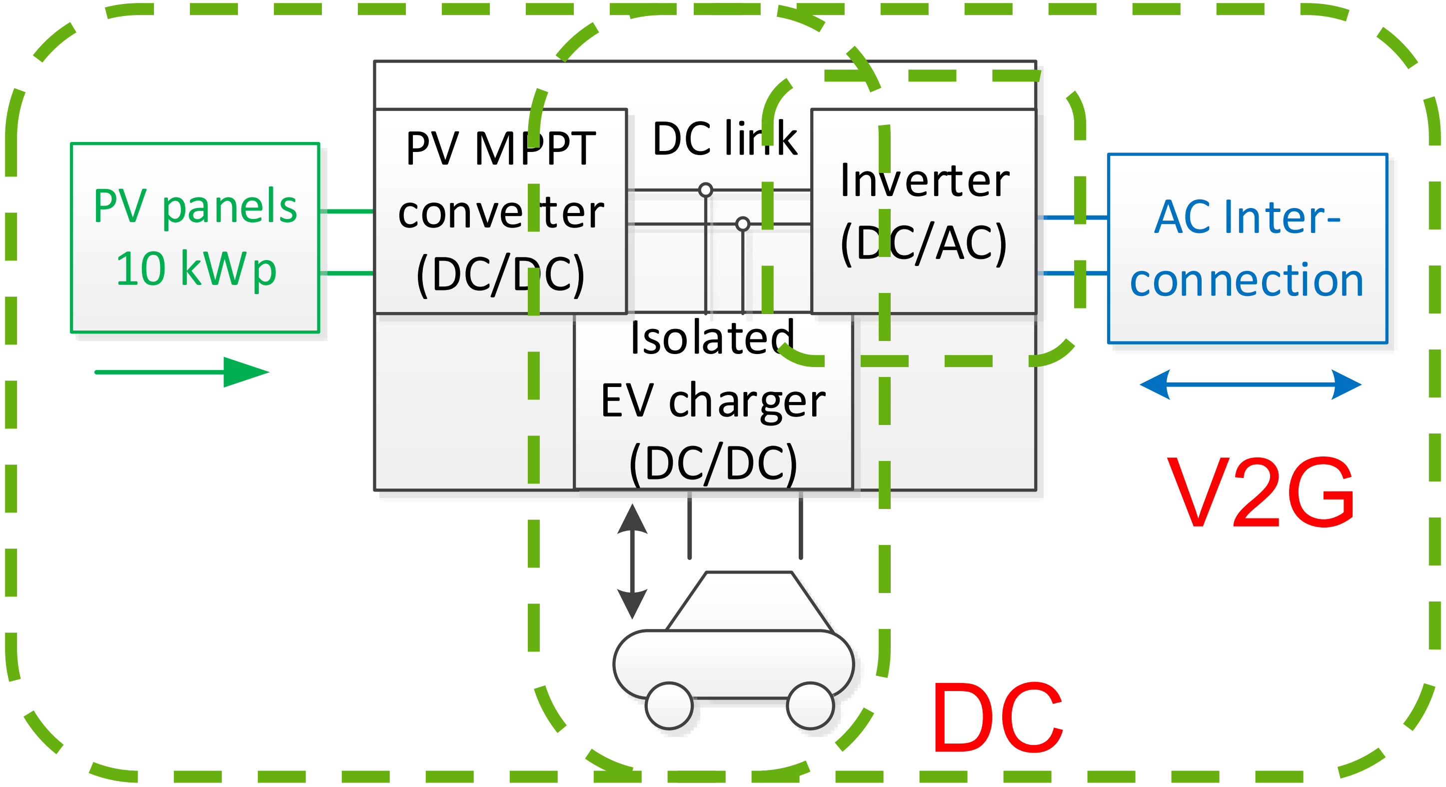


tki switch 2 smartgrids
TUDelft Delft University of Technology
PRE power developers
last mile solutions
TEXAS The University of Texas at Austin
ABB

Project funded by:
TKI Urban Energy, RVO,
Netherlands

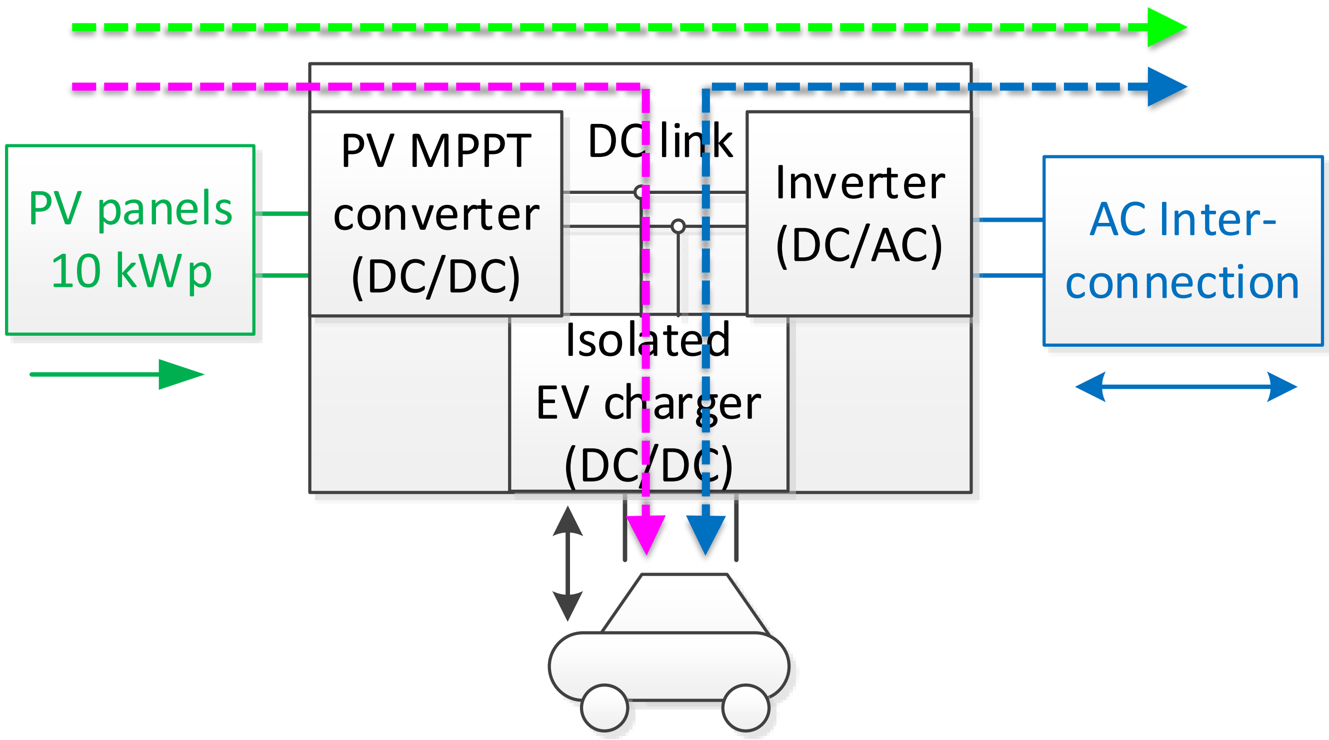
Trend 3: Integrated DC solution

▪ DC-DC connection of EV-PV	→	Improved efficiency
▪ Only one DC/AC converter	→	Lower cost of converter
▪ Bi-directional capability	→	Charge / V2G



Trend 3: Integrated DC solution

▪ DC-DC connection of EV-PV	→	Improved efficiency
▪ Only one DC/AC converter	→	Lower cost of converter
▪ Bi-directional capability	→	Charge / V2G
▪ Four power flows	→	Easy power management



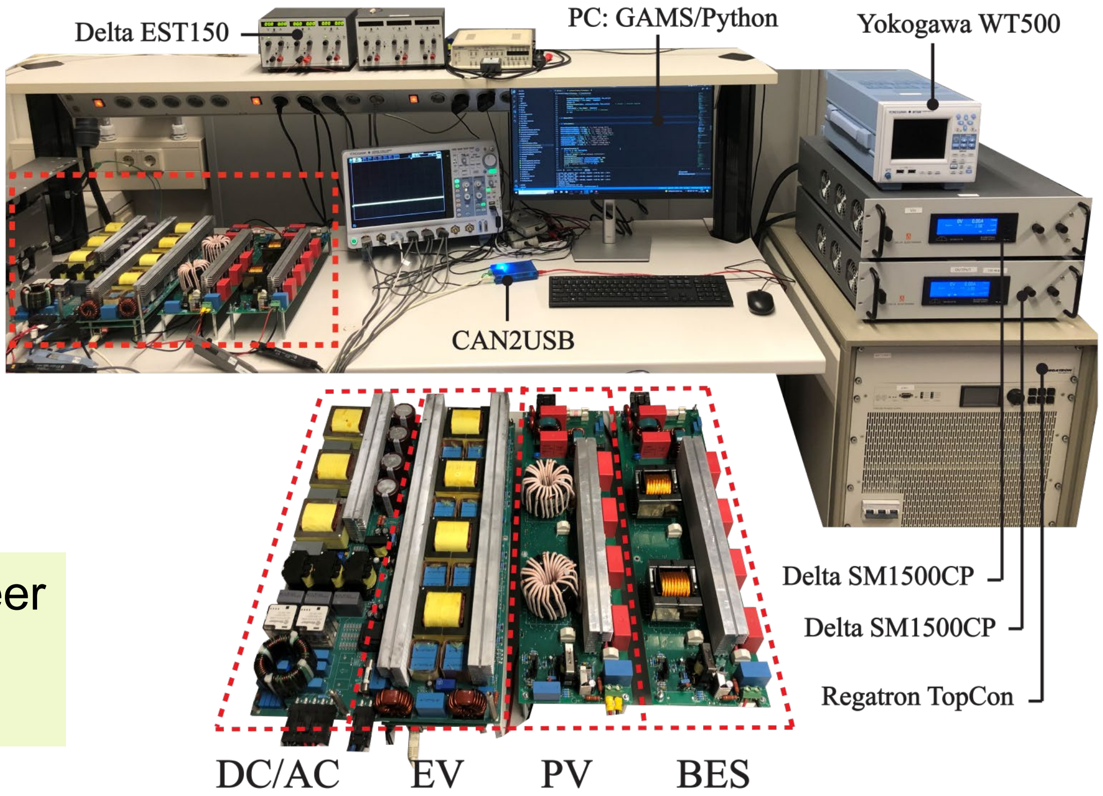
1. PV → EV
2. Grid → EV
3. EV → Grid
4. PV → Grid

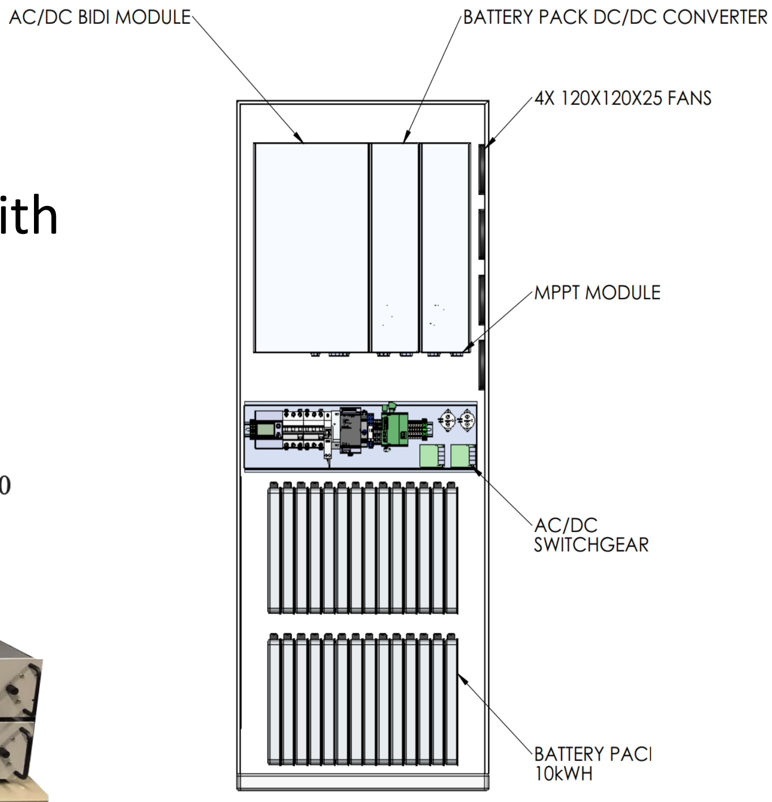
EV + V2G + PV + Battery

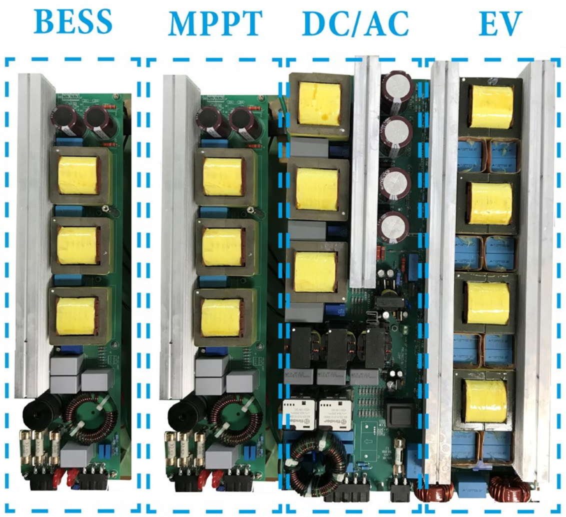
- Goal: Multi-Port DC Converter for PV Charging of Electric Vehicles with flexibility of battery storage
- Combining Smart hardware + Smart charging

PhD project:
Wiljan Vermeer

PhD Defense of Wiljan Vermeer
4 Oct 2023, TU Delft
1700-1900







Project partners: PRE, Stedin (Flexgrid)

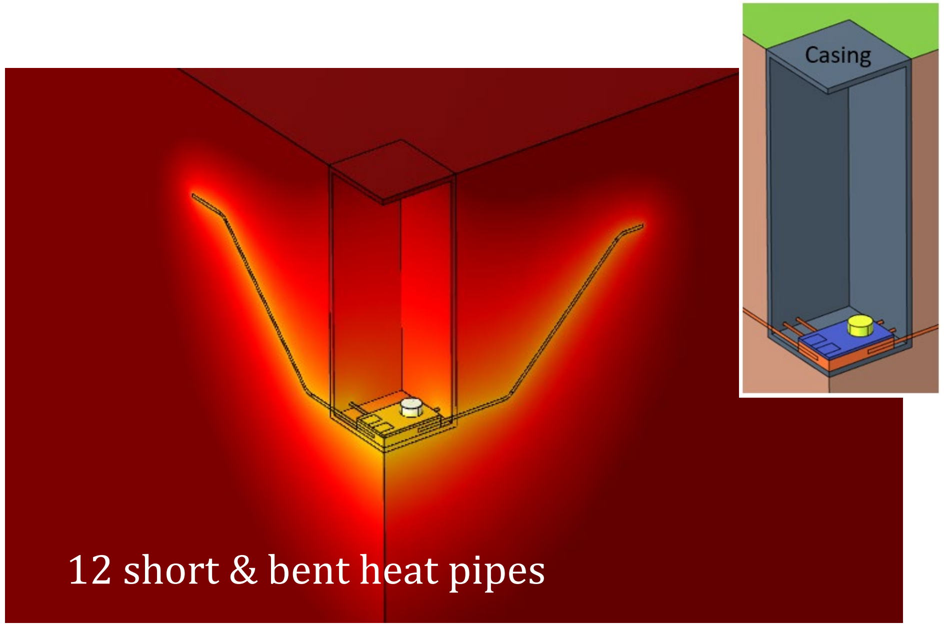
Reference: https://www.tudelft.nl/en/Flexinet; Project funded by: TKI Urban Energy, MOOI

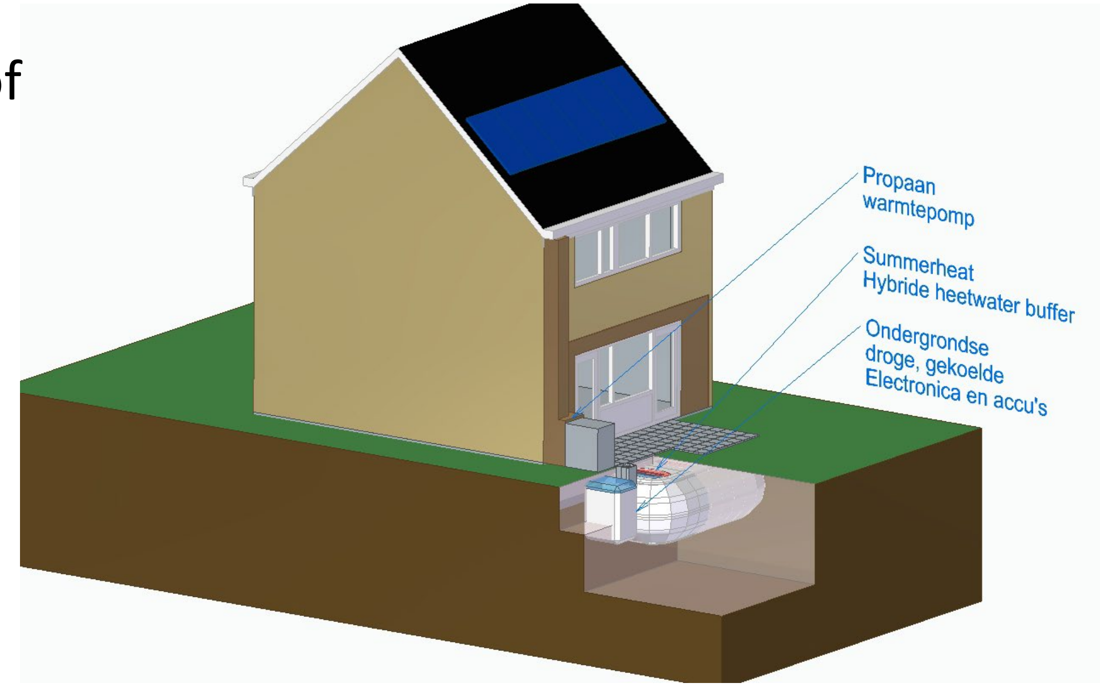
EV + V2G + PV + Battery (Underground)

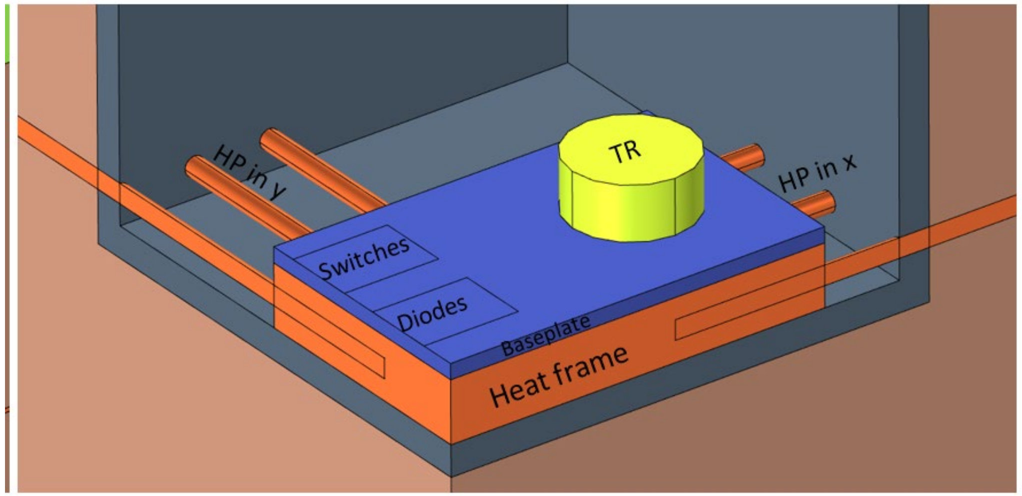
- Goal: 25kW Multi-Port DC Converter for PV Charging of Electric Vehicles with flexibility of battery storage
  - ➢ Underground power electronics for space saving using the soil as a (partial) cooling medium

Project partners: PRE, Heliox (Flexinet)

PhD project:
Siddhesh Shinde







Reference: https://www.tudelft.nl/en/Flexinet; Project funded by: RVO MOOI

Trend 4: V2G with onboard solar

Sono motors:

- 1.2kW PV → 456 half cells over the body
- 54 kWh LFP battery → 305 km (WLTP range)
- V2G on AC -> 11kW bidirectional OBC

Source: Sono

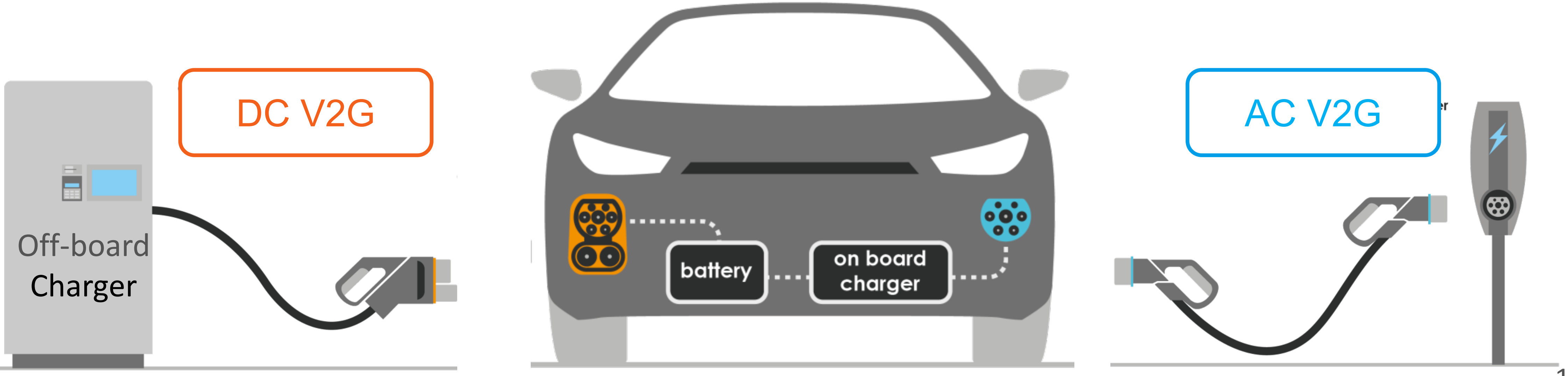
Trend 5: Onboard V2G charger

- DC V2G off-board power converter:
  - ➢ No size and weight limitation
  - -> But needs investment for charger

- AC V2G uses on-board power converter:
  - ➢ More expensive charger - Automotive grade
  - ➢ But comes for 'free' with EV
  - ➢ Type 1 or Type 2 Plug, ISO 15118 comm.

WE DRIVE SOLAR

First bidirectional AC 15118 charging station in the market
2x22 kW AC charging



Trend 6: Vehicle to Load (V2L)

- Hyundai: V2L for standalone (offgrid) power requirements - 240V, 3.6 kW, 15 A
- Kia V2L: Kia EV 6 with 3.7 kW standalone (offgrid) power

Source: IONIQ 5 - Vehicle to Load (V2L), https://www.youtube.com/watch?v=c2tHJD6mMbE; https://www.carmagazine.co.uk/car-news/tech/vehicle-to-load-v2l-does-it-work ; https://www.reddit.com/r/electricvehicles/comments/obgekl/i_loved_v2l_feature_in_ioniq_5_evs_becomes_more/;

Trend 6 extension: Vehicle to Vehicle (V2V)

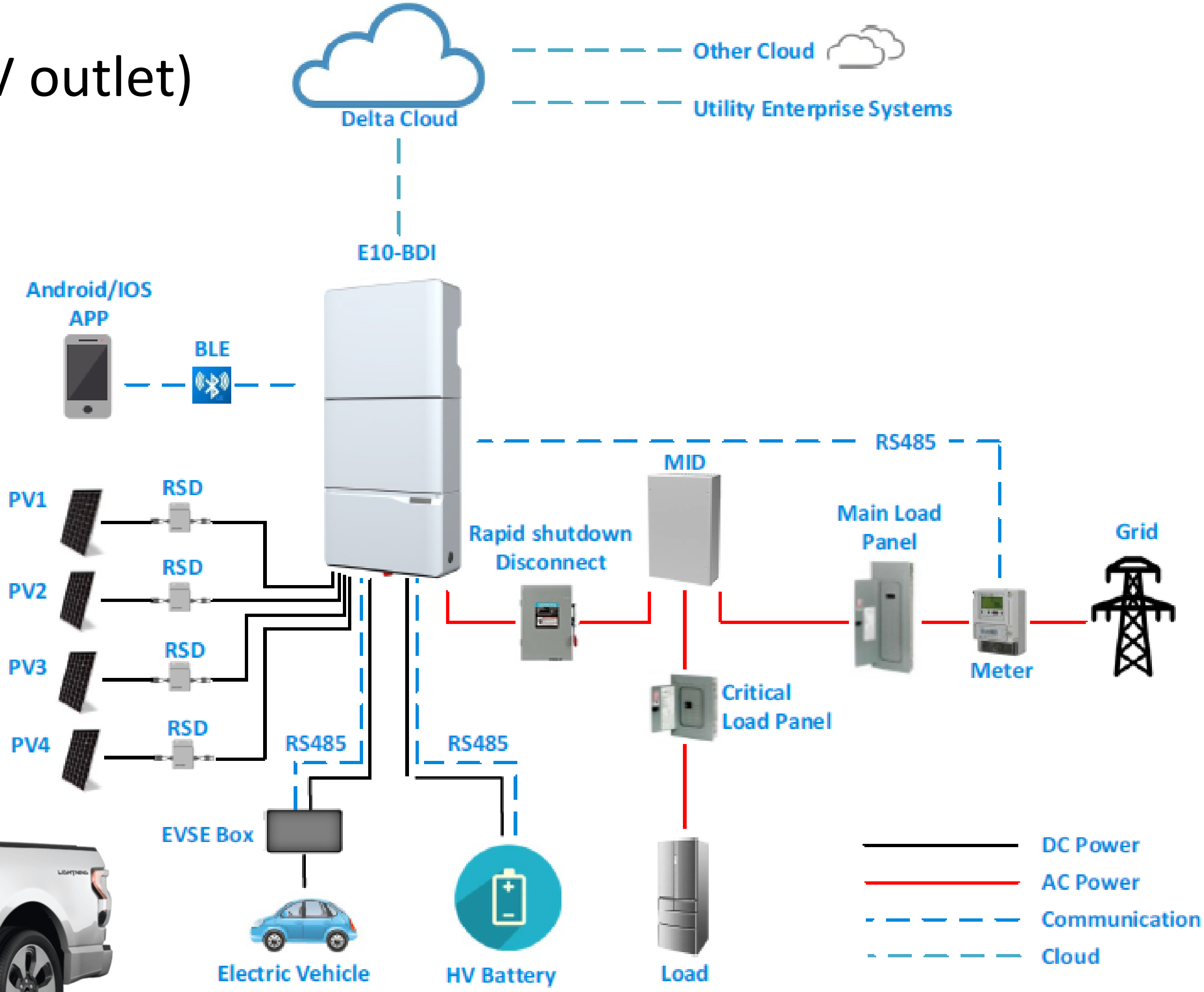
- V2L -> Extension is V2V
  - Sono motors: 3.7 kW V2L/V2V
  - GMC Hummer: 6kW V2L/V2V from 170/200kWh battery

Source: Sono, https://www.greencarreports.com/news/1139021_2024-gmc-hummer-ev-truck-and-suv-can-charge-other-evs-at-6-kw

Trend 7: Vehicle to Home/Building (V2H/B)

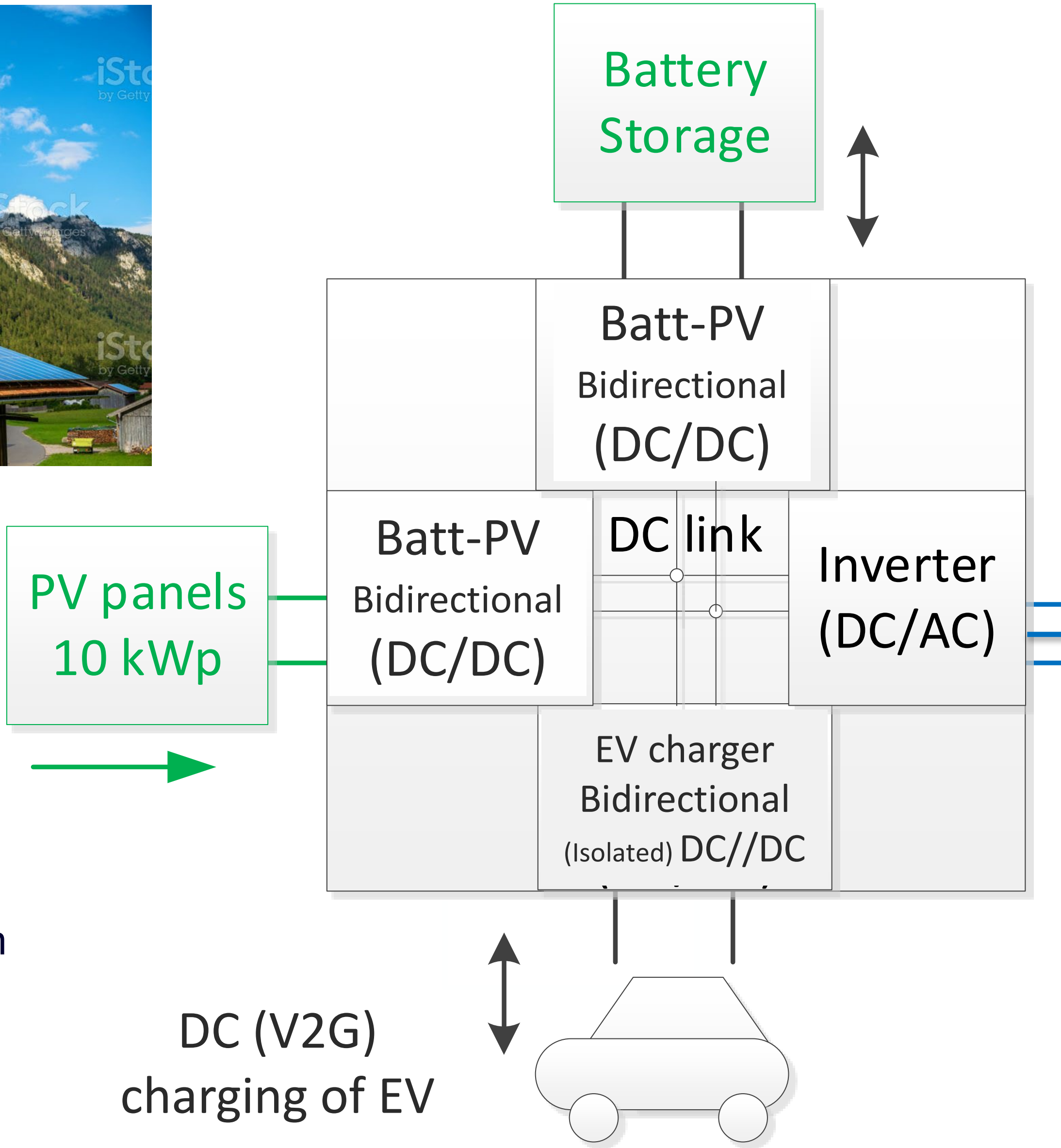
Ford F150 lightning

- 9.6kW V2L power (10x 120V & 1x 240V outlet)
- V2H standalone with Delta converter
  + Ford charge pro 80 amp



Source: Fprd

Trend 7: Vehicle to Home/ (V2H/V2B) + PV + Batt

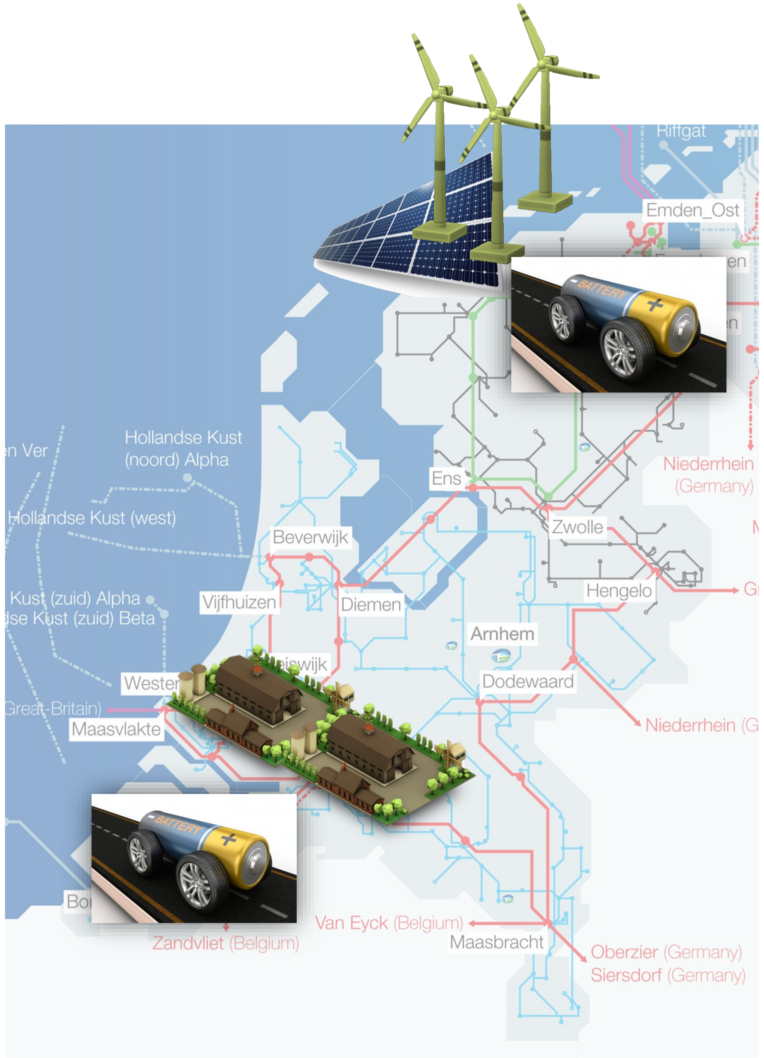


AC charging of EV

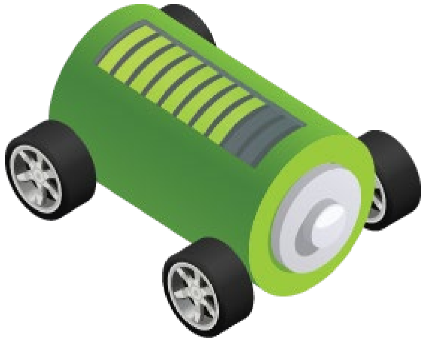
PhD project – Carina Engstrom

Postdoc – Gautam Rituraj

Trend 8: V2G with Automated EVs



Automated EV =
Battery on wheels

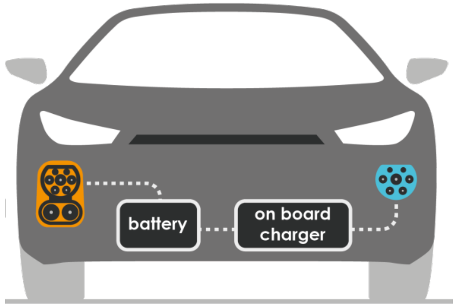


PhD topic
Alvaro Menendez Agudin

TUDelft Source: Tesla

Challenges for V2G

1. Bidirectional chargers (on or off board)
2. Battery capacity degradation (?)
3. Competition from stationery storage
4. Incentives for user to participate (End-user friendly apps)
   - Market mechanisms at DSO & TSO level – for energy & power
   - “Net metering” reduces the incentive for storage
   - Frequency regulation - minimum bid size & delivery period
5. Aggregation and coordination of millions of EVs → ICT
6. Standardization on security/privacy
7. Standards: CHAdeMO is V2G ready (as early as 2014), CCS ongoing (2023-25)

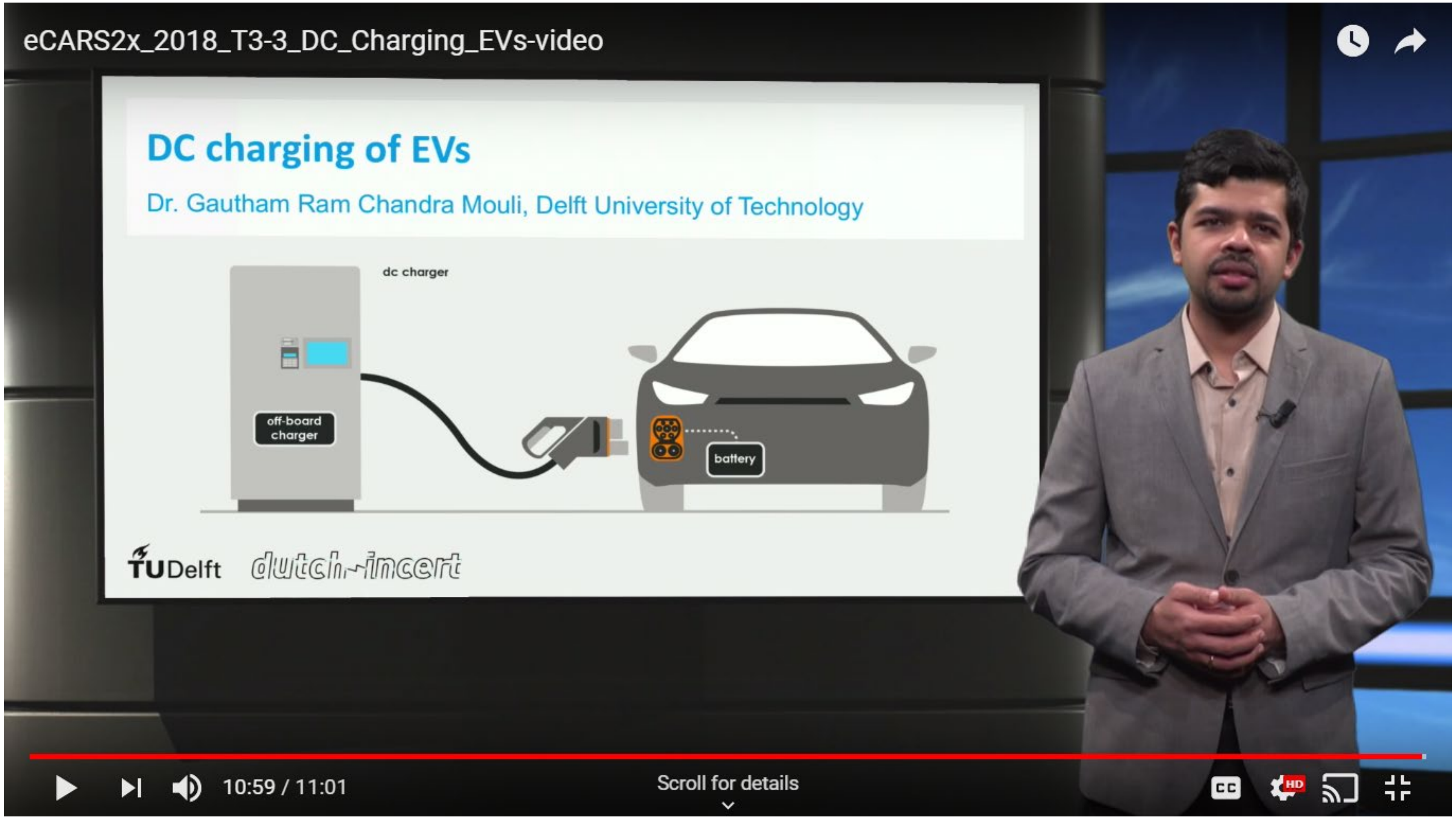


Want to learn more?

www.tiny.cc/ecarsx

Want to learn more?

- Lecture video
- Exercises
- Panel discussion
- Online forums



www.tiny.cc/ecarsx

UCL ENERGY INSTITUTE

V2G vs V2H from the end-user perspective: a story of control and risk allocation

David Shipworth

PowerWeb conference 2023

Central vs personal control

- **Power systems control**

  - Risks: Lower uptake; psychology of control -> more complaints; less tailored

  - Benefits: Firm dispatch; central control; deterministic

- **Contractual control**

  - Risks: Lower participation; Supplier/OEM reputational risk; defection in extreme conditions

  - Benefits: 'Informed consent'; behavioural science mechanisms can help sign-up.

Ref: [Siemens PJM platform]

Central vs personal control

- **Market mechanisms**

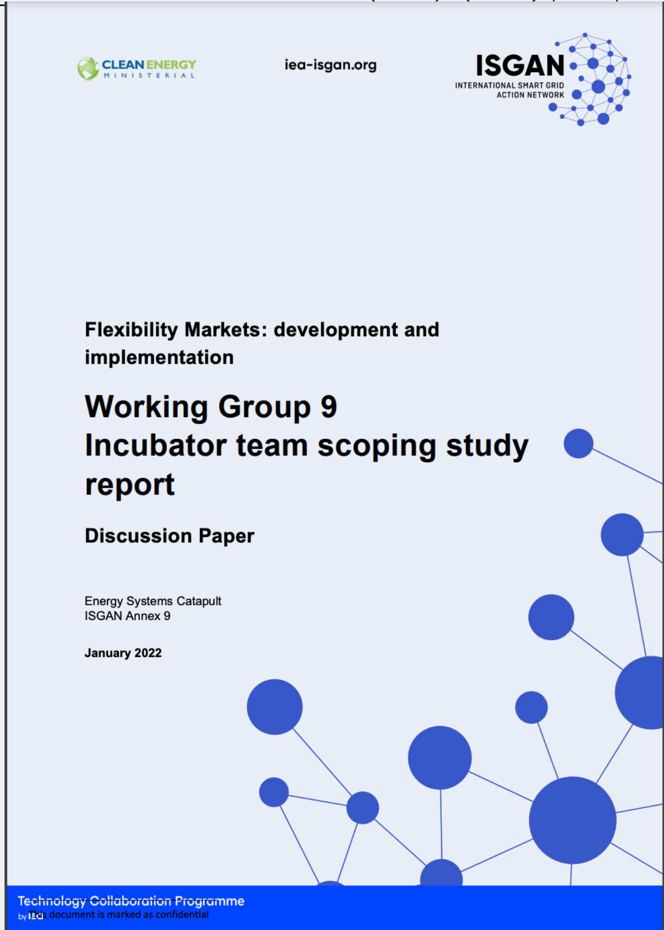
    - ***Risks:*** Market defection in important edge cases (extreme events)

    - ***Benefits:*** Economic efficiency; price discovery; supplier ecosystem incentives.

- **Voluntary mechanisms**

    - ***Risks:*** Unreliability; Low penetration

    - ***Benefits:*** Low to zero cost; potential for pro-social engagement.



CLEAN ENERGY MINISTERIAL

iea-isgan.org

ISGAN INTERNATIONAL SMART GRID ACTION NETWORK

Flexibility Markets: development and implementation

Working Group 9
Incubator team scoping study report

Discussion Paper

Energy Systems Catapult
ISGAN Annex 9

January 2022

Technology Collaboration Programme by iea

This document is marked as confidential

V2G is transactional. V2H is personal

- **Home is personal**
  - Home engages emotions
    - Shelter; security; comfort; etc
  - Home places financial decisions in a different context.
    - What is the payback period on a new kitchen?
    - What is the value of keeping your family safe?

Ref: https://www.ford.com/trucks/f150/f150-lightning/gallery/?intcmp=vhp-seconNav-gallery

V2G vs V2H operating scenarios

- **‘Normal’**
- Grid view: V2G=V2H
  - Risks: Energy/carbon
- User view: V2G≠V2H
  - V2H: Netted off bill at home rate
  - V2G: Credited on bill at (low) grid rate
  - Risks: Financial

- **‘Constrained’**
- Grid view: V2G=V2H
  - Risks: Power/financial
- User view: V2G≠V2H
  - V2H: Netted off bill at home rate.
  - V2G: Credited on bill at (high) grid rate
  - Risks: Power/financial/ comfort

- **‘Blackout’**
- Grid view: V2G≠V2H
  - Risks: Power/financial/ priority services register
- User view: V2G≠V2H
  - V2H: Have power
  - V2G: Don’t have power
  - Risks: Health/ security/comfort

Benefits of a user-centred hierarchy: Car → Home → Neighbours → Others

- **Power Systems**
  - Reduces flexibility market defection risk
  - Reduces grid defection risks
  - Reduces load shedding costs
  - Engages autarkic users
  - Promotes product bundling (EV+PV+Batt+HEMS)
- **Users**
  - Engage psychology of control
    - Give users control and they rarely take it.
    - Deny users control and they rarely grant it.
  - Activate loss/risk aversion
    - Users act to avert losses over realising gains.
  - Mobilise climate crisis salience
    - Foregrounds energy users' planning

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Smart Charging at Scale – ROBUST and DRIVE2X Projects

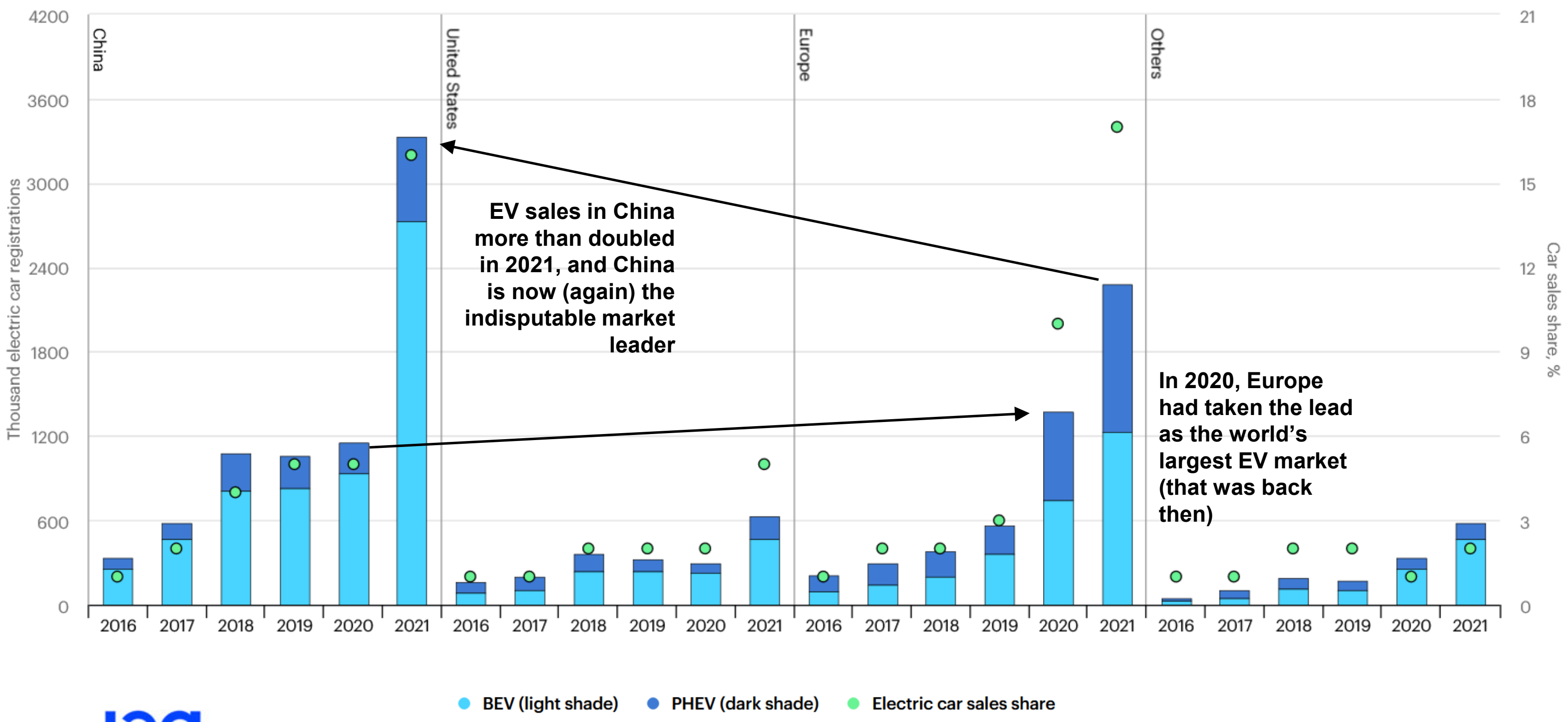
Assistant Prof. Pedro P. Vergara
Intelligent Electrical Power Grids (IEPG)

TUDelft

EV sales keep growing fast

Electric vehicle sales across all transport modes had a steady growth over the last decade (and majorly during the Covid-19 pandemic)

Electric car registrations and sales share in China, United States, Europe and other regions, 2016-2021



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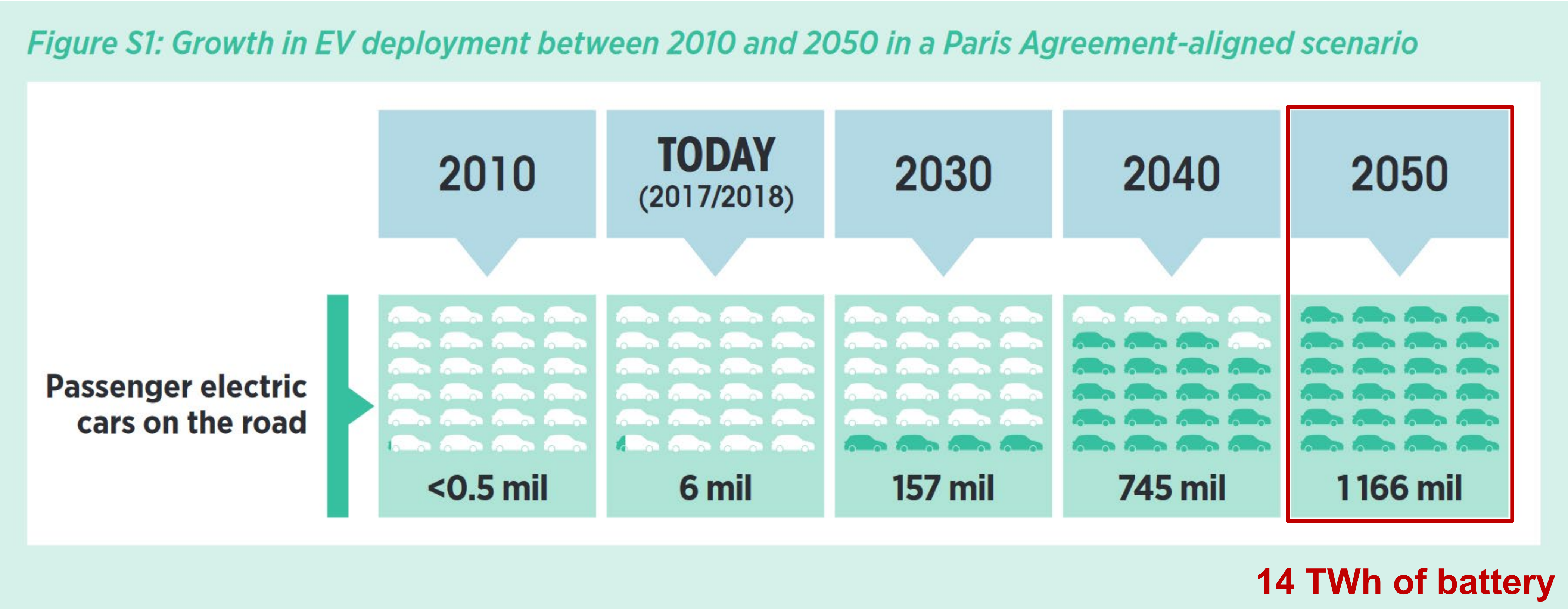
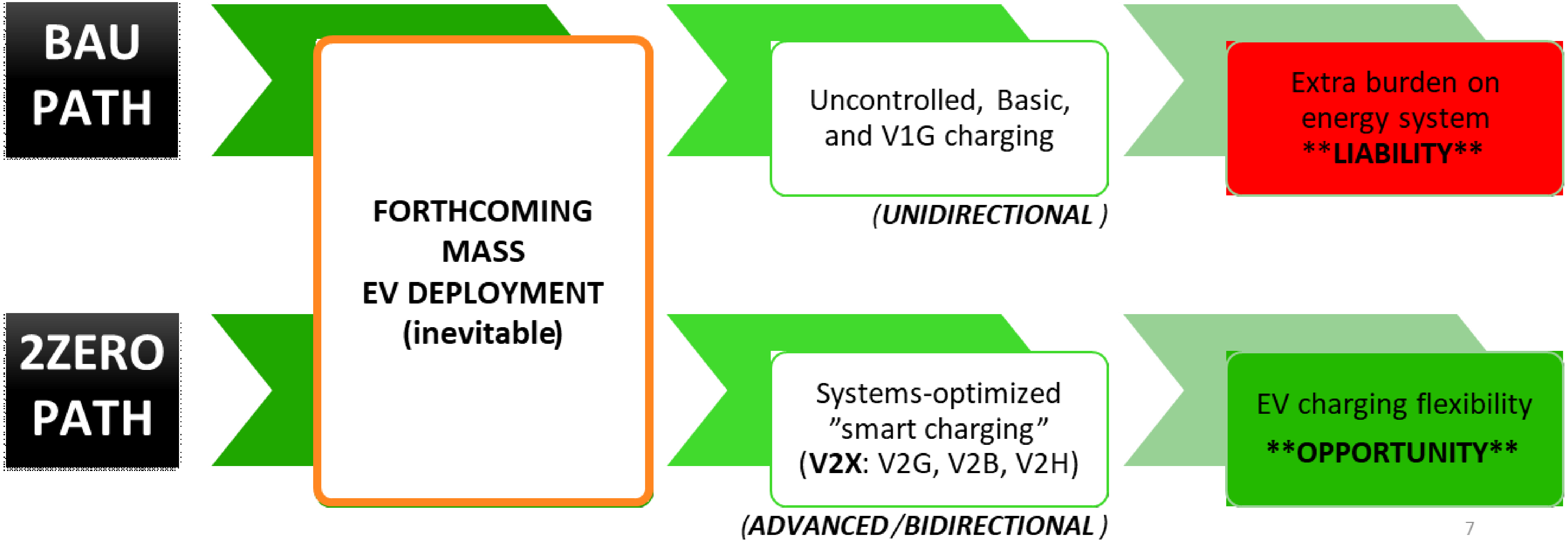
iea

2050 could see more than 1b EVs on the road



14 TWh of battery capacity!

EV growth is a “double-edged sword”



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EV charging flexibility as an opportunity

DRIVE2X Project: Delivering Renewal and Innovation to Mass Vehicle Electrification Enabled by V2X Technologies

HORIZON EUROPE

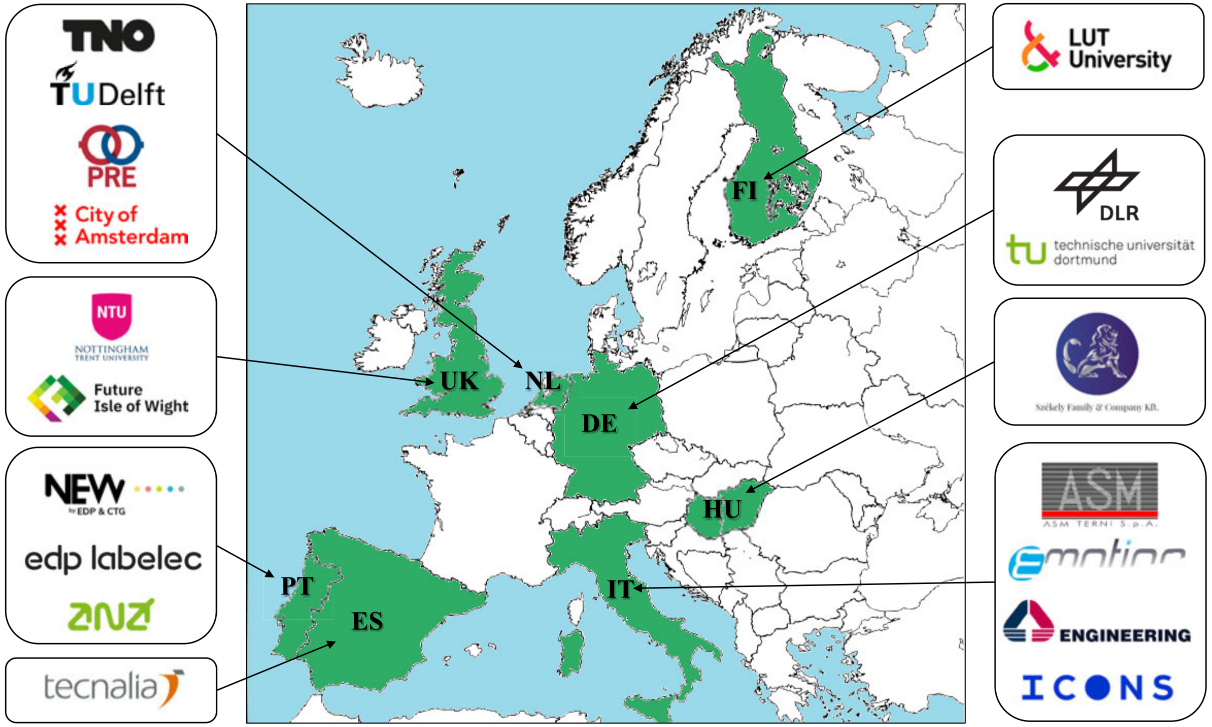
ROBUST: Robust sustainable electricity system through regional flexibility

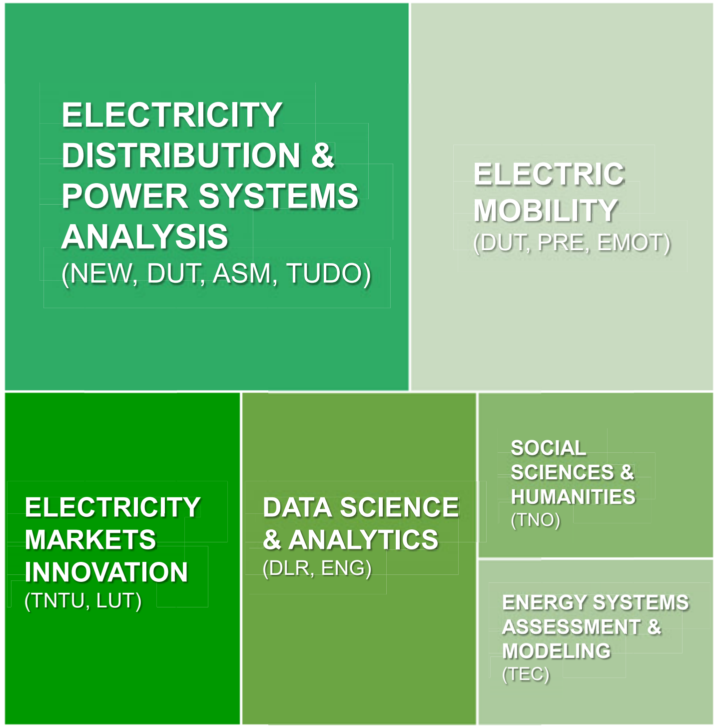
Rijksdienst voor Ondernemend Nederland

EV charging at a scale…

DRIVE2X Project: Delivering Renewal and Innovation to Mass Vechicle Electrification Enabled by V2X Technologies

18 partners, 8 countries, Power systems-led





DRIVE2X's objective

To develop new knowledge, tools, models, and technologies to cope with a V2X-based mass EV deployment future for Europe

01 V2X flexibility markets
New AI and ICT tools enabling exploitation of V2X flexibility

02 V2X charging technology
Affordable, user-friendly bidirectional chargers

03 The social side of V2X
EV user expectations as key success factors of uptake

04 V2X upscaling studies
Novel modeling approaches and roll-out frameworks

drive2x

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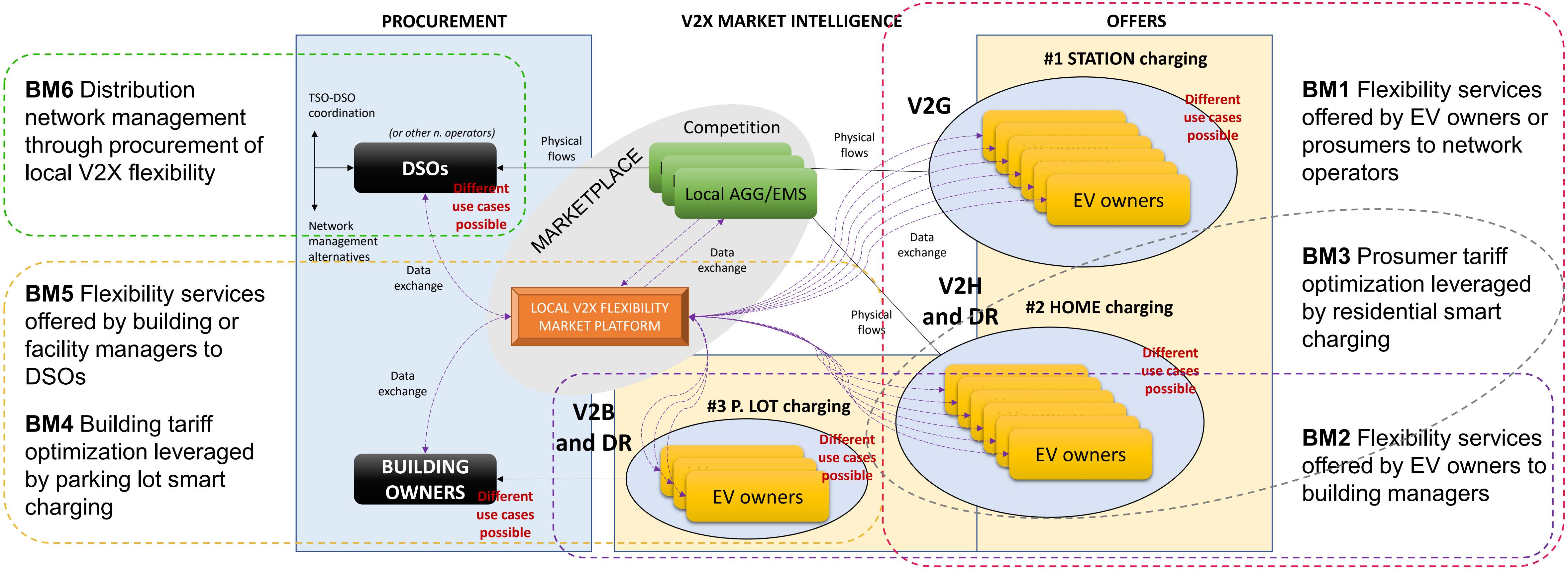
DRIVE2X

Overarching marketplace concept & BMs



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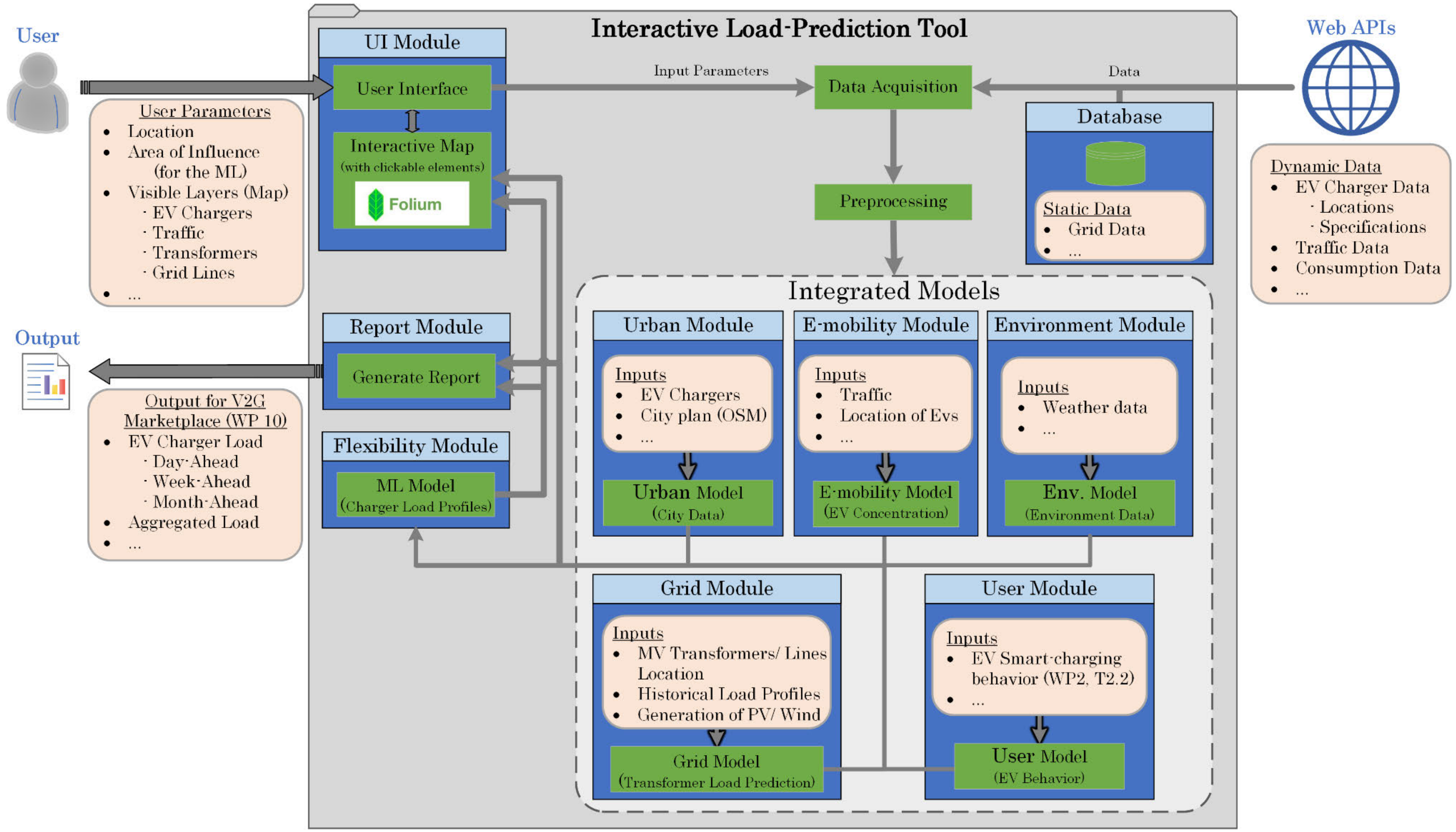
DRIVE2X

TUD is working towards an EV platform to facilitate V2X services



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DRIVE2X

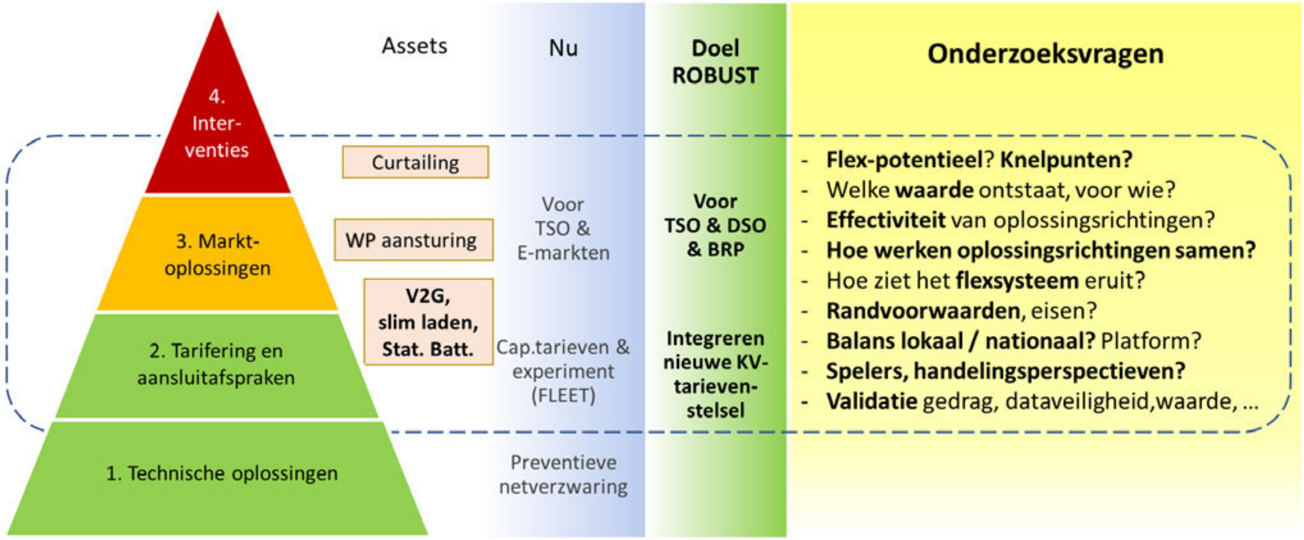
ROBUST Project: Robust sustainable electricity system through regional flexibility

Research partners:

Locality partners:

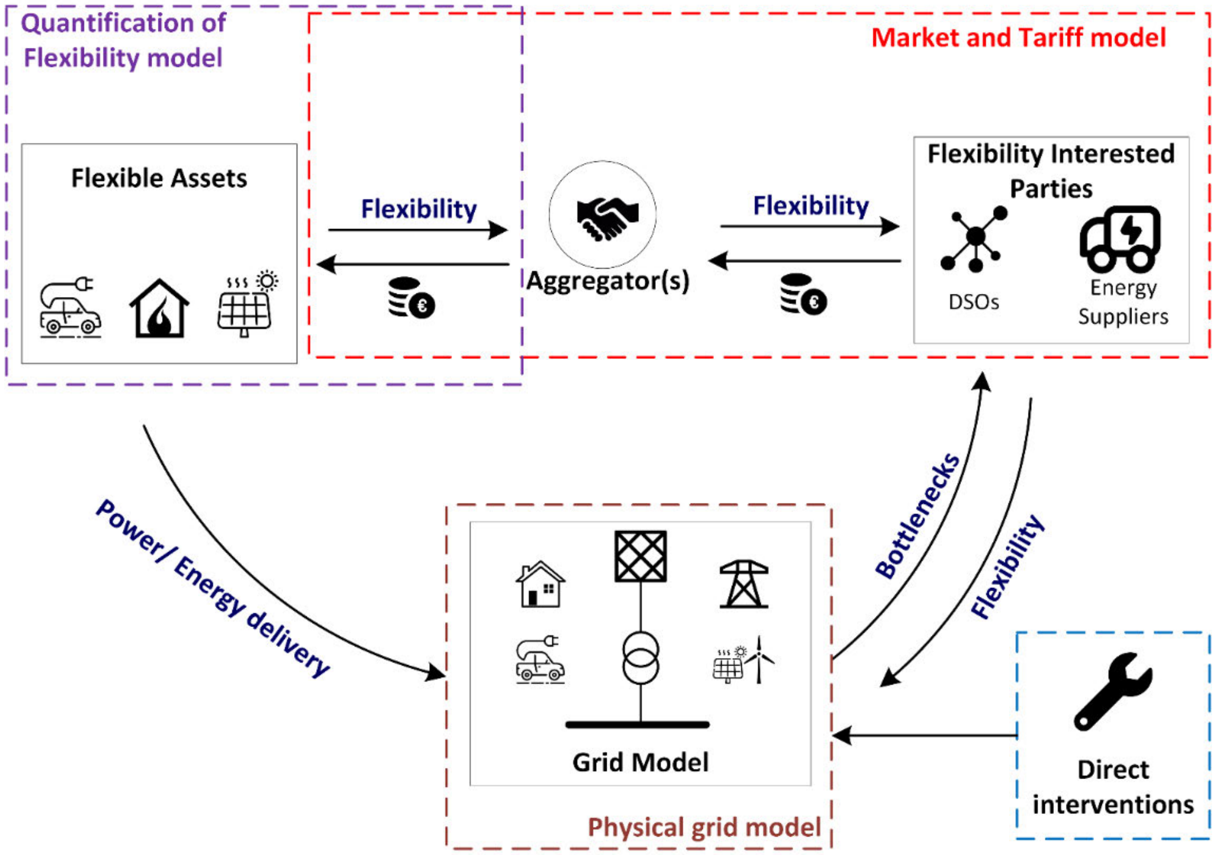
Industry partners:

Funding partners:



ROBUST's objective

Proof-of-principle delivery of an optimal ratio between flexibility and grid reinforcement.



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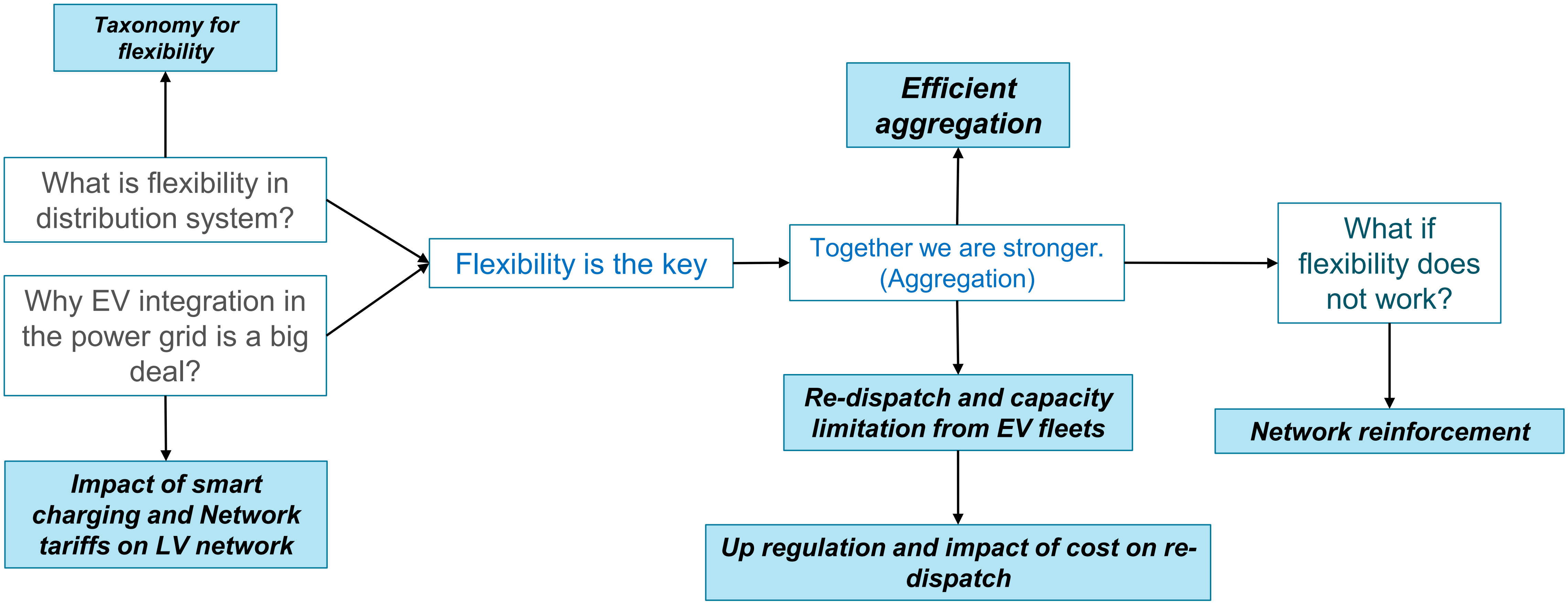
ROBUST

TUD is working towards flexibility quantification



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Challenge: An efficient and scalable approach is required that provides precise solutions rather than mere approximations.

ROBUST

Thank you for your attention.

High Efficiency Wireless Charging of EVs

Jianning Dong

Assistant professor, ESE/DCE&S, Faculty of EEMCS

TUDelft

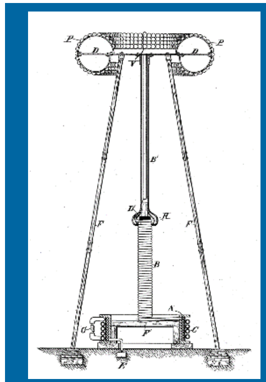
DCE&S

DC systems, Energy conversion & Storage

Why charging wirelessly?

TU Delft

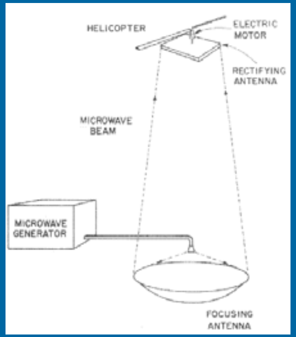
A history perspective



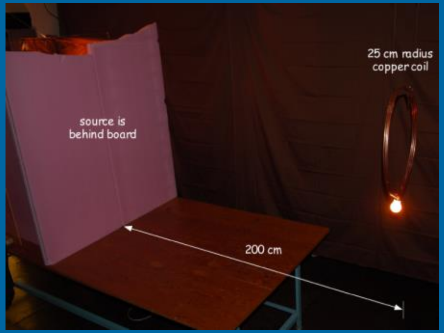
1897:
Tesla WPT patent

1966:
Microwave powered helicopter

Brown, W. C. (1966). The Microwave Powered Helicopter. Journal of Microwave Power, pp. 1–20.

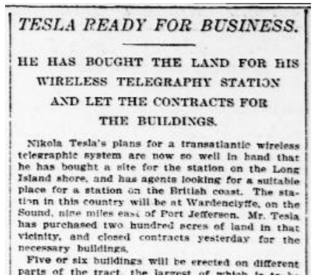


2006:
MIT 2m 60 W WPT experiment



2009:
OLEV by KAIST

1897 – 1917	1950s – 1990s	1990s – early 2000s	2009 – now



TESLA READY FOR BUSINESS.

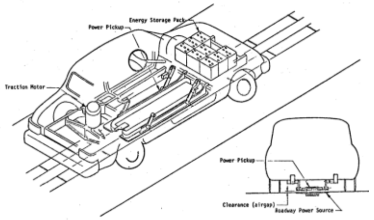
HE HAS BOUGHT THE LAND FOR HIS WIRELESS TELEGRAPHY STATION AND LET THE CONTRACTS FOR THE BUILDINGS.

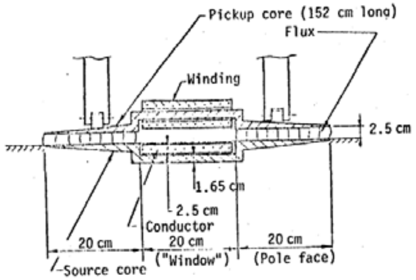
Nikola Tesla's plans for a transatlantic wireless telegraphic system are now so well in hand that he has bought a site for the station on the Long Island shore, and has agents looking for a suitable place for a station on the British coast. The station in this country will be at Wardenclyffe, on the Sound, nine miles east of Port Jefferson. Mr. Tesla has purchased two hundred acres of land in that vicinity, and closed contracts yesterday for the necessary buildings.

Five or six buildings will be erected on different parts of the tract, the largest of which ...

1901:
Tesla's Wardenclyffe Tower

1970s:
Boom of power electronics





Dynamic charging patents
Otto D. V. (1974), Bolger J. G. (1975)

Fast development of EVs

- Renewed attention for dynamic charging
- Standards defined for wireless charging of EVs
- Commercial development

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Classifications of wireless power transfer technologies

Near-Field

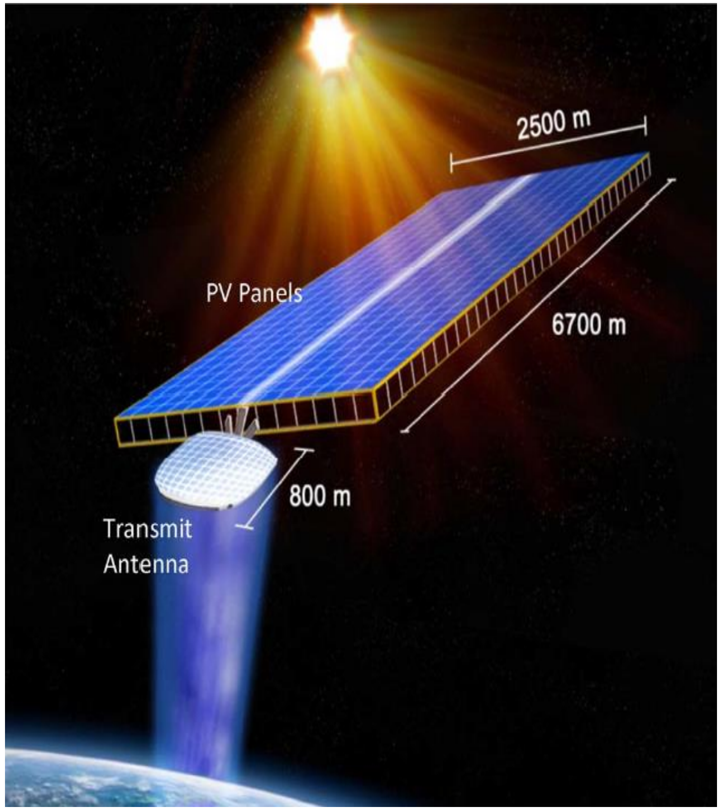
- Electric Field
  - Capacitive Coupling
- Magnetic Field
  - Inductive Power Transfer

Far-Field

- Solar
- Micro-Wave
- Lasers
- Radio Wave

Inductive Power Transfer for Electrical Vehicles
www.witricity.com

Subsea Charging
www.unplugged.no



Space Solar Power Transfer

Paul Jaffe et al (2013), “Energy Conversion and Transmission Modules for Space Solar Power”, Proceedings of IEEE, vol. 101, no. 6, 2013

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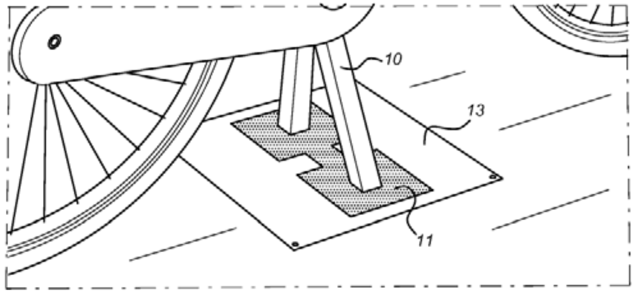
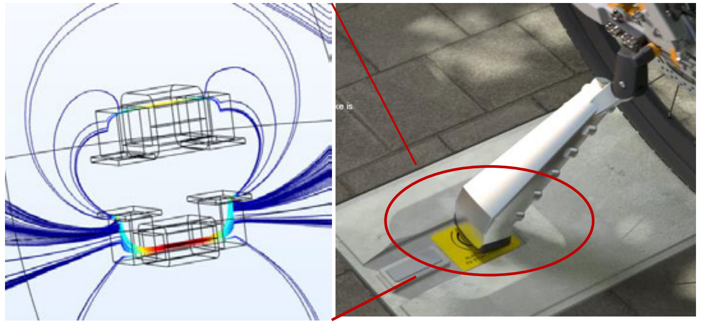
IPT based wireless charging: application examples

E-bike charging

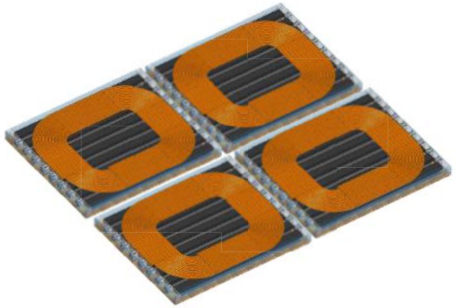


Van Duijsen P., Bauer P. (2017), “Contactless charger system for charging an electric vehicle”, International Patent WO 2018/220164 A1.



TU Delft startup company:
https://www.tilercharge.com/

Bus opportunity charging



200 kW IPT charger

- 1 min charging at stops = 3.3 kWh
- Enough to cover 2.5 km for a rate of 1.3 kWh/km*.

Advantages

- Significant reduction of battery size and weight
- Lower cost and complexity compared to dynamic charging

Research funded by EU project PROGRESSUS
https://progressus-ecsel.eu/

*Based on: Beckers. C. et al (2021), “The State-of-the-Art of Battery Electric City Buses. Paper presented at 34th International Electric Vehicle Symposium and Exhibition (EVS34), Nanjing, China.

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Inductive Power Transfer: System Topology

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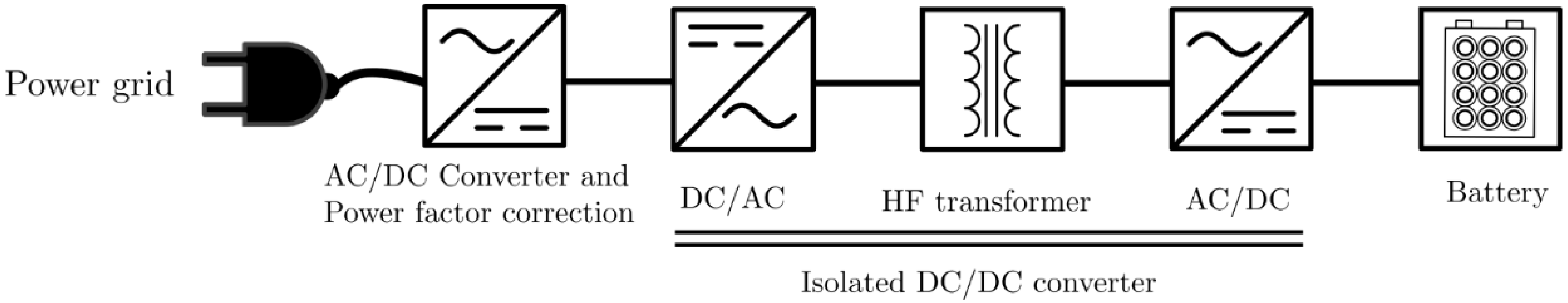
Wired charging system topology



Efficiency from plug to battery:

Assume: 99% efficiency each stage
Total efficiency: 99%^4 = 96%
Reality: <95% end to end

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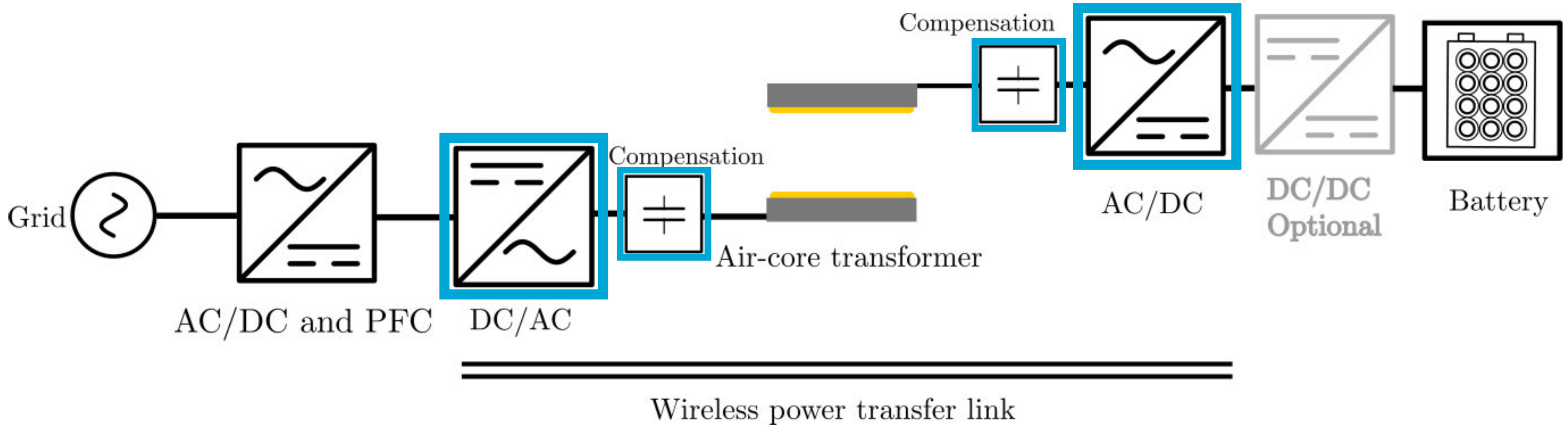
IPT system topology



Primary DC/AC

- Current or voltage source
- Half or full bridge

Compensation

- 4 basic ones: series or parallel
  S-S, S-P, P-S, P-P
- High order compensations

Secondary AC/DC

- Current or voltage source
- Half or full bridge
- Active or passive

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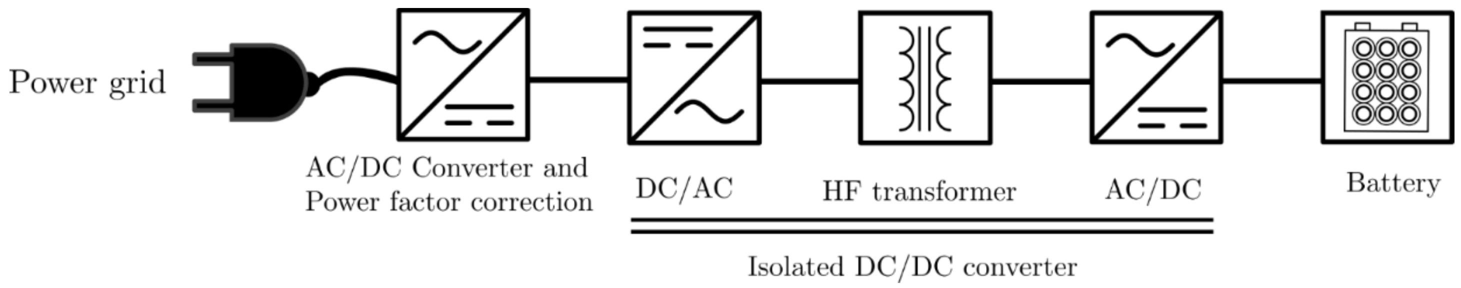
Is high efficiency possible?

Wired charging:

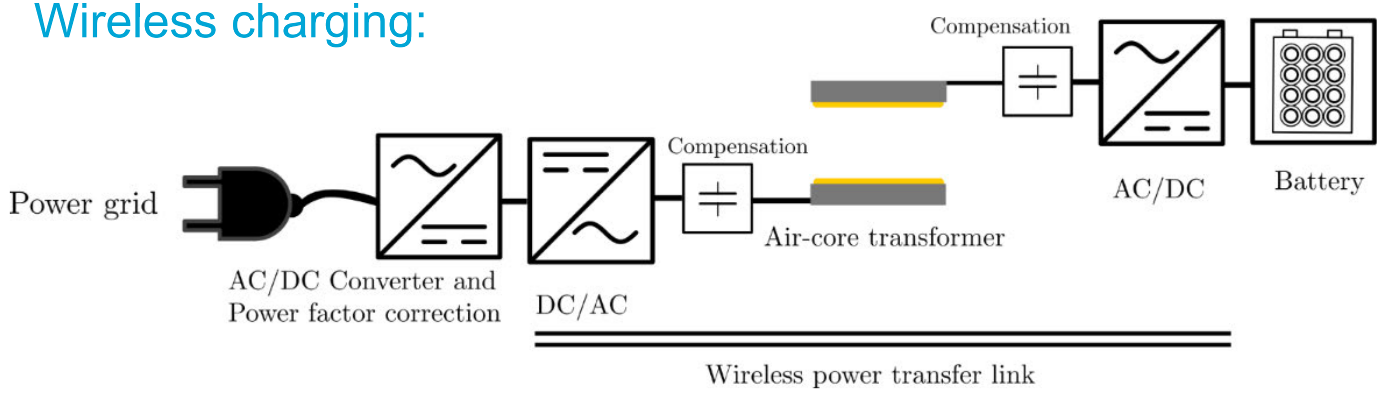


From plug to battery:

Assume: 99% efficiency each stage
Total efficiency: 99%^4 = 96%
Reality: <95% end to end

Source: H. Tao, et al. (2019), "Extreme Fast Charging of Electric Vehicles: A Technology Overview," IEEE TTE, vol. 5, no. 4.

Wireless charging:



From grid to battery:

Added: two passive compensation stages (~99.7% efficient)
Replaced: HF transformer -> air-core transformer (>98% efficient)
Total efficiency: 99%^3*98%*99.7% = 95%
Reality: <95% end to end

But how? A multi-objective optimisation problem

Search space

- Dimensions
- Number of turns/strands/coil diameter
- Core material/shielding material
- Compensation topology
- Core arrangement
- …

IPT system model

- 3D FEA, inductance evaluation
- Circuit model
- Loss models
- Weight/volume calculation
- …

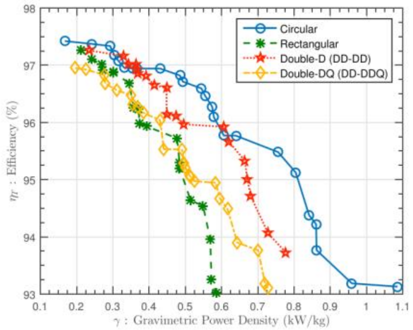
Conflicting objectives

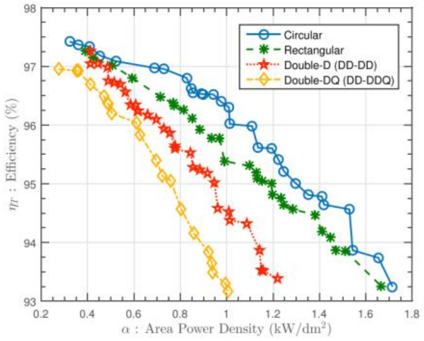
- Aligned efficiency
- Stray field
- Gravimetric power density
- Area power density
- …

Multi-objective optimizer

- Genetic algorithm
- Particle swarm
- …

Pareto fronts



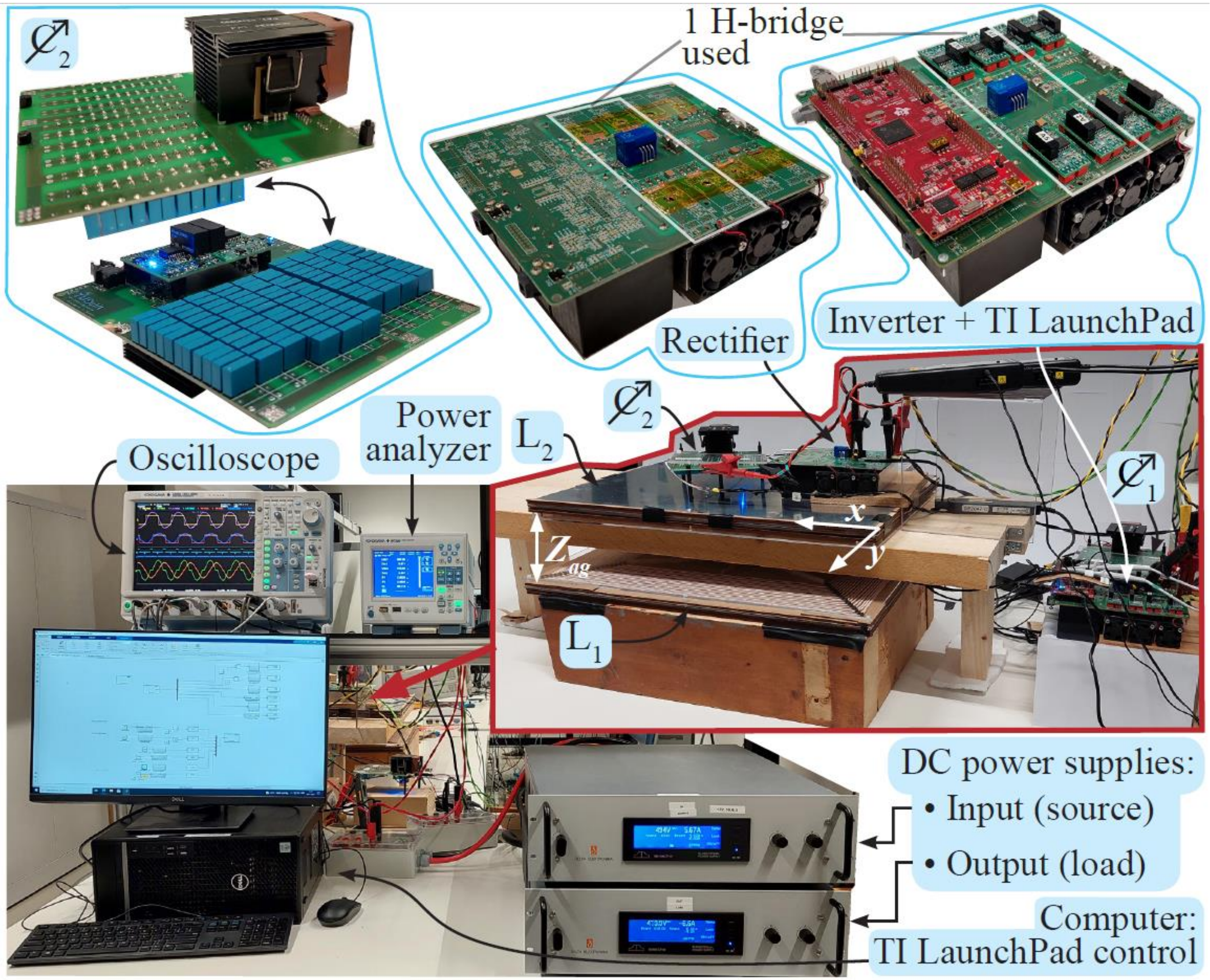


Bandyopadhyay S., et al. (2019), “Comparison of Magnetic Couplers for IPT-Based EV Charging Using Multi-Objective Optimization,” *IEEE TVT*, vol. 68, no. 6, pp. 5416–5429.

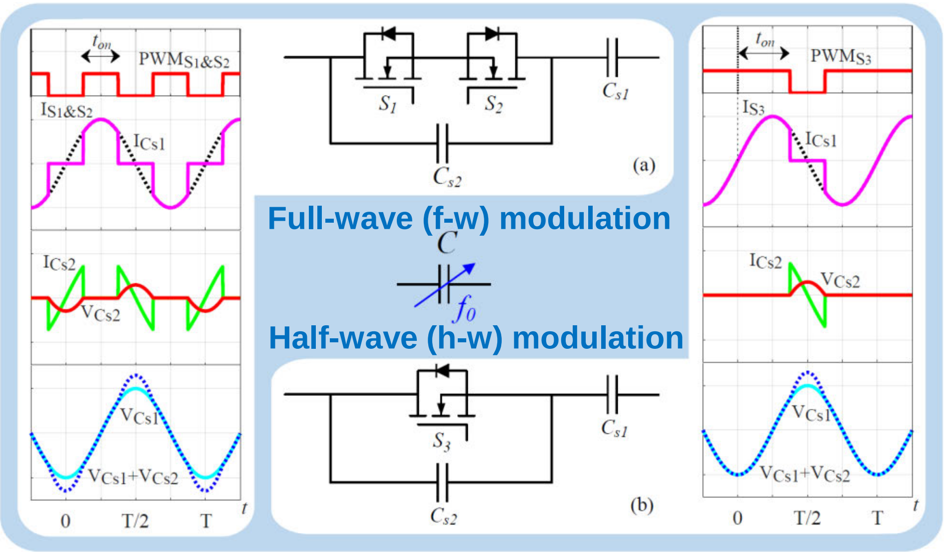
Design Examples

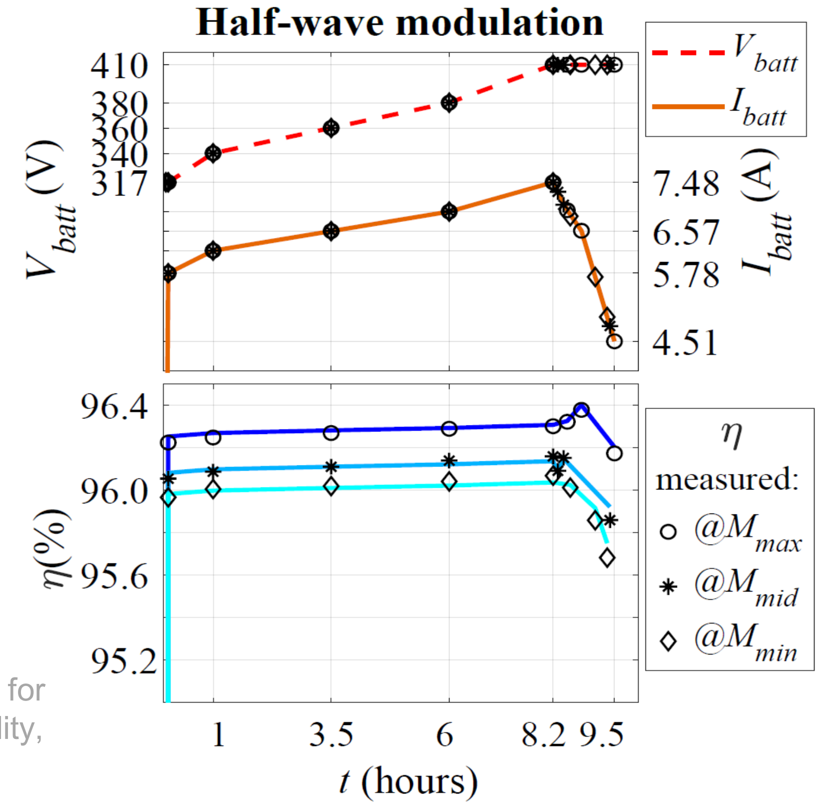
High efficiency 3.7 kW IPT system

Variable series compensation capacitor



Switch-controlled capacitor (SCC) as compensation





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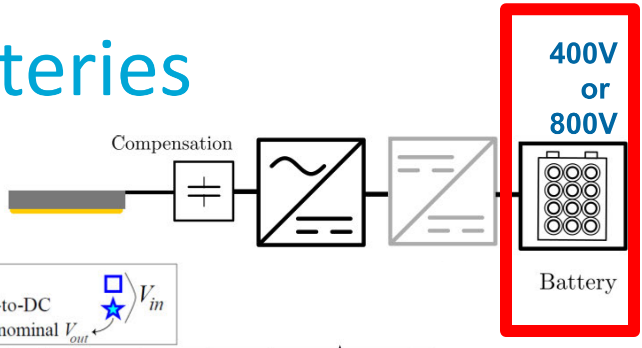
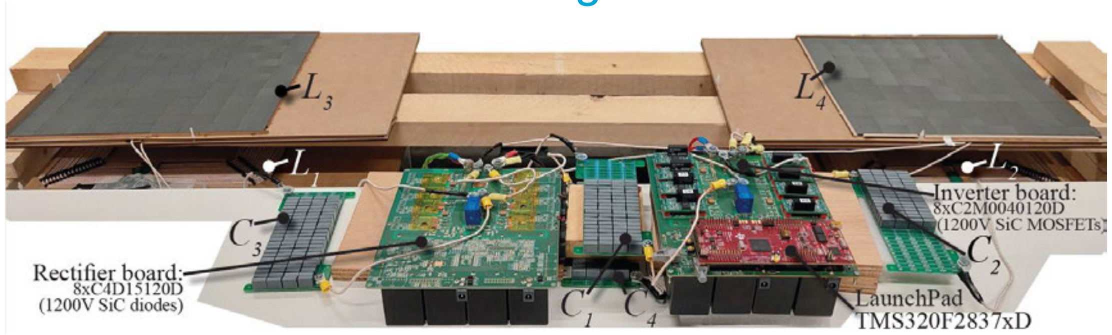
F. Grazian, Highly Efficient Inductive Power Transfer: Variable Compensation for Misalignment Tolerance and Voltage/Current Doubler for Battery Interoperability, PhD Thesis, TU Delft, 2023.

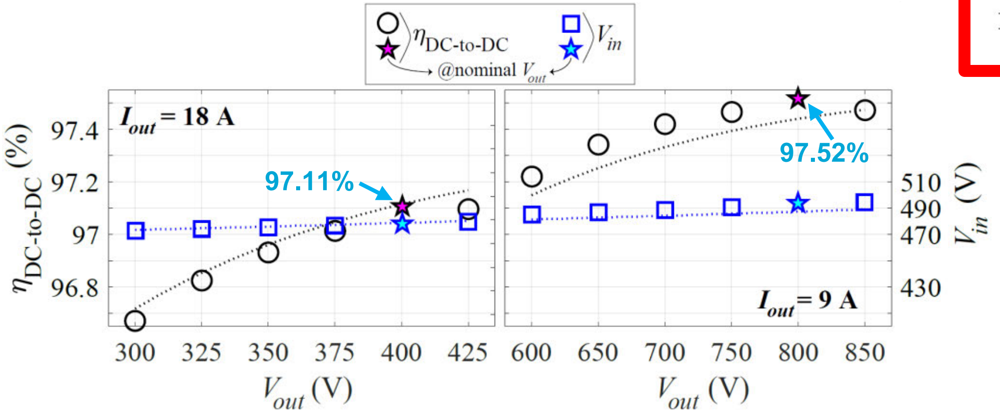
7.7 kW IPT system universal for 400 V and 800 V batteries

Voltage/current doubler (V/I-D) converter → *Multicoil design*

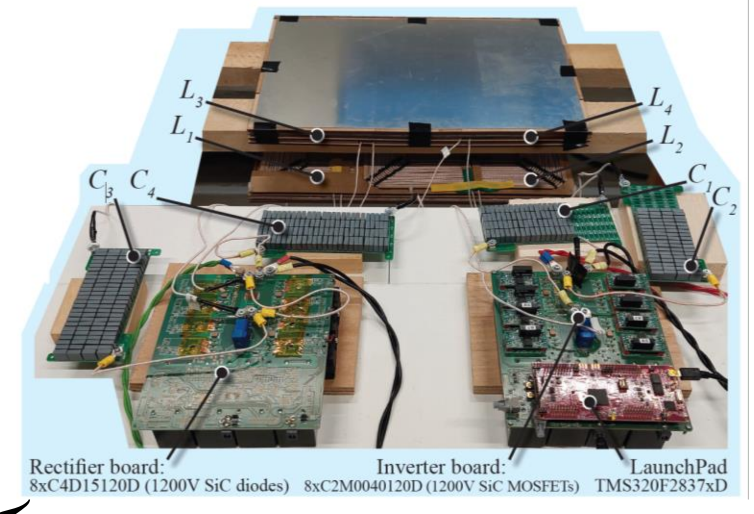


2 sets of rectangular coils

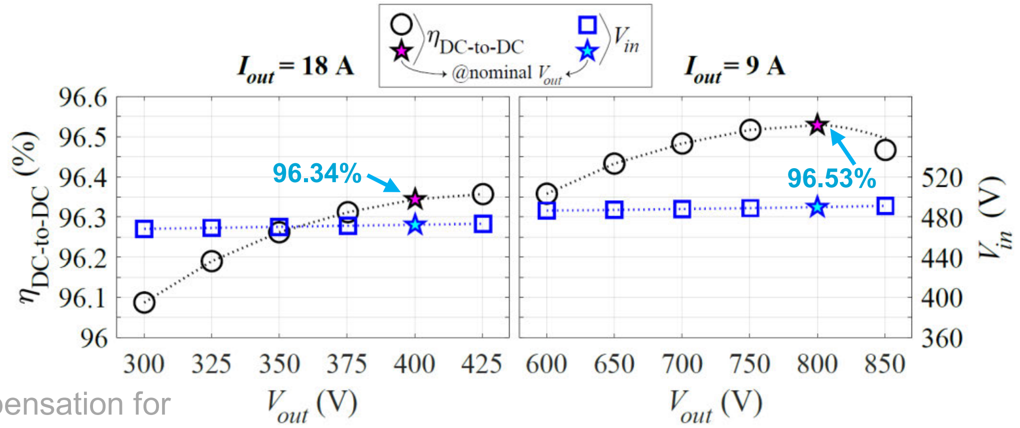




Bipolar pads (BPPs) → Compact solution



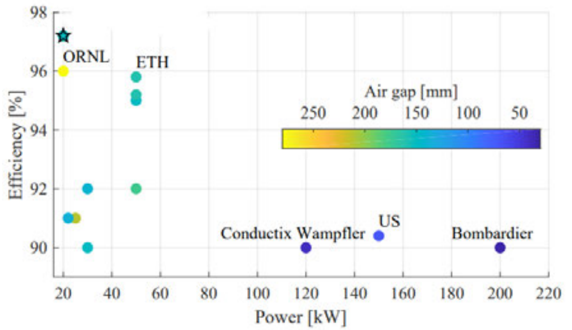
Slight efficiency difference between the two charging modes!



TU Delft

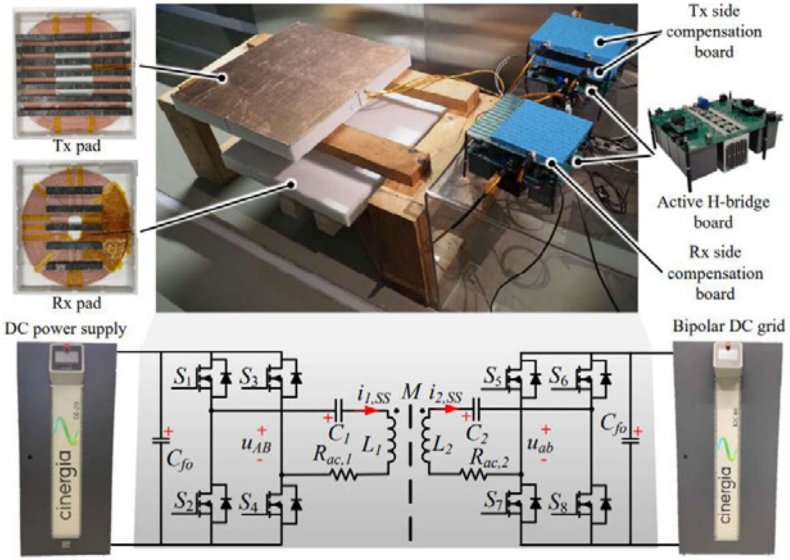
F. Grazian, Highly Efficient Inductive Power Transfer: Variable Compensation for Misalignment Tolerance and Voltage/Current Doubler for Battery Interoperability, PhD Thesis, TU Delft, 2023.

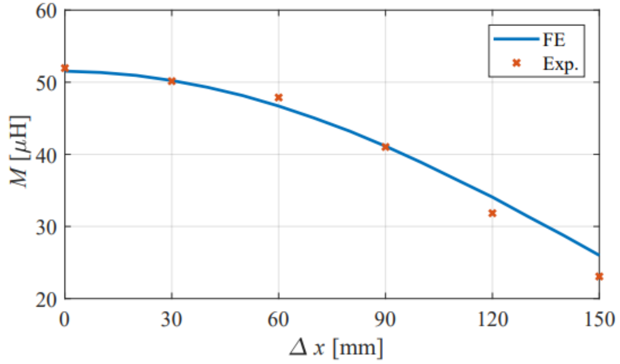
High efficiency 20 kW IPT system



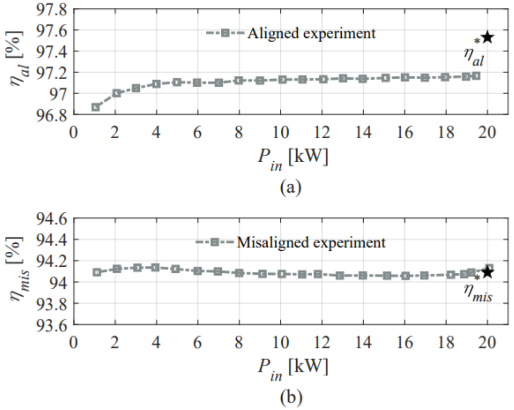
Test result

W. Shi, et al. (2021), "Design of a highly efficient 20-kW inductive power transfer system with improved misalignment performance," IEEE TTE, vol. 8., no. 2.

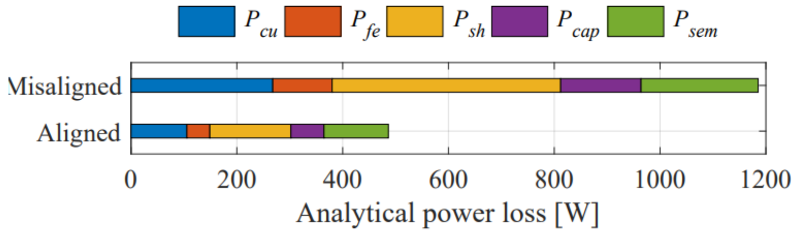


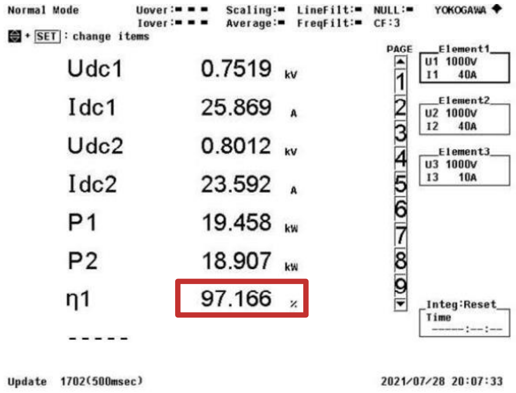


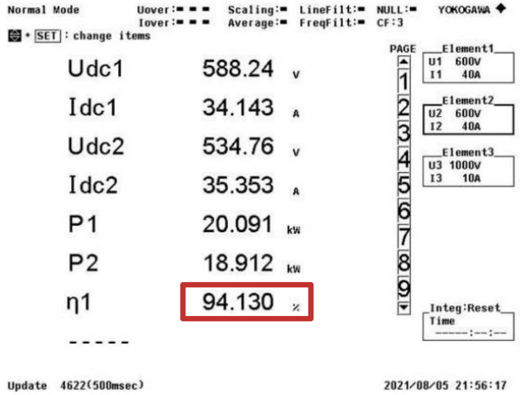
Inductance measurement vs. FEA



Efficiency measurement vs. analysis







Loss breakdown

Aligned and misaligned efficiency

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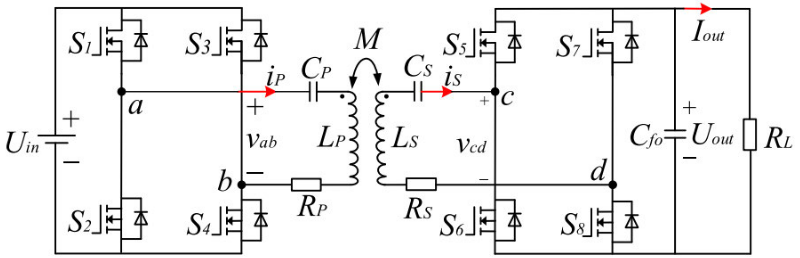
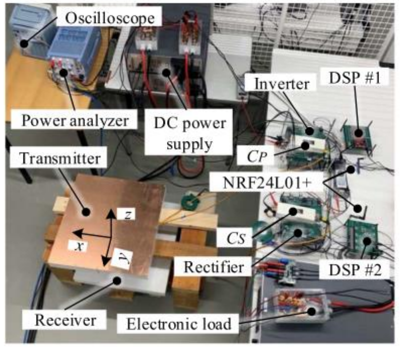
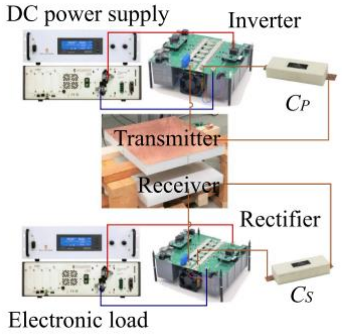
Wide high efficiency range: mode shifting

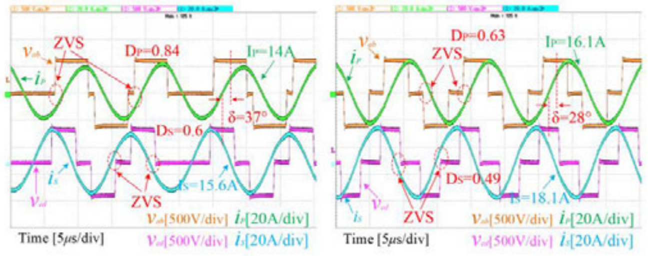
$$P_{out} = \mathrm{Re}\{\dot{V}_S \dot{I}_S^*\} = \frac{|\dot{V}_P||\dot{V}_S|\sin(\delta)}{\omega M}$$



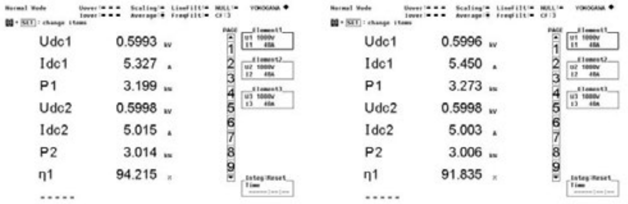




- Mode-switching as output power decreases, to increase D_P and D_S, hence δ



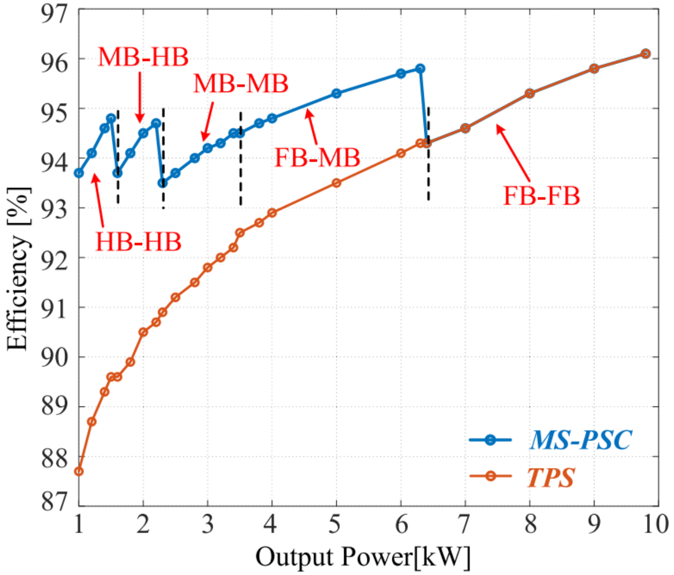
(a) (b)



	(c)	(d)
Udc1	0.5993	0.5996
Idc1	5.327	5.450
P1	3.199	3.273
Udc2	0.5998	0.5998
Idc2	5.015	5.003
P2	3.014	3.006
η1	94.215	91.835

(c) (d)

Comparison at 3 kW, MB vs. FB modes



Measured efficiency in experiments

Zhu G., et al. (2022), "A Mode-Switching Based Phase Shift Control for Optimized Efficiency and Wide ZVS Operations in Wireless Power Transfer Systems", IEEE TPE, vol. 38, no. 4.

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Other Challenges

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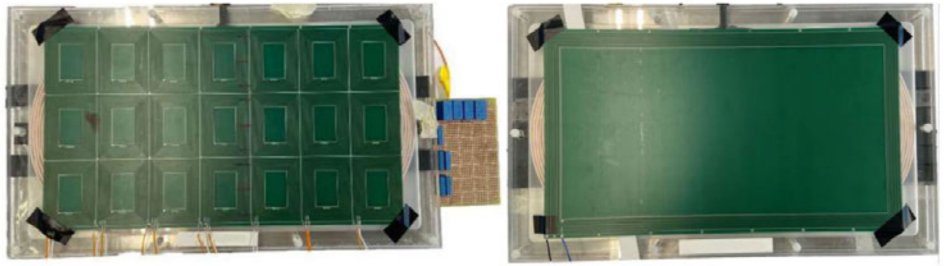
Safety and foreign object

Combined EV and foreign object detections

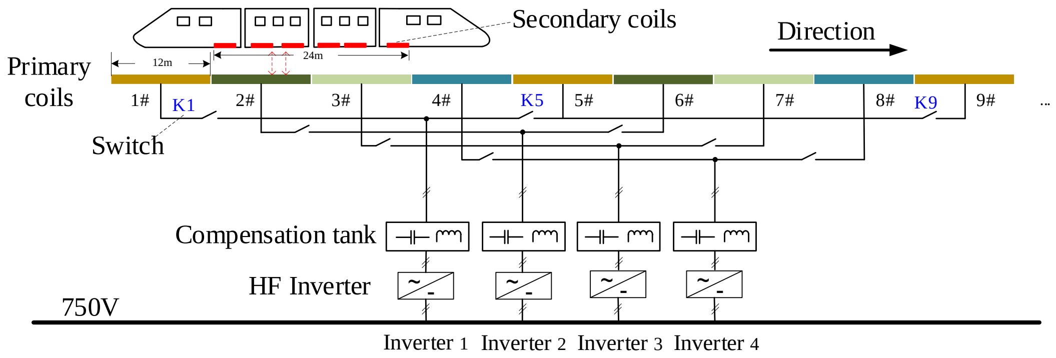


EV and foreign object detecion auxiliary coils: transmitter (left) and receiver (right)

W. Shi, et al. (2021), Integrated Solution for Electric Vehicle and Foreign Object Detection in the Application of Dynamic Inductive Power Transfer, IEEE TVT, vol. 70, no. 11.

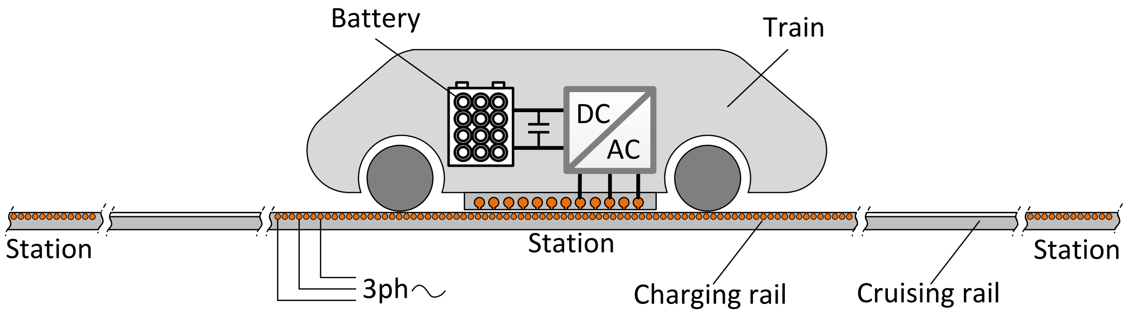
- EV and metallic foreign object detection simultaneously using high frequency injection;
- Complicated detection circuit;
- Unable to detect “living objects”.

Heavy duty vehicle charging



Pantograph and catenary free wireless tram

Wang Z., Wang Y., et al. (2020), “A 600 kW wireless power system for the modern tram,” WOW.



Wireless solution for ultra-high speed vacuum tube train (hyperloop), MSc study at DCE&S

Veltman A., et al. (2019), “Tunnel-Vision on Economic Linear Propulsion?,” in 12th LDIA.
Becetti B. (2021), Design and optimisation of linear doubly fed induction machine for wireless charging operation of novel vactrain system, MSc thesis, TU Delft.

Applications: public transportation, maritime, mining (explosion proof)

- Stray field and EMI
- High cost
- Inter/cross coupling between charging modules
- …

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Questions?

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