eHighway
Sustainable road freight transport

Unrestricted © Mobility GmbH 2019  siemens.com/mobility
Highway electrification for trucks has already started

VIDEO available at www.siemens.com/eHighway
Agenda:
Catenary electrification of heavy trucking corridors

Catenary trucking basics

The sustainable road freight challenge
The case for eHighway
Alternative fuels and drives
Outlook for implementation
How an eHighway for HDVs works

Overhead catenary wires

Wayside substation

Truck equipped with
- active current collector (pantograph)
- and drive train with an electric engine (hybrid or full electric)

https://www.youtube.com/watch?v=zV2yZkRFBK0
eHighway truck technology – from proof-of-concept to field trials

Development of the eHighway vehicle technology

- **2010**
  - 1. Generation
    - Proof of concept

- **2019**
  - 2. Generation
    - Swedish and US Demonstration projects
  - 3. Generation
    - Field trials

**Operations up to 100 km/h possible**
**Connection and disconnection to catenary in motion**
**Recharging of onboard energy storage while driving**
**No limitations for first and last mile**
Catenary electrification is compatible with and complementary to other alternative fuel technologies

<table>
<thead>
<tr>
<th>Truck types</th>
<th>Drive system</th>
<th>On-board source of electricity</th>
<th>Combustion engine</th>
<th>Non-electrical source of energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tractor truck (2 axles)</td>
<td>Parallel-hybrid</td>
<td>Battery (small)</td>
<td>Engine (small)</td>
<td>Diesel</td>
</tr>
<tr>
<td>Tractor truck (3 axles)</td>
<td>Serial-hybrid</td>
<td>Battery (medium)</td>
<td>Engine (medium)</td>
<td>Bio-fuel</td>
</tr>
<tr>
<td>Rigid truck (2 axles)</td>
<td>Full electric</td>
<td>Battery (large)</td>
<td>Engine (large)</td>
<td>CNG/LNG</td>
</tr>
<tr>
<td>Rigid truck (3 axles)</td>
<td></td>
<td>Fuel cell</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rigid truck (4 axles)</td>
<td></td>
<td></td>
<td></td>
<td>H₂</td>
</tr>
</tbody>
</table>

The eHighway hybrid truck can be configured to suit specific applications
Agenda:
Catenary electrification of heavy trucking corridors

Catenary trucking basics

The sustainable road freight challenge

The case for eHighway

Alternative fuels and drives

Outlook for implementation
Trucks are responsible for 2/5 of all transport CO₂
Road freight activity and CO₂ are expected grow >2x by 2050

Source: ICCT - Transitioning to zero-emission heavy-duty freight vehicles (2017) page 1 & 2
Governments striving for rapid cuts in CO\textsubscript{2}, putting truck manufacturers under great pressure to find solutions

Action is urgent - waiting makes the necessary transition shorter and disruptive

We need to put emissions, including those from road freight,

- on a path towards zero
- with minimum total emissions getting there

EU regulation raise risk of fines

- New legislation set 30% reduction target of truck CO\textsubscript{2} by 2030. Failure to meet this will results in big financial penalties
- Daimler Truck wrote “If a manufacturer of 50,000 vehicles missed the target by 10 percent, it would be fined 2 billion euros”. Daimler in 2018 sold 85,000 trucks in the EU and has a global EBIT of 2.75 bn EUR
- Volvo Trucks calculated selling a single ZEV truck can help avoid fines of 820,000 EUR

Source: Figueres et al, *Nature* June 2017
Source: Daimler 2018 & Volvo 2018

*Data from The Global Carbon Project.
Agenda:
Catenary electrification of heavy trucking corridors

Catenary trucking basics
The sustainable road freight challenge

The case for eHighway
Alternative fuels and drives
Outlook for implementation
Surface freight density: 2010
Shows high density of freight on European corridors

Source: ITF - Transport Infrastructure Needs for Future Trade Growth (2016) page 31
Surface freight density: 2050
Shows global need for road freight solutions suitable for corridors

Source: ITF - Transport Infrastructure Needs for Future Trade Growth (2016) page 31

Remember: 2050 needs to be a world with no net green-house gas emissions
Surface freight density: 2010
Analysis of Germany at the center of Europe’s transport network

Source: ITF - Transport Infrastructure Needs for Future Trade Growth (2016) page 31
Long haul road transport is highly concentrated to the highway network, as illustrated by German data.

The analysis of the German road network leads to the following key messages:

1. **60%** of the HDV emissions occur on 2% of the road network (BAB = 12,394 km)

2. The most intensely used **3,966 km** handle **60%** of all ton-km on the BAB

3. **89%** of truck trips after leaving the highway are ≤50 km

The use case logic is analogous to railway:
- Use direct electrification wherever possible
- Catenary on busy routes
- Battery on less busy and short routes
- Elsewhere efuels can play a role

**Image:** HDV density on BAB-network; Source: Verkehr in Zahlen 2012; TREMOD 2012

**Legend:**
- BAB = Federal freeways (12,394 km)
- BS = Federal roads (40,400 km)
- LS = State roads (86,600 km)
- KS = District roads (91,600 km)
- GS = Municipal roads (>420,000 km)

**Source:** BMVI website. Study available here
Siemens eHighway

Electrified road freight transport – contributing to a sustainable transport sector

4,000 km

network of contact lines on German autobahn is recommended by the Federation of German Industries (BDI) as a cost-effective decarbonization measure.

11%

of expected truck toll revenue (Lkw-Maut) would cover the investment in a 4,000 km network.

16,000 €

of fuel savings can be achieved by a 40-ton truck driving 100,000 km on the eHighway (based on 1.25 €/l diesel and 0.15 €/kWh electricity).

> 80%

efficiency level with overhead contact lines.

> 80%

of heavy duty trucks would have an economic incentive to switch to contact line, given that the busiest 4,000 km of autobahn are electrified.

> 7,000,000 t

of CO₂ savings per year if 30% of truck traffic on German highways is electrified and supplied with renewables.

Driving on non-electrified roads (e.g., when overtaking or “first and last mile”) is ensured by the hybrid drive technology of the truck and on-board energy storage.

Braking energy can be recovered.
Agenda:
Catenary electrification of heavy trucking corridors

Catenary trucking basics
The sustainable road freight challenge
The case for eHighway

Alternative fuels and drives
Outlook for implementation
Outlook for battery trucks in heavy duty truck segment not very encouraging in the coming decades

EV share of global vehicle fleet by segment

IEA Global EV Outlook 2019
“Electric trucks reach 0.9 million units in 2030 in the New Policies Scenario and 3.3 million in the EV30@30 Scenario, corresponding to 1% and 3% of the total truck stock. The penetration of electric heavy trucks is higher in medium size than in heavy truck segments.”

Source: IEA Global EV Outlook 2019

Battery leaders’ perspective
Countries leading battery technology development (i.e. Japan, South Korea and China) are not pushing in this direction. Instead they are looking for alternative solutions for the trucks handling the majority of freight (tkm).

Source: BNEF EV Outlook 2019
Zero emission trucks are possible with renewable energy, but efficiency varies greatly

### Electric Road Systems

<table>
<thead>
<tr>
<th>Range</th>
<th>Cost per km</th>
<th>Efficiency WTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 km</td>
<td>19 ct/km</td>
<td>77%</td>
</tr>
</tbody>
</table>

![Diagram of Electric Road Systems]

- **100 kWh**
- **6.0 ct/kWh**

### Hydrogen

<table>
<thead>
<tr>
<th>Range</th>
<th>Cost per km</th>
<th>Efficiency WTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 km</td>
<td>55 ct/km</td>
<td>29%</td>
</tr>
</tbody>
</table>

![Diagram of Hydrogen Pathway]

- **99 kWh**
- **15 ct/kWh**

### Power-to-Gas

<table>
<thead>
<tr>
<th>Range</th>
<th>Cost per km</th>
<th>Efficiency WTW</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 km</td>
<td>70 ct/km</td>
<td>20%</td>
</tr>
</tbody>
</table>

![Diagram of Power-to-Gas Pathway]

- **2.7 kWh/km**
- **18 ct/kWh**

1) Including storage

Source: German Ministry of Environment
ICCT* sees electrification with contact lines as crucial for reaching deep decarbonization of HDVs

![Graph showing lifecycle CO₂ emissions over vehicle lifetime and per kilometer by vehicle technology type.]

**Figure 6.** China, Europe, and U.S. lifecycle CO₂ emissions over vehicle lifetime (left axis) and per kilometer (right axis) by vehicle technology type.

Source: ICCT - [Transitioning to zero-emission heavy-duty freight vehicles](https://www.icct.org) (2017) page 26

* ICCT = International Council of Clean Transportation
System cost assessment shows that efficiency of energy supply plays a far greater role than vehicle and infrastructure costs.

Key assumptions:
- Length of electric network: 4,000 km; Infrastructure costs: 2.2 million €/km; Maintenance 2.5% of investment per year
- Additional vehicle costs: per today 50,000 € / truck; per 2050 19,000 € per truck; share of direct electric traction: 60% in 2050

- Business case for zero emission need to assess several factors, in addition to vehicles
- It is equally important to assess cost of refueling (quickly).
- Especially cost of energy appear to impact total system cost significantly

• Contact line trucks are the cheapest way to decarbonize the German road freight sector!
• Importance of superior energy efficiency will only grow in future

Source: ICCT - Transitioning to zero-emission heavy-duty freight vehicles (2017) page 23
Agenda:
Catenary electrification of heavy trucking corridors

Catenary trucking basics

The sustainable road freight challenge

The case for eHighway

Alternative fuels and drives

Outlook for implementation
German field trials in 2019 are a necessary near term step for the development of the system

**Information and routing**

**Federal State of Hesse**
- Infrastructure project awarded to Siemens
- Track length / Amount of trucks: 5km / 5
- Construction: April-Nov 2018
- Demonstration: Official start **May 7 2019**

**Federal State of Schleswig Holstein**
- Infrastructure project awarded to Siemens
- Track length / Amount of trucks: 5-6km / 5
- Construction: Started Oct 2018
- Demonstration: Start in 2019

**Federal State of Baden-Wuerttemberg**
- Tender published Nov 2018
- Track length / Amount of trucks: 5-6km / 5
- Customer’s targeted start of Demonstration: 2020

Project homepage: [ELISA](#)  [FESH](#)  [eWayBW](#)
Field trial near Frankfurt: Infrastructure construction with minimum disruption, delivered on time and on budget

Many pictures available at: https://mobil.hessen.de/verkehr/elisa/baustellen-news
Maintenance & Operation
For electric and road infrastructures

Many similarities to already known aspects of poles, guard rails and contact lines.

**Maintenance of road infrastructure**
- Ploughing of snow
- Grass cutting
- Once a year

**Maintenance of electrical infrastructure**
- Long lasting (cf. road surface)
- Visual inspections

Integration into Traffic Control Center
Scania will deliver 15 trucks for German field trials
This represents the third generation of eHighway trucks

Latest Scania truck and third generation of pantograph
See Scania press release
Private data on geographical distribution of truck energy consumption

- Can tell us what a **optimal ERS network** should look like

- And can **pinpoint the clusters** where the deployment should begin. This is of crucial importance.
Independent institutes in Germany have identified early shuttle applications and how to scale up to a full system

**Selected recommendations**

- Suitable first applications are on routes around Hamburg, in Ruhr area and southern Germany
- With a comprehensive network of catenaries it is possible that 65% of the vkm by heavy duty trucks could be commercially viable to switch to catenary-trucks
- Using electricity with a carbon footprint of 412 g/ kWh this would help reduce the total GHG emissions from heavy duty trucks in Germany by 17%
- Without a transparent development plan for the infrastructure the risks faced by OEMs and trucking companies during the transitions are too big

**Identified routes based on freight goods flow suitable for catenary systems usage**

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>BAB</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Essen/Gladbeck – Dreieck Heumark</td>
<td>A3/A2</td>
<td>85 km</td>
</tr>
<tr>
<td>2</td>
<td>Düsseldorf – Kreuz Kamen</td>
<td>A46/A1</td>
<td>81 km</td>
</tr>
<tr>
<td>3</td>
<td>Neckarsulm - Stuttgart</td>
<td>A81/A6</td>
<td>57 km</td>
</tr>
<tr>
<td>4</td>
<td>Hamburg – Lübeck</td>
<td>A1</td>
<td>49 km</td>
</tr>
<tr>
<td>5</td>
<td>Krefeld – Köln</td>
<td>A57</td>
<td>45 km</td>
</tr>
<tr>
<td>6</td>
<td>Schwerte – Lüdenscheid-Süd</td>
<td>A45</td>
<td>32 km</td>
</tr>
<tr>
<td>7</td>
<td>Essen – Dortmund</td>
<td>A40</td>
<td>26 km</td>
</tr>
<tr>
<td>8</td>
<td>Kreuz Kamen – Hamm-Uentrop</td>
<td>A2</td>
<td>23 km</td>
</tr>
<tr>
<td>9</td>
<td>Pfaffenhofen – München</td>
<td>A9</td>
<td>20 km</td>
</tr>
<tr>
<td>10</td>
<td>Bremen – Hamburg</td>
<td>A1/A261</td>
<td>81 km</td>
</tr>
</tbody>
</table>

German Transport Ministry is supporting overhead contact line shuttles as part of their climate action plan

- The German federal transport ministry (BMVI) support was listed among recently announced measures for transport decarbonization.

- Road freight is the area where 1/3 of the CO$_2$ savings are expected to be achieved, making it biggest contributing segment to the overall reductions from transport

<table>
<thead>
<tr>
<th>Nutzfahrzeuge</th>
<th>CO$_2$-arme Lkw auf die Straße bringen</th>
<th>CO$_2$-Flottenregulierung (auf EU-Ebene)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kaufprämie für Nutzfahrzeuge mit alternativen Antrieben</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CO$_2$-Differenzierung der Lkw-Maut</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tank- und Ladeinfrastruktur ausbauen</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Infrastrukturaufbau und -förderung (z.B. Wasserstofftankstellen, Mega-Charger, Oberleitungen auf Pendelstrecken)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>17-18 Mio. Tonnen</th>
</tr>
</thead>
</table>

- German government’s climate action plan calls for 1/3 of truck traffic to be electric or using eFuels by 2030. Supporting this goal is an infrastructure plan including for catenary systems

Source: [BMVI website](#) and [Government plans](#) (announced on Oct 09, 2019)
A European and harmonized solution could take shape already today - enabling zero emission trucking on TEN-T corridors by 2050

**UK**
- £ 400m invest in charging infrastructure (PEV) announced
- DfT: dynamic electrification of HDV supports zero emission pathway

**Germany**
- 2018-2022: Three fields trials on motorways A1 and A5 and national road B462 publicly funded by BMU € 45.3m
- Extension of catenary network part of climate protection program 2030

**Austria**
- Federal Environment Agency considers catenary solution high potential intensity in order to abate 2.7m t CO₂ emissions

**Sweden**
- 2km Demonstration project on E16 in operation since 2016
- Start / roll-out of national ERS by 2022

**Hungary**
- Minister of Technology & Innovation announced to cooperate in third German Field trial in Baden-Wurttemberg

**International**
- USA: UC Davis study outlines advantages of catenary solution compared to alternative propulsion solutions for trucks
- China: Deputy’s Minister for Transport showed serious interest into the technology
- India: Minister for Road Transport & Highways Nitin Gadkari proposes plan to electrify India’s highways with catenary system

Interest in catenary solution exists
Study with regard to catenary solution for HDV exists or under preparation
Catenary solution: demo / field trial realized or in preparation
Back ups – Sector coupling
eHighway offers efficient and low cost electricity supply, thanks to smooth load profiles and high connection voltage

Detailed load profiles from BEV, PHEV and eHighway, and supply though conventional and renewable generation in Germany

- Flexible distributed loads are essential for an energy supply based mainly on fluctuating renewable based generation
- The charging of BEV and PHEV vehicles leads to daily peak loads. eHighway exhibits a smoother load profile.
- eHighway-enabled trucks using hybrid drives (e.g. combustion engine using sustainable biofuels) can contribute to system peak load reduction (active load management/deferrable load).
- Grid connected eHighway truck systems enable a more efficient use of energy.

Source: [http://www.energieversorgung-elektromobilitaet.de/Kernaussagen.html](http://www.energieversorgung-elektromobilitaet.de/Kernaussagen.html)
Back ups –
Experiences so far and outlook
Oberleitung auf der Autobahn

Der Allgemeine Deutsche Automobil Club (ADAC) hat 18 m members and is Europe’s largest car club.

“We have a very positive view on the field trials” – Wolfgang Herde, Transport expert for the local ADAC chapter

“If it can work here [on the busy A5], it will work everywhere” – Wolfgang Herde, Manager for the project at Hessen Mobil

Source: https://www.adac.de/_ext/motorwelt/ADAC-Motorwelt-7-8-2019.pdf
Individual trucking companies are also excited about the technology

“The e-road technology looks very promising and we’re very excited to learn more about how it works in practice” - Kerstin Seibert, co-owner of Spedition Schanz.

“I’d read that Spedition Schanz would participate in the pilot project and immediately became interested. Electromobility is an exciting development – that’s the future and I want to be part of it.” - Thomas Schmieder, truck driver.

Back ups – Economics
ICCT* sees electrification with contact lines as crucial for reaching deep decarbonization of heavy duty vehicles

- TCO lower than diesel, and most economical use of renewable electricity

Figure 4. Cost of ownership in China, Europe, and the United States for each long-haul heavy-duty truck technology for a vehicle purchased in 2015-2030 broken down by capital cost, maintenance cost, and fuel cost.

Source: ICCT - Transitioning to zero-emission heavy-duty freight vehicles (2017) page 20

* ICCT = International Council of Clean Transportation
German industry association BDI recommends 4.000 to 8.000 km of overhead catenary lines as a cost-effective climate action for HDVs

Background
• BDI published in 2018 an independent report looking at all sectors of the economy
• It investigated the most cost effective ways to reach German climate goals: -80% and -95% GHG
• Involved 68 BDI-member associations and companies, 200 industry experts and 40 workshops

Major findings
• Reaching the 80% reduction is possible by pushing existing technologies to the max. Has economically positive effects, even if Germany acts alone.
• Reaching the 95% reduction goal touches the limit of what can be expected from technology and citizens. Only in joint action with G20 economies would this be economically manageable

Transport highlights
• Shift to rail leads to an increase by 88% of ton-km of freight activity on rail by 2050
• No additional biofuels for transport, because other sectors will be prepared to pay more
• PtX only in 95% scenario. Imported from Middle East & North Africa, and it will still be very pricey

eHighway
• Building overhead catenary is the cheapest solution for HDVs, despite high infrastructure costs.
• Recommends building 4.000 km overhead contact line in the 80% scenario and 8.000 km in 95%
• Based on GER perspective. EU solution brings large synergies and is even more cost-effective
• Investment decision needs to be made by 2025, leading to first 400 km in operation by 2028.

Investment in eHighway network covering 4,000 km of Autobahn could be financed by 11% of annual expected truck toll revenue

*average annual toll revenues or infrastructure investments during the indicated period

**the rising infrastructure costs per kilometer with increasing network expansion (from the start to the final expansion network) are caused by the assumed increasing performance of the infrastructure.

German government changed the toll scheme in 2018 and now expects annual truck toll revenue to exceed EUR 7.2bn.

Source: Handelsblatt
## Translated Table 7 from German Transport Ministry (BMVI) report

<table>
<thead>
<tr>
<th>Components</th>
<th>Basis for calculations</th>
<th>Costs (EUR/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid connection point</td>
<td>Ca. 15,000 EUR per connection. At a pattern of a connection point every 3 km leads to 5,000 EUR/km</td>
<td>5,000,--</td>
</tr>
<tr>
<td>Feed line from grid connection point to substation along the route</td>
<td>Ca. 200 EUR per m of cable trench (underground, built up area), ca. 100 EUR per m cable; At an average of 2.5 km connection length leads to 750,000 EUR per connection. At a pattern of a connection point every 3 km leads to 250,000 EUR/km</td>
<td>250,000,--</td>
</tr>
<tr>
<td>Substation</td>
<td>Ca. 300,000 EUR per MVA (incl. communication and safety technology); A 6 MVA power rating results in costs of 1,8m EUR per substation; At a pattern of a connection point every 3 km leads to 0,6m EUR/km</td>
<td>600,000,--</td>
</tr>
<tr>
<td>Poles</td>
<td>Ca. 10,000 EUR per pole (incl. cantilever and foundations); A pole distance of 50m results in costs of 400,000 EUR per km (covering both road directions)</td>
<td>400,000,--</td>
</tr>
<tr>
<td>Catenary (contact line)</td>
<td>Ca. 300 EUR per m, e.g. 600,000 EUR per km (covering both road directions)</td>
<td>600,000,--</td>
</tr>
<tr>
<td>Guard rails</td>
<td>Ca. 100 EUR per m; under the assumption that the entire route needs to be equipped, costs are 200,000 EUR/km (covering both road directions)</td>
<td>200,000,--</td>
</tr>
<tr>
<td>Planning, Procurement and Project management</td>
<td>Ca. 10% of the investment costs</td>
<td>205,000,--</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>2,260,000,--</strong></td>
</tr>
</tbody>
</table>