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Options for Zero Carbon Transport

Nick McCarthy

Technical Specialist

nick.mccarthy@cenex.co.uk

Introduction

- Who is Cenex?
- Defining emissions
- UK Zero emissions capability
- Customer attitudes
- Demonstration projects

Introduction to Cenex

- Established in 2005 as the UK's first Centre of Excellence for Low Carbon and Fuel Cell technologies.
- Cenex has developed a UK-leading reputation for low carbon vehicle and infrastructure analysis and fleet deployment support for ultra-low carbon alternative fuel use, including:
  - Electricity
  - Biomethane
  - Hydrogen
- Today Cenex operates as an independent, not-for-profit, RTO and consultancy specialising in the delivery of R&D projects, supporting innovation and market development.

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Why Low Carbon (Low Emission) Vehicles?

- **Low Carbon**
  - Sustainability (climate change, economic competitiveness)
  - Energy (security, diversity)

- **Air Pollution Impact**
  - Health
  - Environment
  - Economy

- **Government Policy**
  - “Stick and carrot” policy framework for motor industry
    - European regulation
    - Local city policies
    - Innovation policy framework supporting supply chain capability development

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Pathways to Low Emission Vehicles

Current Baseline

- Reduce Carbon in Fuel
- Improve Vehicle Energy Efficiency
- Vehicle Light-weighting
- Connected Vehicle (ITS)

Vehicle Meeting Carbon Targets

For road transport three alternative energy pathways are actively promoted by interested parties.

- Internal Combustion Engine (+ Plug In + Bio-fuels)
- Advanced Battery Electric Vehicles
- Hydrogen Fuel Cells

Critical Success Factors

- *Electrified powertrain*
- *Ability to leverage renewable energy sources for fuel*
- *Zero emissions at tailpipe*

Defining 'Zero Emissions'

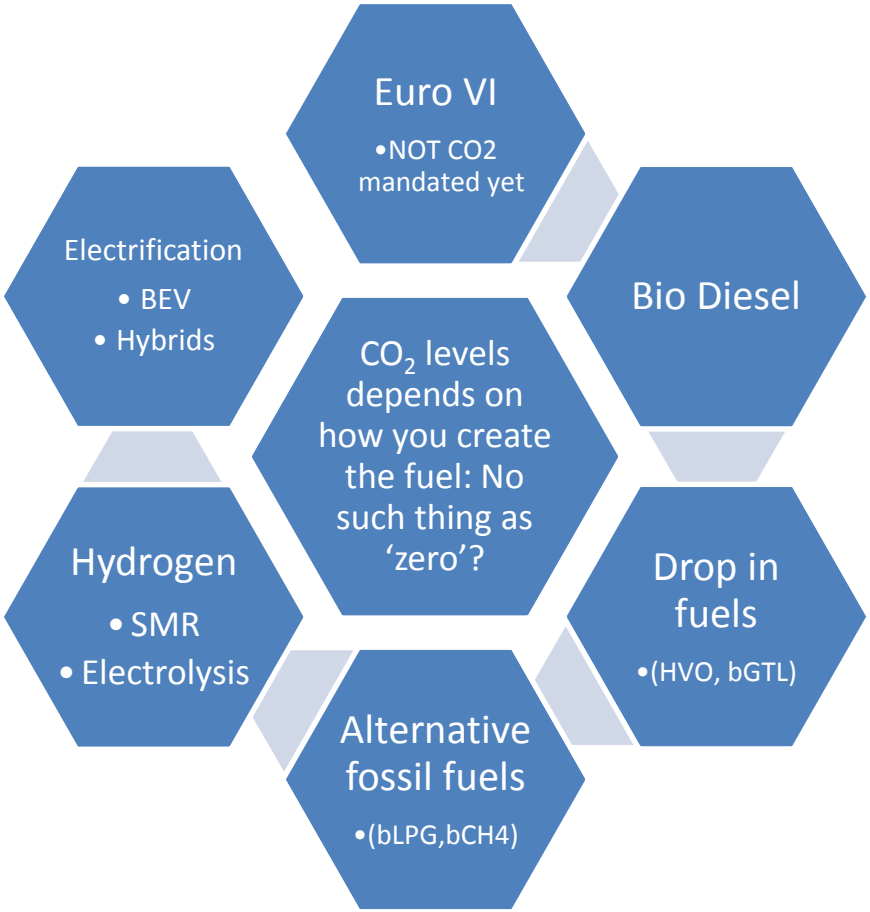
- The point of measurement is critical
  - **Tailpipe – Urban NOx and particulate emissions**
  - Tank to wheel – UK guidance for many reported standards
  - Well to wheel - more progressive fleets report this
  - **Life cycle analysis – global, long term impact**
    - Academics only?
- We are not all working to the same standard
- Well to wheel of the fuel easier than life cycle analysis of entire vehicle system

CO_2e

- National statistics recommended 0.48 kg of CO2e/kWh for BEVs
- Depends on time of year and time of day
- http://www.gridwatch.templar.co.uk/

NO_x & Particulates, Unburnt hydrocarbons, CO

- Significant public health issue
- Urban NOx and particulates driving tail-pipe measurements at the moment


Euro VI
•NOT CO2 mandated yet
Electrification
• BEV
• Hybrids
Bio Diesel
CO_2 levels depends on how you create the fuel: No such thing as 'zero'?
Hydrogen
• SMR
• Electrolysis
Drop in fuels
•(HVO, bGTL)
Alternative fossil fuels
•(bLPG,bCH4)

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Hydrogen Refuelling

Where will you find it?

UK
14 stations open by April 17[1]

UKH2Mobility recommended a national network of 1,150 HRS by 2030[2]

Hydrogen Mobility Europe

Sources:
1) www.H2ME.eu (2017), 2) www.ukh2mobility.co.uk (2015)

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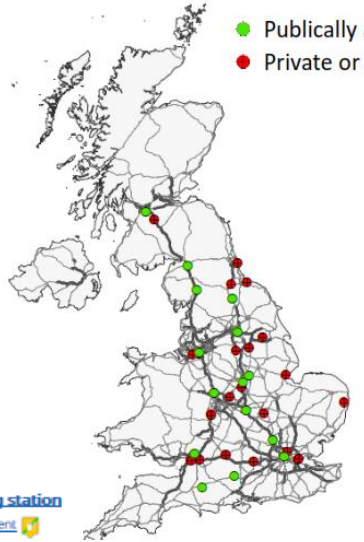
Gas Refuelling

- 16 publicly accessible stations in the UK[1,3] and additional private stations
- c3,090 publicly accessible stations across Europe[2]

Where will you find it?



LNG filling station
LNG bio-content

CNG filling station
CNG bio-content

Potential for >350 stations in UK by 2030 for optimistic scenarios[3] for vehicle market penetration (van, truck, bus)

Sources:

1) www.gasvehiclehub.com/refuelling-facility (2017)

2) cngeurope.com (2017)

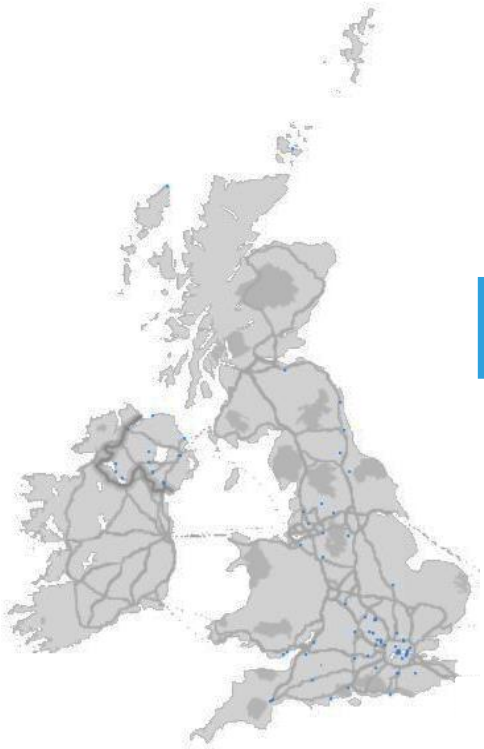
3) Transport Energy Roadmap, LowCVP\Element Energy (2015)

What is it used for?

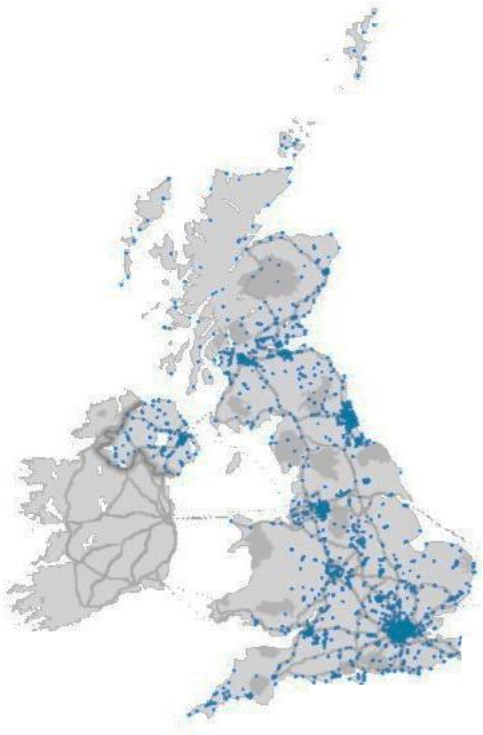
Cars, LCVs (mainland Europe), Vans, Buses & Trucks (pan-Europe)

EVSE Infrastructure Growth – National Charge Point registry

2012



2017

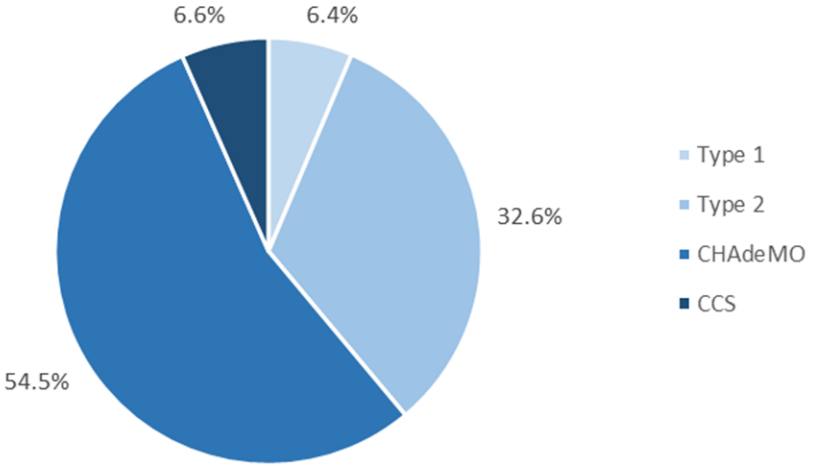


Connector Type Market Share

CCS

Type 1

CHAdeMO



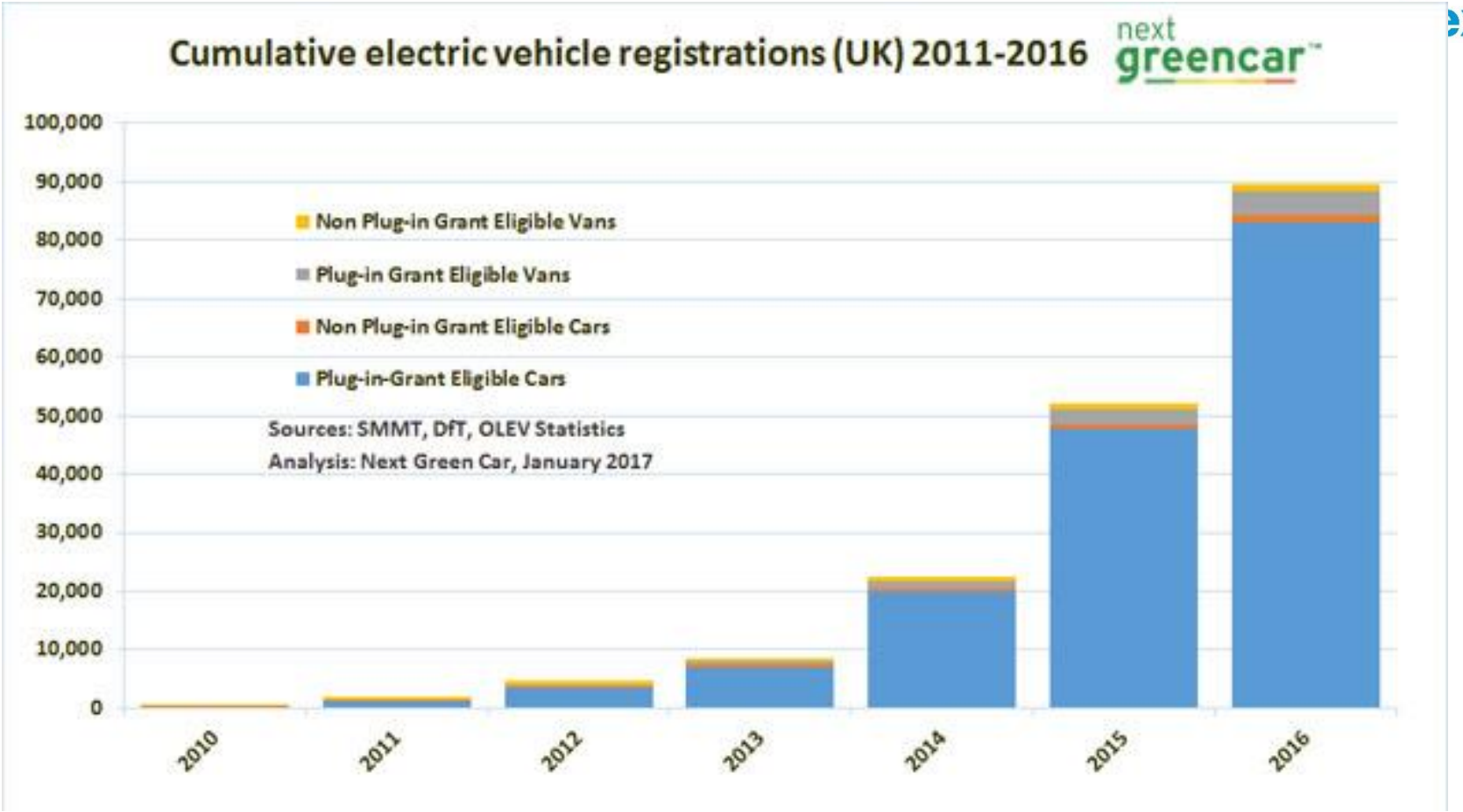
Type 2

How many EVS could the UK Support ?

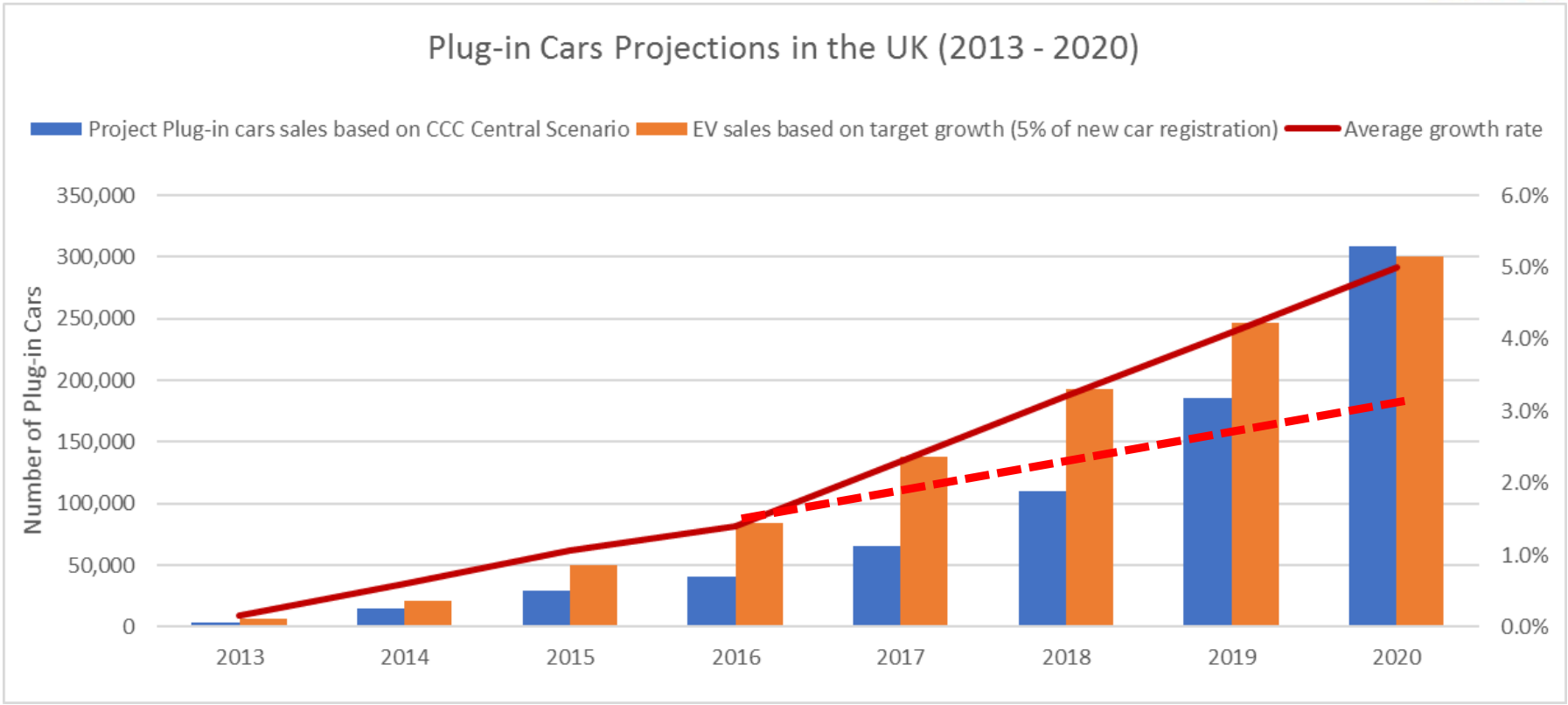
- 31.7 million cars in the UK (2016)
  - Average C-segment saloon (Astra/Focus/Golf)
  - travels 24 miles/day (38.2km) (Ricardo 2010)
  - Requires **12 kWh/day** from the grid

- Without use of smart charging to manage grid loading, capacity could be limited to as few as **1 million** vehicles

- With smart overnight charging, generation capacity remains unchallenged at much greater numbers


Cumulative electric vehicle registrations (UK) 2011-2016
next greencar
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Non Plug-in Grant Eligible Vans
Plug-in Grant Eligible Vans
Non Plug-in Grant Eligible Cars
Plug-in-Grant Eligible Cars
Sources: SMMT, DfT, OLEV Statistics
Analysis: Next Green Car, January 2017
2010
2011
2012
2013
2014
2015
2016

EVSE Infrastructure Growth



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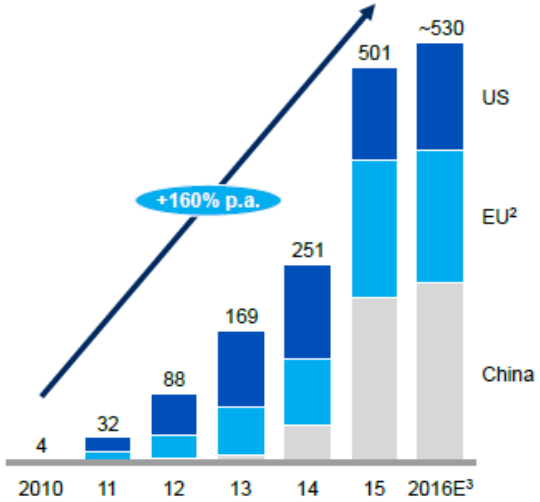
Rapid decreases in battery prices have helped accelerate EV sales, especially in Europe and China

Average battery pack price
$ per kWh

US, EU, and China electric vehicle sales[1]
Units, thousands



1 Plug-in hybrid electric vehicles and battery electric vehicles; excludes low-speed vehicles and hybrid electric vehicles without a plug
2 Includes Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, and the UK
3 Extrapolated based on Q1-Q3 2016 IHS data and assuming continued growth in all three markets in Q4
SOURCE: IHS, Bloomberg, New Energy Finance

Anecdotal evidence

- In certain key location or market sectors, electrification is not cost effective due to cost of grid reinforcement (e.g. new substations and cabling):
  - Parcel delivery company (London)
  - Refrigerated transport company (London)
  - Heavy plant hybridisation and electrification

What Zero emission vehicles (tailpipe) are on the market?

Electric Vehicle – Examples of Cars & Vans

BMW i3 (60 Amp-h battery)

Out Now (2014)

£ Cat. 1	26.5k
Seats	5
Range	118 EV
AC	4 h 4.6 kW
DC	T2 80% in 30 min
Bat	22 kWh
Con	CCS, T2

Mercedes B-Class

Out Now (2014)

£ Cat. 1	28.5k
Seats	5
Range	124 EV
AC	9-21 (3-4) h 13A (16A)
DC	unknown
Bat	28 kWh
Con	T2

VW e-golf

Out Now (2014)

£ Cat. 1	27k
Seats	5
Range	118 EV
AC	8 h
DC	CCS 80% in 30 min
Bat	24 kWh
Con	CCS & T2

Nissan Leaf (83 Amp-h battery)

Out Now (2016)

£ Cat. 1	20-22k
Seats	5
Range	155 EV
AC	5 h
DC	CHA 80% in 30 min
Bat	30 kWh
Con	CHA & T1

Renault ZOE

Out Now (2013)

£ Cat. 1	16k
Seats	5
Range	150 EV
AC	4 h (7kW) / 1 h (22kW)
DC	T2 80% in 30 min
Bat	22 kWh
Con	T2

Tesla Model X (250 Amp-h battery)

Out Now (2016)

£ Cat. 1	83k
Seats	7
Range	303 EV
AC	14 h
AC	Rapid AC 80% in 30 min
Bat	90 kWh
Con	T2 & TS

Nissan e-NV200

Out Now (2014)

£ Cat. V	17k (van) or 23k (taxi)
Seats	2 (van), 5 (taxi)
Pld	728 kg
Range	110 EV
AC	4 h
DC	CHA 80% in 30min
Bat	24 kWh
Con	CHA & T1

Citroen Berlingo électrique

Out Now (2013)

£ Cat. V	21k
Seats	2 (van)
Range	106 EV
Pld	636 kg
AC	12 h
DC	CHA 80% in 35min
Bat	22.5 kWh
Con	CHA & T1

BD Otomotiv eTraffic

Out Now (2012)

£ Cat. V	Unknown
Seats	3 (van)
Range	100 EV
Pld	790 kg
AC	8 h
DC	CHA 80% in 45min
Bat	53 kWh
Con	CHA & T1

Electric Vehicle – Examples of Bus & Taxi

BYD K9 ebus (12 metres)

£	315k-475k
Seats	31 (68 Total capacity)
Range	186 EV
AC	6 h normal charge
AC	3 h fast charge
Bat	380 kWh
Con	T2

Out Now (2010)

Volvo 7900 (12 metres Hybrid)

£	350k-400k
Seats	36 (95 Total capacity)
Range	4.4 EV, 470 diesel
AC	6 mins
Bat	19 kWh
Tank	205 litres
Engine	5 litre diesel
Con	Roof charging

Out Now (2014)

Metrocab taxi REEV

Taxi use – 348 miles out 2017:

- Hackey carriages
- Private hire (Uber)

Types of H2 vehicles in the UK & EU today

Hyundai ix35

£	53k
Seats	5
Range	369 miles
H2	5.6 kg (2 tanks)
H2 P	700 bar
Bat	24 kWh
FC Stack size	100 kW

Out Now (2014)

Toyota Mirai

£	61k
Seats	4
Range	312 miles
H2	5 kg (2 tanks)
H2 P	700 bar
Bat	1.6 kWh
FC Stack size	113 kW

Out Now (2016)

Honda Clarity

£	42k
Seats	5
Range	435 miles
H2	5 kg (2 tanks)
H2 P	700 bar
Bat	1.6 kWh
FC Stack size	100 kW

Out Now (2016)

Symbio RE Kangoo

£	Vehicle +18k (+ 60/month battery/H2 rental)
Seats	2
Range	100 EV, 250 EV-H2 miles
H2	1.8 kg
H2 P	350 bar
Bat	22kWh
FC Stack size	5kW

Out Now (2015)

ULEMCo dual fuel H2 - diesel Ford Transit

£	-
Seats	2
Range	95 - 135 miles
H2	3.2 kg (2 tanks)
H2 P	350 bar
Engine size	2.2 litre
Engine type	Euro 5

Out Now (2015)

Symbio RE Maxity

£	Vehicle +40k
Seats	2
GVW	4.5 tonne
Range	120 miles
H2	4 kg (2 tanks)
H2 P	350 bar
Bat	42 kWh
FC Stack size	20 kW

Out Now (2015)

Types of H2 vehicles in the UK & EU in the future

Audi A7 H-Tron Quattro Hybrid FCREx

Debut in 2017

£	TBA
Seats	5
Range	31 miles EV, 370 miles EV + FCREx
H2	6 kg (3 tanks)
H2 P	700 bar
Bat	1.8 kWh
FC Stack size	110 kW

Mercedes-Benz GLC F-CELL Hybrid FCREx

Debut in 2018

£	TBA
Seats	5
Range	31 miles EV, 310 miles EV + FCREx
H2	4 kg (2 tanks)
H2 P	700 bar
Bat	9 kWh
FC Stack size	100 kW

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Examples of potential EV reinforcement points from other automotive megatrends

Autonomous

- EV vehicle architecture has a central control unit to facilitate autonomy
- Autonomous charging could add convenience

Connected

- A connected EV ecosystem could increase the convenience of charging
- Connected car grid solutions could enable cost-effective load balancing

Automotive industry megatrends

Shared

- Greater annual driving distances can offer a decisive TCO edge for EVs
- Some consumers may prefer access to multiple vehicle types over ownership (including EVs)

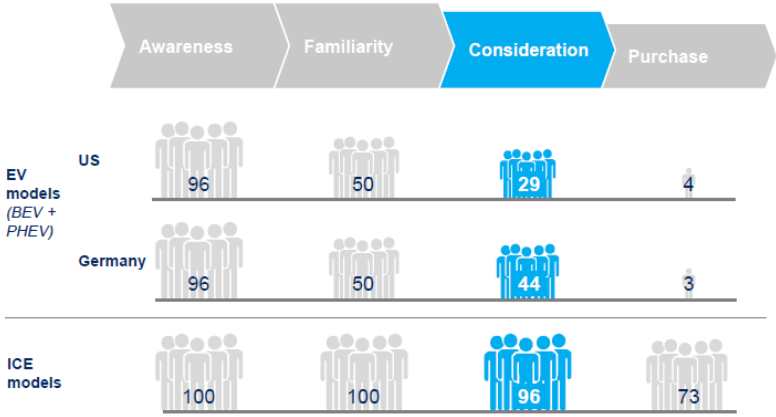
Electrified

- Tightening emissions efficiency rules make EVs necessary to meet standards
- Lower battery costs improve EV economics

SOURCE: McKinsey Sustainable Mobility Initiative

Percentage of responses, US and Germany, 2016

Percentage of consumers that identify themselves at each purchase funnel stage



SOURCE: McKinsey Sustainable Mobility Initiative – 2016 Electrified Vehicle Consumer Surveys

Why do demonstration projects?

- Prove range & durability of new emerging technologies
- Put vehicles in the hands of real customers
- Begin to form a refuelling network – even with a mature vehicle technology an infrastructure is needed before people will invest

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UK & EU ongoing projects – 2015 to 2022

Hydrogen Mobility Europe

Project Name	Dates	No. Vehicles	No. HRS	Locations
H2ME	2015-2020	Month 12: 40 FCEV cars & 59 FC REx vans By 2020: 325 FCEVs	Month 12: 1 HRS By 2020: 29 HRS	UK, France, Germany, Denmark, Norway, Sweden
H2ME2	2016-2022	By 2022: 1,200 FCEV cars & vans	By 2022: 20 HRS	UK, France, Germany, Denmark, Norway, Sweden, Holland

H2 Refuelling Infrastructure

- Hydrogen refuelling station planning and commissioning are a choke point
  - Local planning
  - Regulations - Codes & standards
  - Hydrogen Supply
- Unified ISO standards recently published include local authority ‘check lists’ for approval:
  - **PD ISO/TS 19880-1:2016** (Gaseous hydrogen — Fuelling stations: Part 1: General requirements)
  - **SAE J2601** (Fuelling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles)
  - **SAE J2799** (Hydrogen Surface Vehicle to Station Communications Hardware and Software)
- Full international standard for Hydrogen refuelling facilities on forecourts to be published in 2017

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Preparation >>> Siting >>> Planning >>> Commissioning >>> Open

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Country	Location	GA	Status
France	Lyon	H2	Prep. (2018)
	Valence	H2	TBC
	Montelimar	H2	
	Bordeaux	H2	Prep. (2018)
	Nantes	H2	Prep. (2018)
	Paris Versailles	H2	Prep. (2017)
	Paris Ouest (La defense)	H2	Prep. (2020)
	Paris Nord (Roissy-CDG)	H2	Prep. (2018)
	Nancy	H2	TBC
	Paris Sud (Orly)	H1	Comm. (2017)
	Rodez	H1	Comm. (2017)
	Sarreguemines	H1	Open
The Netherlands	The Hague	H2	Planning (TBC)

Country	Location	GA	Status
UK	London / Beaconsfield	H1	Planning (2017)
	London / Gatwick	H1	Plan/Comm. (2017)
	Aberdeen	H1	TBC
	Swindon	H2	Prep/siting Confirmed: Swindon & Birmingham. Investigating 6 more sites (2017-18)
	Birmingham	H2	
	UK South England	H2	
Denmark	Kolding	H1	Open
Sweden	Sandviken	H1	Open
	Mariestad	H2	Open
	Stockholm	H2	Siting
Iceland	Reykjavic	H2	Siting (2018)
	sites tbc	H2	Prep/Siting (2018)
	sites tbc	H2	Pre/Siting (2018)
Norway	Ryen	H2	Site/planning (TBC)
	Hvam	H2	Site/planning (TBC)
	Hovik	H1	TBC

Results from Projects – H2ME & H2ME2

Hydrogen Mobility Europe

40 FCEV cars &
57 FC REx vans
By 2020: 325 FCEVs
By 2022: 1,200
FCEV cars & vans

Vehicles

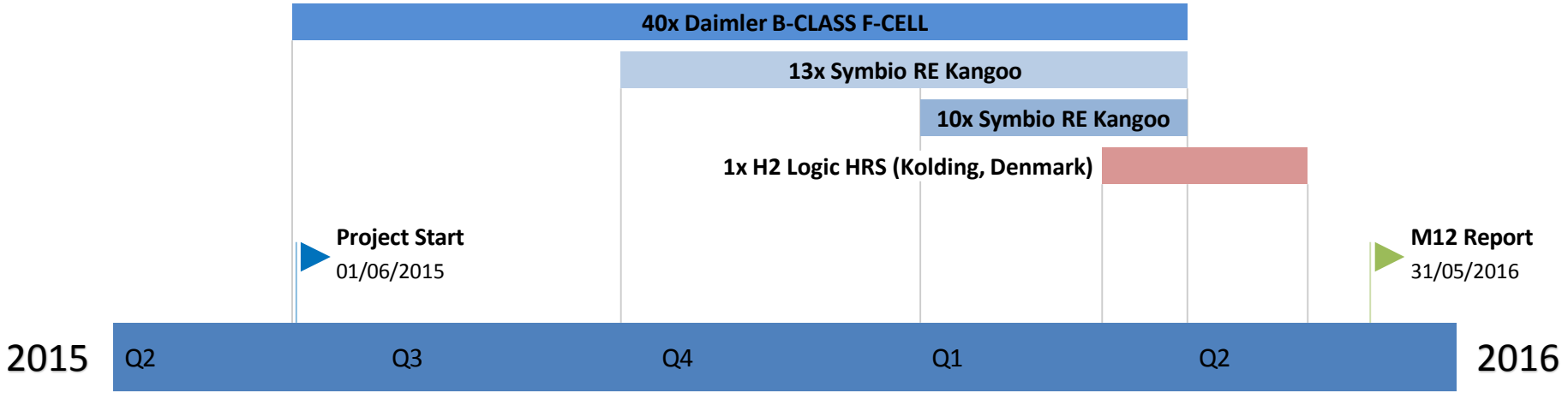
- **Miles driven: To date -**
  ~278,000 miles (448,079 km)
- **Fuel efficiency:**
  Vans - 100km/kgH2
  Cars - 103km/kgH2
- **Range:**
  Vans - 400 km (250 miles)
  Cars - 380 km (235 miles)
- **Reliability:** *much higher that 98%, TBC.*

Refuelling stations (HRS)

- **Amount of H2 dispersed:**
  To date - 5,676 kg
- **Time of day refuelled:** *peaks 18:00 to 05:00 and 11:00 to 12:00*
- **Reliability:** Stations have been available for 98% (downtime from un-scheduled downtime due to Compressor/Pump) of the trial so far and reliability has been rated as good

Results from Projects – H2ME

- **M12 (First Year) H2ME Milestone Report Summary – June 2015 to May 2016:**
  - **40** Daimler B-CLASS F-CELL fuel cell passenger cars were operated by variety of organisations in Germany as company fleet vehicles.
  - **23** Symbio RE Kangoo range extended fuel cell vans operated as work vehicles in a number of fleets and locations in France.
  - **One** NEL Hydrogen HRS was deployed in Kolding, Denmark from March 2016 to refuel existing fuel cell vehicles.



H2ME 1 Fleet Daily Trip Distance

- The overall avg. distance travelled per day was found to be **36.5 km**.
- The avg. distance travelled per day for the Symbio RE fleet ranged from ca. **27-47 km**.
- As a percentage, the overall avg. amount of H2 refuelled per event by the **10%** of the for the Symbio RE fleet was **0.2 kg**, or **11%** of the **1.8 kg** tank capacity. **Note trend**

- The overall avg. trip length was found to be **14.9 km**. Comparable to German national trip data – avg. car trip length during the working week was approximately **15 km** (1).
- As a percentage, the overall avg. amount of H2 refuelled per event by the **10%** of the FCEV Daimler fleet was **2.18 kg**, or **59%** of the **3.7 kg** tank.

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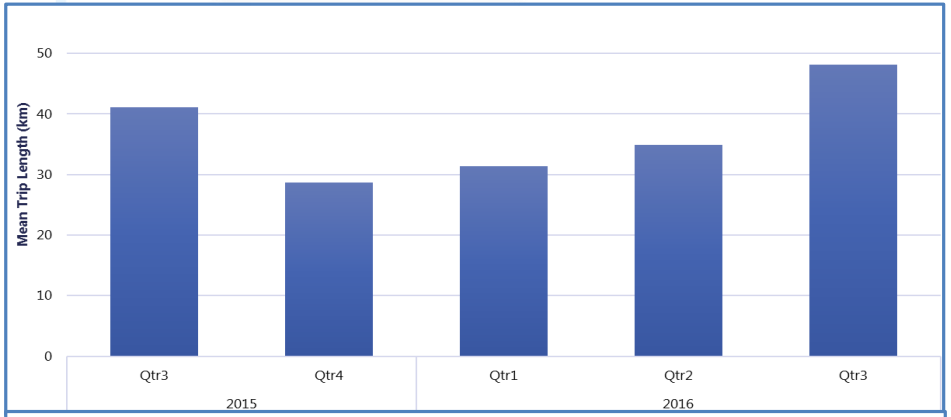
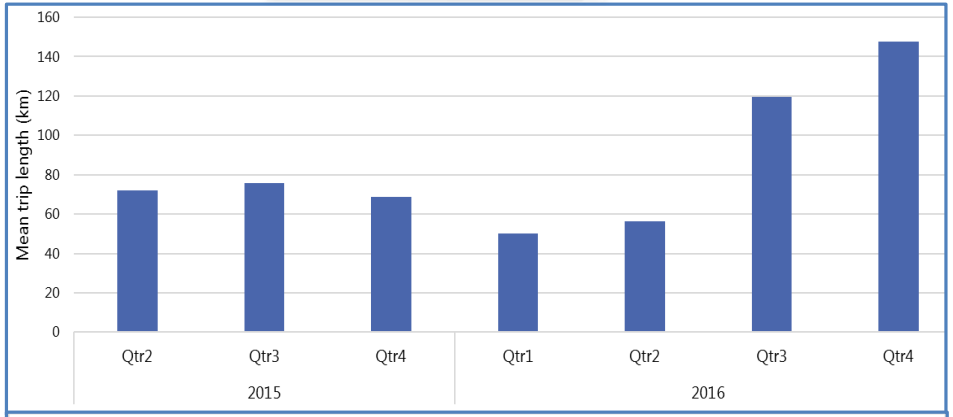
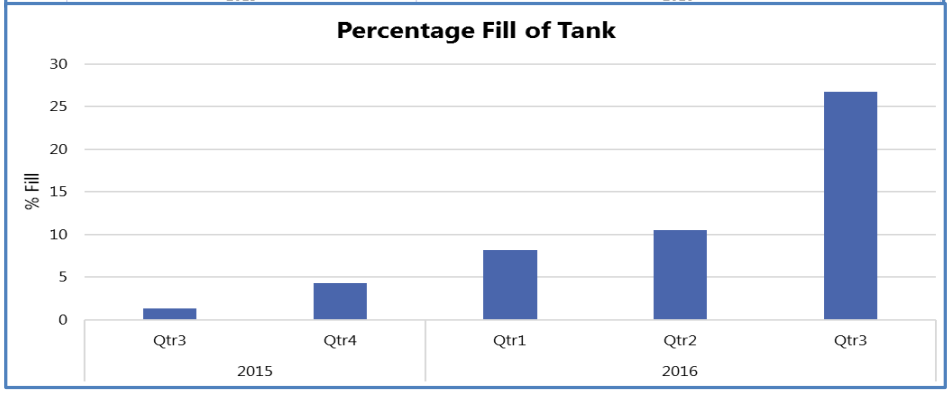
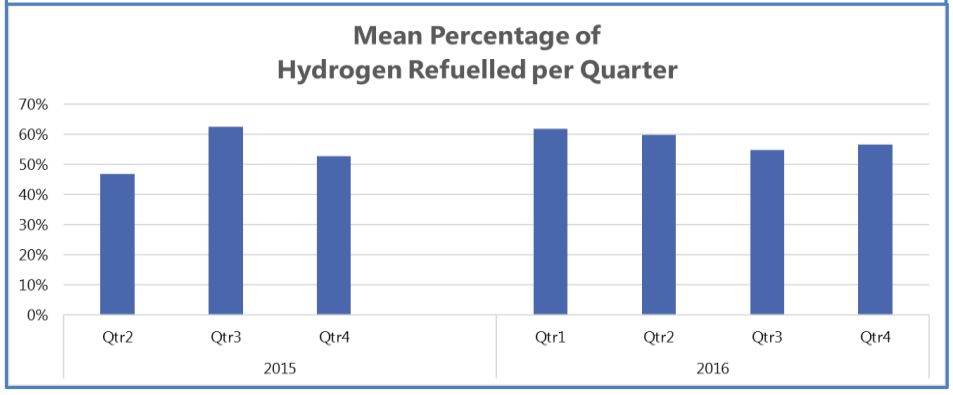








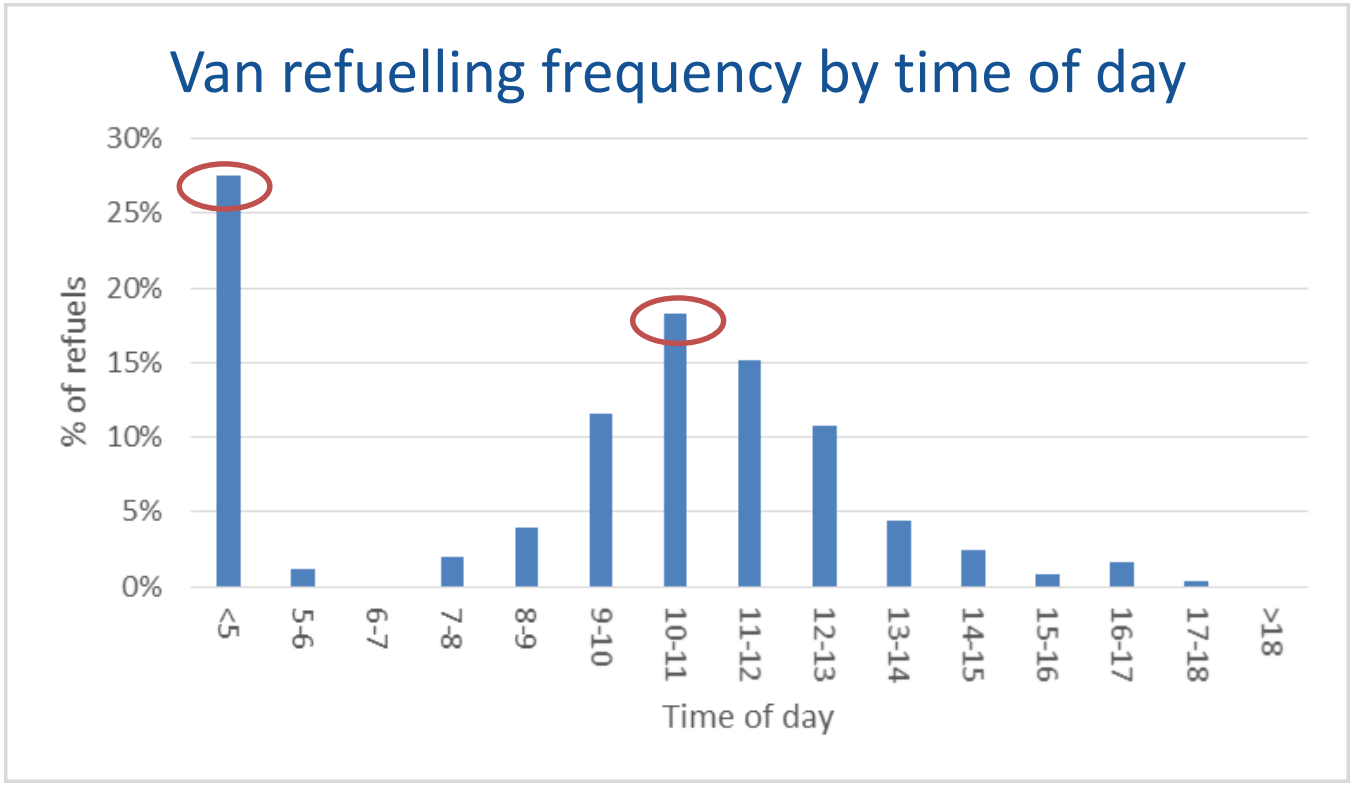
Conclusions – H2 Vehicles

- **Versatile & Reliable**
  - Greater range than Electric vehicles
  - Used similar to ICE passenger vehicles & by fleets in real applications
  - The only tailpipe emission is water - zero local emissions for clean air zones (CAZ)
  - Timelines predict fuel cell vehicles as the only viable pathway to achieving low carbon transportation for longer range, larger vehicles – HGV prospect
- **Demonstration Projects – future fast-tracking**
  - Invaluable to prove technologies work and gain feedback
  - Pioneer the next iteration of hydrogen & fuel cell development

Conclusions – Hydrogen refuelling stations (HRS)

- **Reliable**
  - The Station availability for the trials were >90% (Hytec >99%,H2ME & Hyfive 98%, LHNE 92%)
  - Outage periods combined with a lack of backup stations can cause users to lose confidence
    Hytec: Users rated stations poorly due to two relatively long (up to three week) planned outage periods to upgrade the only two existing stations at the time
- **Limited Number – High Demand**
  - Observed vehicle refuelling patterns display that delivery vehicles (vans) will fill up on hydrogen as part of their delivery routes
  - As a consequence, these vehicles are more likely to refuel at certain times during the day, creating predictable and repeating demand peaks for the HRS

Conclusions – Hydrogen refuelling stations (HRS)



London Hydrogen Network Expansion (LHNE) Project summary report - September 2016

In conclusion

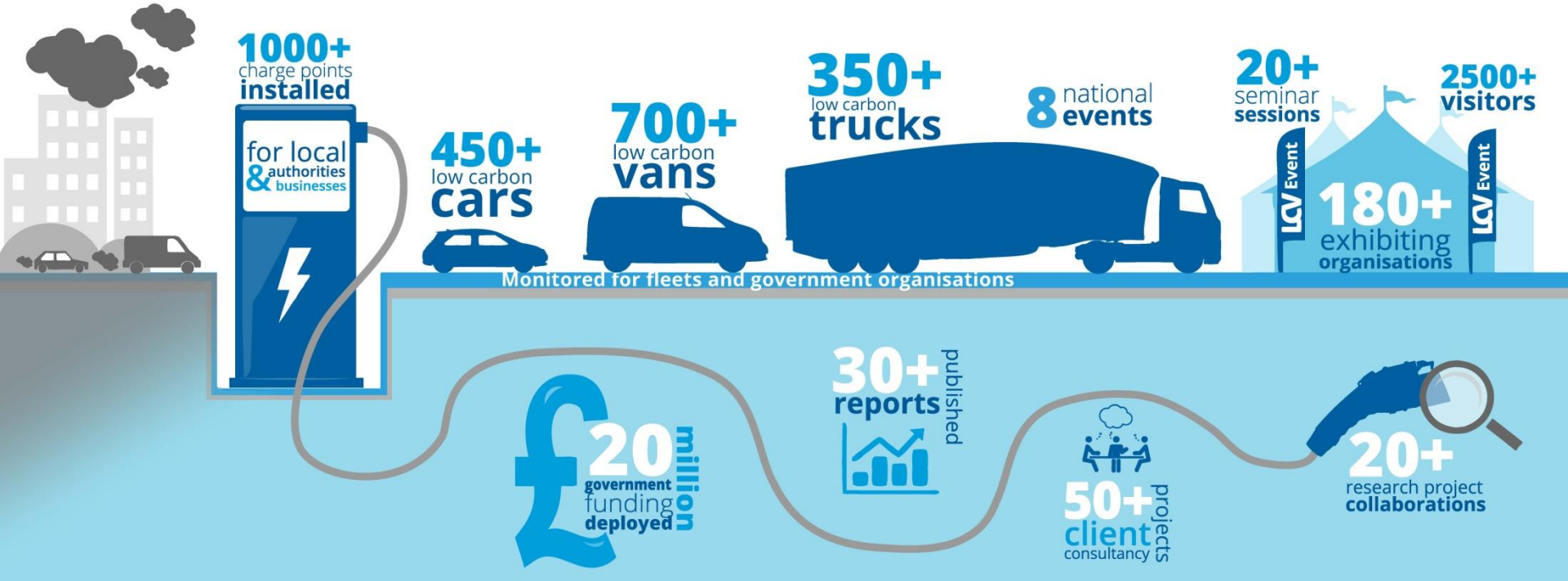
- Cenex offer independent verification of results to funding bodies and industrial partners
- Emission type defines point of interest
  - Tail pipe, W-T-W or lifecycle?
- BEV market is well served and growing
  - But not fast enough?
- Customer attitudes
  - critically important
- Demonstration projects
  - Build real world knowledge base
  - Build infrastructure

Thank you for listening

Nick McCarthy

Technical Specialist

nick.mccarthy@cenex.co.uk



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