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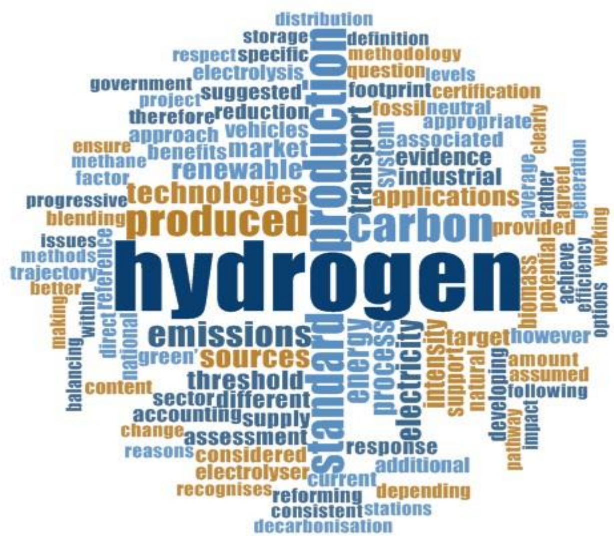
Market trends for ULEVs: FCEVs, BEVs and beyond



Dr Anthony Velazquez Abad

New Energy Forum Roundtable: “Evolving markets for hydrogen", Wednesday 6th December 2017

Agenda

- Factors shaping the UK market
  - policy
  - commercial context
- Key developments
  - Milestones
  - Uncertainties
- Lessons from Abroad
- Conclusion

Factors Shaping the UK Market: Policy

1. Climate Change
   - Several hydrogen pathways can yield low well-to-wheel GHG emissions
   - Energy efficiency. Electric powertrains are more efficient than internal combustion engines (and BEV more than FCEV)
2. Human Health
   - Tailpipe emissions are negligible
3. Industrial Strategy
   - The strong position of the UK's research capabilities and automotive sector, and their potential to deliver economic growth and job creation.
4. Energy Security
   - Energy carriers

Main Policies influencing the Automotive UK Market

- Environmental Policy
  - Air quality: Air Quality Directive / Emissions Standards
  - GHG Emissions: RED / RED2 -> RFNBO vs Biofuels
  - Other: Environmental Noise Directive
- Energy Security, Resilience and affordability
- Alternative Fuel Infrastructure Directive
- Industrial Strategy

Relevant Policies

Table 25. Example of policies to be aware of when operating in the electric vehicle sector.

Policy	Objective	Type of Policy	Main stakeholder	Comments
Renewable Transport Fuel Obligations (RTFO 5% - 8%)	Increase the share of renewables	Regulatory	Fuel Producers	Hydrogen will be included as a 'Renewable Fuel of Non-Biological Origin' in the Renewable Transport Obligation.
Local Sustainable Transport Fund	Economic growth / Employment	Economic	Local businesses	This scheme can promote the development of new local automotive supply chains.
FCEV Fleet Support scheme	Create a market	Economic, voluntary	Public procurement Private enterprise fleet owners/operators	This scheme provides grants for the uptake of FCEV fleets.
Road vehicle efficiencies: Car , HGV, HGV Natural Gas, PSV Fuel Efficiency, Van	Reduction of air pollutants / GHG emissions	Fiscal, regulatory, research. Voluntary/negotiated (e.g. HDVs)	Vehicle manufacturers / users	Vehicle efficiency thresholds are measured on a TTW basis, and these vehicle tailpipe emissions are zero. Indirectly, by becoming more stringent, these technologies benefit from the challenges experienced by ICE vehicles. These vehicles will meet any present and future Euro Emission Standard.
Alternative Fuels Infrastructure	Energy security	Economic, regulatory (voluntary for hydrogen)	Infrastructure owners / operators.	It sets reporting requirements for EU members pursuing the hydrogen agenda in their national policy frameworks and recommends a holistic view to allow refuelling for long distance travel around the EU when locating HRS infrastructure.
Advanced Propulsion Centre programme	Create a market	Economic, voluntary	Public procurement Private enterprise fleet owners/operators	This scheme provides funding for R&D of BEV.

Decarbonisation of Transport

Table 1. GHG emissions reductions to be achieved by different sectors in the EU by 2030 and 2050 to meet climate change targets. Adapted from: European Commission (2011b).

GHG reductions compared to 1990	2030	2050
Total	-40 to -44%	-79 to -82%
Sectors		
Power (CO_2)	-54 to -68%	-93 to -99%
Industry (CO_2)	-34 to -40%	-83 to -87%
Transport (incl. CO2 aviation, excl. maritime)	+20 to -9%	-54 to -67%
Residential and services (CO_2)	-37 to -53%	-88 to-91%
Agriculture (non-CO_2)	-36 to -37%	-42 to -49%
Other non-CO_2 emissions	-72 to -73%	-70 to -78%

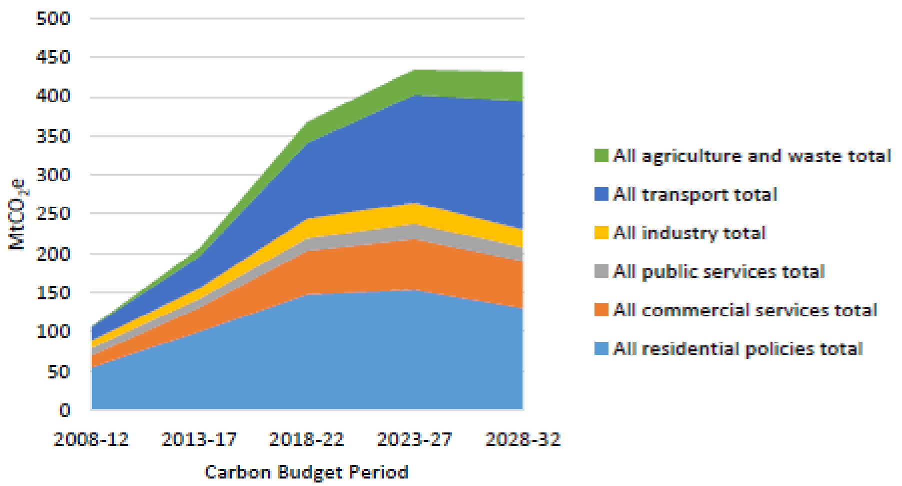


Figure 2. UK GHG Savings from policies by each sector according to the interim 'Carbon Budgets'. Adapted from DECC (2015).

Air Quality

- COP21 Mayoral Targets: Madrid, Paris, etc.
- London Environmental Strategy.
- Phasing out ICE by 2040 or sooner: China, UK, France, Norway.

Commercial Context

- Battery & Fuel Cell cars are both electric vehicles, hence, have very similar technologies and supply chains.
- The main technological difference is that FCEV have an smaller battery, and an additional fuel cell and hydrogen feeding system
- The main operational difference between BEV and FCEV is recharging/refuelling time and range
- Average price FCEV is double of BEV
- Difference in Total Cost of Ownership can be even greater.
- In the UK, no FCEV is eligible for plug-in grants (35% purchase price, up to £4,500) as their retail price is over £60,000.

BEV vs FCEV models commercially available in the USA in May 2017

Brand	Model	kW	Category		Vehicle Class	Price[3] (£)	EPA Range[4] (mi)	EPA MPG_e	NEDC Range[5] (mi)	Energy (kWh /100km)	Size battery (kWh)	Recharging Time (hrs)[6]
BMW	i3 BEV/60A	125	M1	B								
BMW	i3 BEV/94A	125	M1	B								
Chevrolet	Bolt	150	M1	A								
Fiat	500e	83	M1	A								
Ford	Focus Electric	107	M1	C								
Hyundai	IONIQ Electric	88	M1	C								
Kia	Soul EV	81	M1	B								
Mercedes	B250e	132	M1	M								
Mitsubishi	i-MIEV ES	49	M1	A								
Nissan	LEAF S	80	M1	C								
Smart	ForTwo	55	M1	A								
Volkswagen	e-Golf SE	100	M1	C								
Tesla	Model S 75	193	M1	E								
Tesla	Model X AWD 75D	193x2	M1	J								

[3] Excluding subsidies.

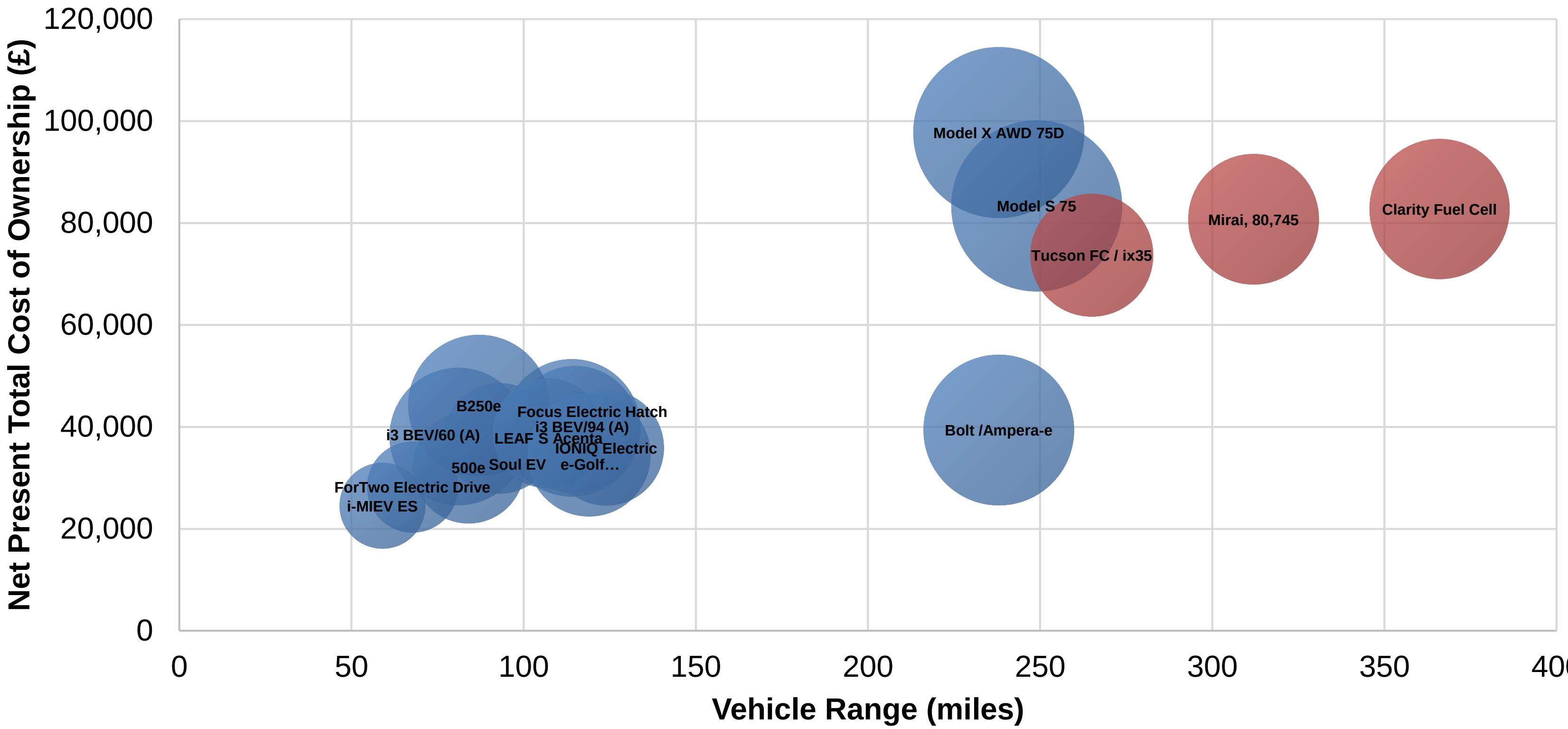
[4] EPA combined driving cycle.

[5] NEDC driving cycle.

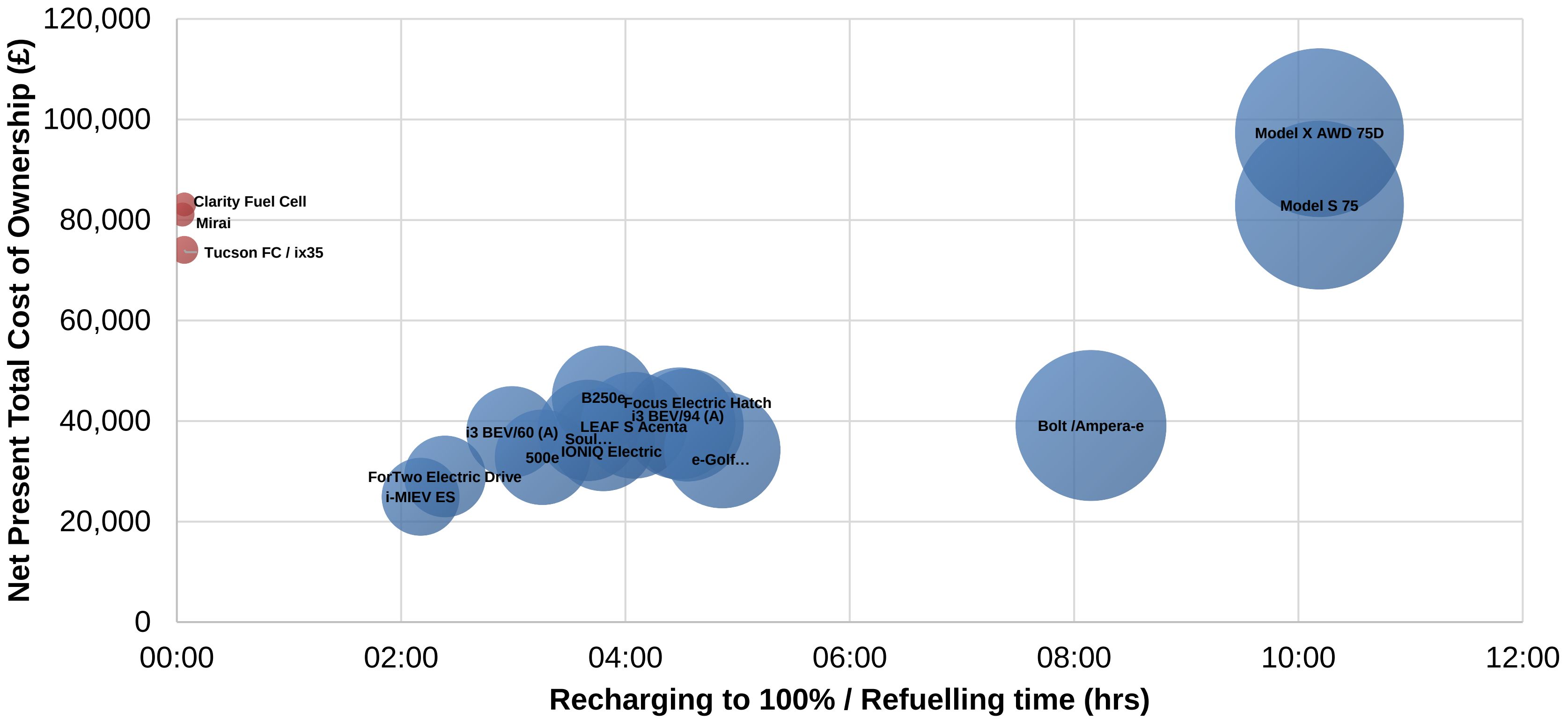
[6] Assuming a 7.4 kW (230VAC/32A) chargers for all BEV.

Brand	Model	kW	Category	Vehicle Class	Price[8] (£)	EPA Range[10] (mi)	EPA MPG_e	NEDC Range[11] (mi)	Energy (kWh /100 mi)	Size H_2 tank (kWh)	Refuelling Time (h:min)
Honda	Clarity FC	130	D	Midsize Car							
Hyundai	ix35	100	J	Small SUV							
Toyota	Mirai	113	D	Subcompact Car							

Net Present TCO BEV vs FCEVs in May 2017 – Private Owner



BEV vs FCEV models commercially available in the USA in May 2017



Net Present TCO BEV vs FCEVs in May 2017 – Private Owner

Table 9. Economic key performance indicators of BEV for private buyers.

Brand	Model	NPC (£)	NPC(£) /100 mi	£/mi of Range	£/Power Load[24]
BMW	i3 BEV/60 (A)	38,472	24.54	475	4,024
BMW	i3 BEV/94 (A)	40,166	25.62	352	3,738
Chevrolet / Opel	Bolt /Ampera-e	39,742	25.35	167	3,669
Fiat	500e	33,068	21.09	394	2,094
Ford	Focus Electric Hatch	39,832	25.40	346	2,580
Hyundai	IONIQ Electric	36,927	23.55	298	2,288
Kia	Soul EV	38,774	24.73	417	2,007
Mercedes	B250e	45,250	28.86	520	3,463
Mitsubishi	i-MIEV ES	25,570	16.31	433	1,071
Nissan	LEAF S Acenta	39,774	25.37	372	2,121
Smart	ForTwo Electric Drive	29,231	18.64	432	1,649
Volkswagen	e-Golf SE	34,860	22.23	293	2,199
Tesla	Model S 75	83,723	53.39	336	7,665
Tesla	Model X AWD 75D	98,113	62.57	412	7,920

Table 10. Economic key performance indicators of FCEV.

Brand	Model	NPC (£)	NPC(£) /100 mi	£/mi of Range	£/Power Load[24]
Honda	Clarity Fuel Cell	83,421	53.20	228	5,738
Hyundai	Tucson FC / ix35	74,368	47.43	281	3,305
Toyota	Mirai	81,417	51.92	261	4,973

Net Present TCO BEV vs FCEVs in May 2017 – Fleet Owner

Table 16. Economic key performance indicators of BEV for commercial fleet owners.

Brand	Model	(Excluding 1st Year Allowances)			Monthly Rental
		NPTCO (£)	NPTCO (£) /100 mi	£/mi of Range	
BMW	i3 BEV/60 (A)	21,053	21.93	260	423
BMW	i3 BEV/94 (A)	22,454	23.39	197	437
Chevrolet	Bolt /Ampera-e	22,401	23.33	94	423
Fiat	500e	16,714	17.41	199	327
Ford	Focus Electric	21,831	22.74	190	422
Hyundai	IONIQ Electric	19,754	20.58	159	382
Kia	Soul EV	20,387	21.24	219	399
Mercedes	B250e	23,530	24.51	270	474
Mitsubishi	i-MIEV ES	11,552	12.03	196	210
Nissan	LEAF S Acenta	20,699	21.56	193	404
Smart	ForTwo Electric	14,594	15.20	215	288
Volkswagen	e-Golf SE	19,025	19.82	160	352
Tesla	Model S 75	50,313	52.41	202	924
Tesla	Model X AWD 75D	60,327	62.84	253	1,147

Table 17. Economic key performance indicators of FCEV for commercial fleet owners.

Brand	Model	Without Claiming Tax			Monthly Rental
		NPTCO (£)	NPTCO (£) /100 mi	£/mi of Range	
Honda	Clarity Fuel Cell	57,711	60.12	158	918
Hyundai	ix35 Fuel Cell	48,867	50.90	184	765
Toyota	Mirai	56,116	58.45	180	890

Milestones: Cost Parity

Table 8. Forecasted total costs of ownership of different vehicle types in 2030 and 2050 in GBP (1 GBP=1.15 EUR=1.23 USD). Adapted from 1. Körner, Tam, Bennett, and Gagné (2015) (BEV range = 150 km). 2.E4tech and Element Energy (2016). 3.Element Energy (2016).

Source \ Type of vehicle	1 (2030)	1 (2050)	2 (2030)	3 (2030)	4 [18] (2050)	5 (2030)	5 (2050)
ICE petrol	22,845	23,902	-	21,593	-	27,365	27,876
ICE Diesel	23,414	24,471	£28,800	21,188	£61,000	27,873	27,114
BEV	24,227	25,447	-	21,907	£54,000	30,161	27,368
FCEV	24,878	24,634	£31,200	24,792	£51,000	30,924	27,789

Milestones: Cost Parity

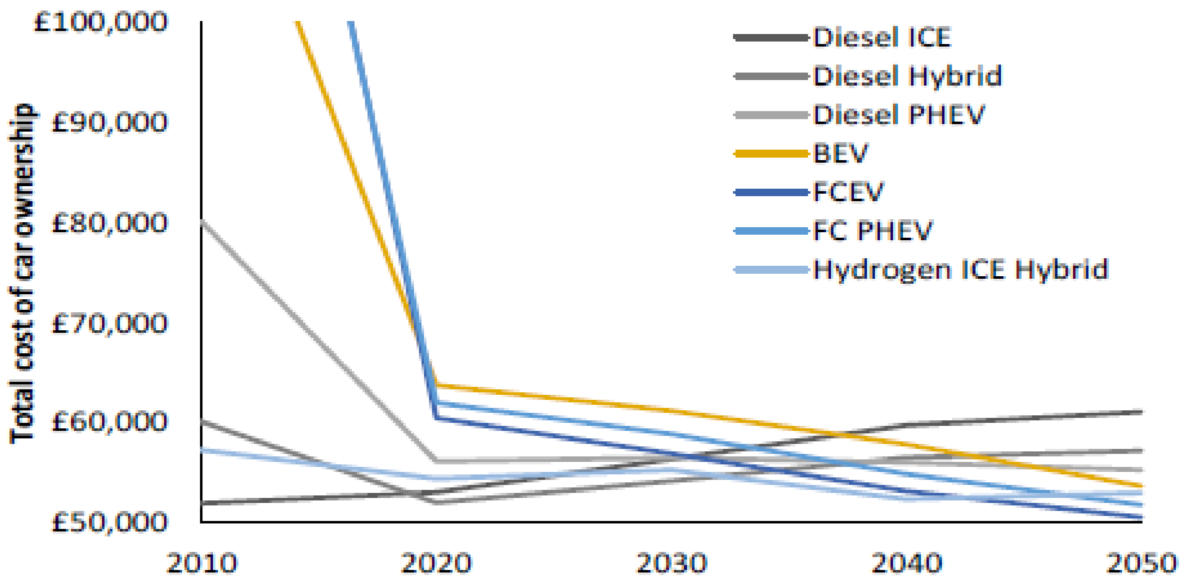


Figure 18. Total cost of ownership (TCO) for principal powertrains using the energy systems method, for the scenario with an 80% reduction in CO_2 emissions in 2050 relative to 1990. Source: Paul E. Dodds and Ekins (2014).

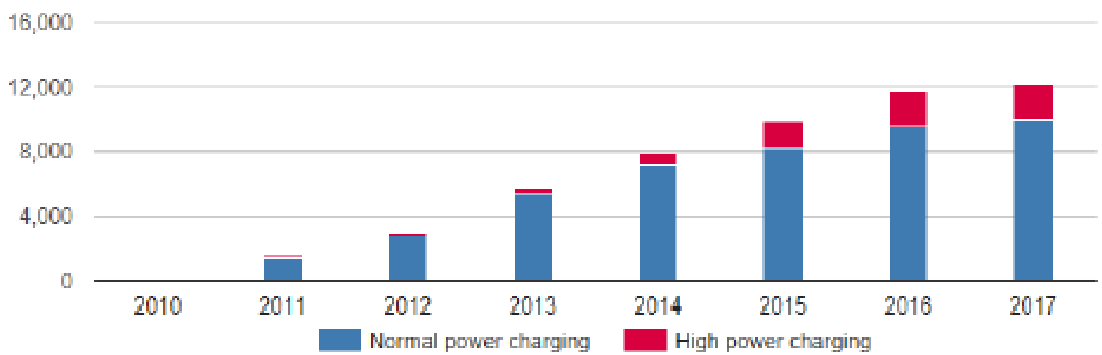
Milestones: FC Efficiencies

Table 7. Efficiency of different hydrogen production pathways. Source: Velazquez Abad and Dodds (2017).

Production Technology	Main Feedstocks	System Energy Efficiency[a] (%)		USA H_2 Cost[b] ($/kg)		Maturity Level[c]
		2015	2020	2015	2020	
Reforming: Steam Methane	Natural Gas + steam	74%	≥74%	2.1	≤2.1	Commercial
Gasification: Biomass	Biomass	46%	48%	2.1	2.0	Pilot Projects
Electrolysis: Alkaline	Water + electricity	73%[d] 72%[e]	75%[d] 75%[e]	3.0[d] 3.9[e]	2.0[d] 2.3[e]	Commercial
Water Splitting: Solar Thermo-chemical	Water + sunlight	10%[f]	20%[f]	14.8[f]	3.7[f]	Pilot Projects
Biological: Photolysis (Photosynthesis)	Water + Sunlight	2%[f]	5%[f]	N/A	9.2[f]	Pilot Projects
Biological: Dark fermentation	Biomass	4 mol H_2 / mol glucose	6 mol H_2 / mol glucose	N/A	N/A	Research Lab
Biological: Photo fermentation	Biomass + sunlight	0.1%	N/A	N/A	N/A	Research Lab

a) LHV; b) Estimated hydrogen levelised cost in the USA; c) As per November 2016; d) Central production; e) Distributed production; f) Solar-to-hydrogen ratio; defined as the energy of the net hydrogen produced divided by net full spectrum solar energy consumed.

Sales Chargers / FC & HRS



Recharging points in the UK. Source: EAFO (2017)

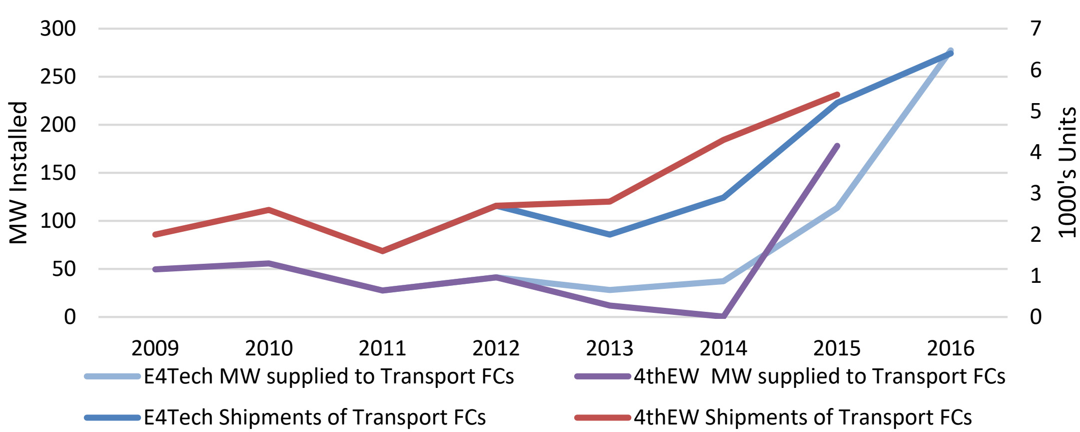


Figure 30. Map of UK hydrogen refuelling stations. Source:H2stations.org (2017)

Key Developments

- Tesla HGV (costs/density?)
- Battery technology: New solid-state batteries
  - 200,000 km, 20/30% higher energy density, faster charging
- Cost reduction batteries:
  - ~$150/kWh now (Nissan) to $100/kWh by 2020?
- Hydrogen Council investment €1.4bn/year

Energy Density Batteries

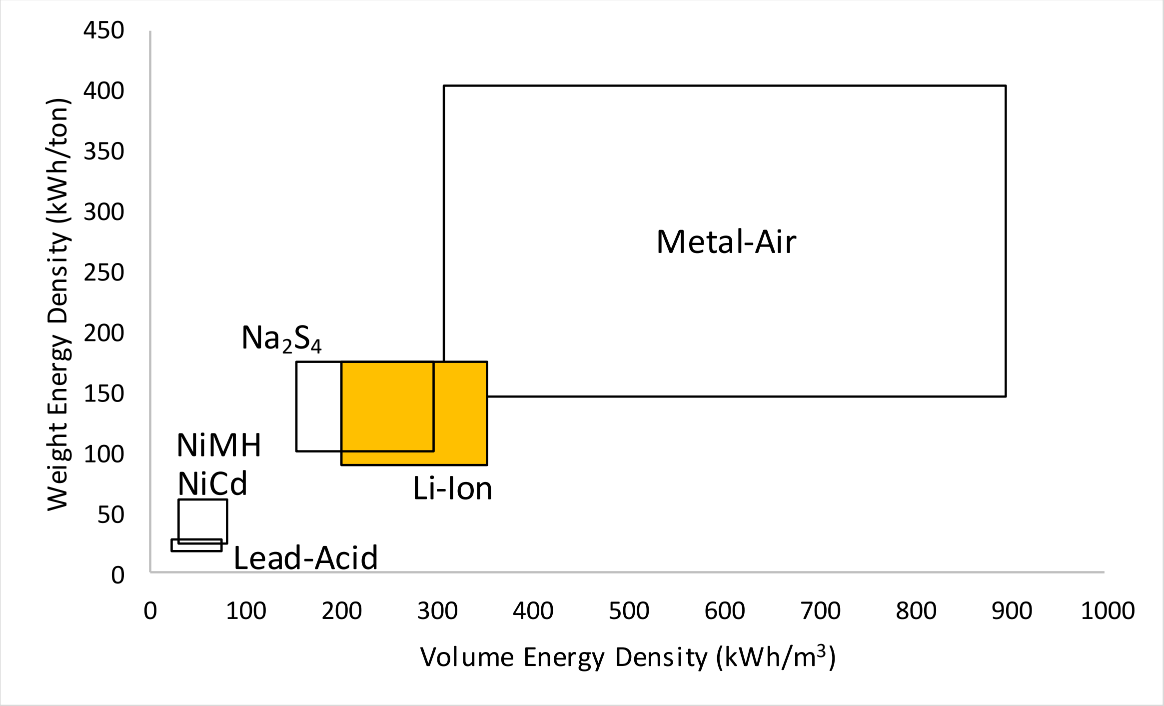


Figure 5. Energy density of batteries. Adapted from Berecibar and Zhou (2013).

Current Consumer Needs

The Tables below indicate the average trip distance driven by cars since 2005 and the number of trips that each individual drives according to the distance driven. This has been used to justify that BEV have enough range for most trips.

Table 52. Table NTS0308. Average number of trips by trip length and main mode: Great Britain, 2012. Adapted from: DfT (2016c)

	Trips per person per year							
Main mode	Under 1 mile	1 to under 2 miles	2 to under 5 miles	5 to under 10 miles	10 to under 25 miles	25 to under 50 miles	50 to under 100 miles	100 miles and over
Private:								
Car / van driver	24	64	134	89	65	17	6	3
Cumulative %	6.0%	22.0%	55.3%	77.5%	93.7%	97.9%	99.4%	100.0%
All modes	190	174	264	163	114	31	12	6
Cumulative %	19.9%	38.1%	65.8%	82.8%	94.8%	98.1%	99.3%	100.0%

Table 53. Table NTS 0306. Average trip length by main mode: Great Britain. Adapted from: DfT (2016a)

Miles/number/thousands

Main mode	2005	2006	2007	2008	2009	2010	2011	2012
Private:								
Car / van driver	8.4	8.5	8.9	8.5	8.4	8.4	8.6	8.4
All modes	6.9	6.9	7.3	7.0	7.0	7.0	7.1	7.0

Current Consumer Needs: BEV

Figure 29. Range of distances from Manchester. Adapted from: Google (2017)

Table 19. Recharging times according to charging point power and cost of each unit

Characteristics charger					Size of the battery (kWh)			Retail price
					60	75	90	
	Voltage (input)	A	P	kW	Recharging time (hr : min)			(£)
VAC	230	16	1	3.7	16:18	20:22		
	230	16	3	11	05:27	06:49		
	230	32	1	7.4	08:09	10:11		
	230	32	3	22.1	02:43	03:23		
	230	63	3	43.5	01:22	01:43		
VDC	400	125	1	50	01:12	01:30		
	400	300	1	120	00:30	00:37		
	500	700	1	350	00:10	00:12		

Future Consumer Needs

	Mobility model	Description of model	Typical trip duration
Traditional alter-natives to vehicle ownership	Traditional rental cars	Renting cars to individual drivers for a predetermined number of days	Days
	Taxis	Hired to transport passengers point-to-point; based on distance and time traveled	Minutes
	Carpooling	Traditional method of aggregating carpools by driver and riders; based upon a fixed departure schedule	Minutes/hours
Emerging vehicle ownership alternatives	E-hailing	On-demand hiring of a private car using a virtual app or electronic device; one group of riders matches with one driver	Minutes
	Shared e-hailing	On-demand hiring of a shared-occupancy car using a virtual app or electronic device; multiple riders can match with one driver	Minutes
	Car sharing – fleet operator	On-demand short-term car rentals with the vehicle owned and managed by a fleet operator	Hours
	P2P car rental	Consumers go onto platform and share individual vehicles. A peer-to-peer way to rent vehicles per hour or per day	Hours or days
	Carpooling v2.0	Technology and app-enabled carpooling between a non-professional driver and riders to share empty seats; multiple riders can match with one driver	Minutes/hours

Table 18. Automakers can sell EVs in a range of alternative mobility models. Grey cells represent the business models that can improve EV economics. Source: Knupfer et al. (2017).

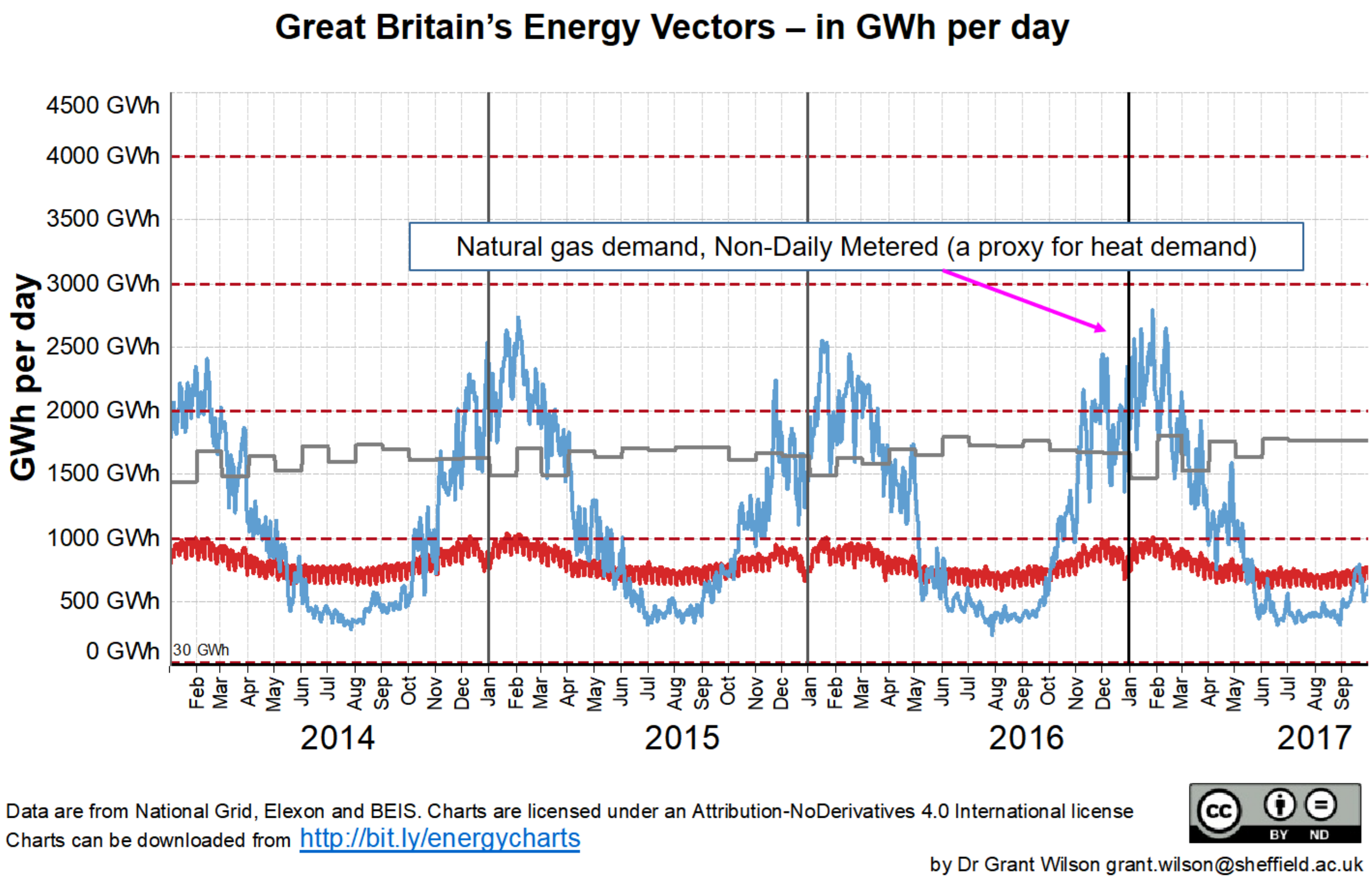
Uncertainties

- Technology breakthroughs
  - Battery capacity, FC efficiency, Hydrogen Storage, CCS
- Policy landscape
  - Creating a level playing field among energy carriers / Technology neutral approach
- Critical Materials
- Revealed choices consumers

Uncertainties

- Price differential with incumbent technologies
- Evolution of the policy landscape
- Supply of critical materials
- Public perceptions, attitudes, behaviour
- New business models (e.g. Mobility as a Service)
- Efficiency breakthroughs in battery / H2 storage
- Economies of scale / Costs reductions

Uncertainties – Capacity Investment

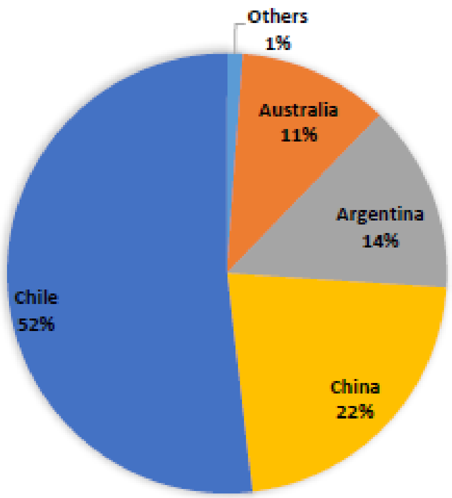


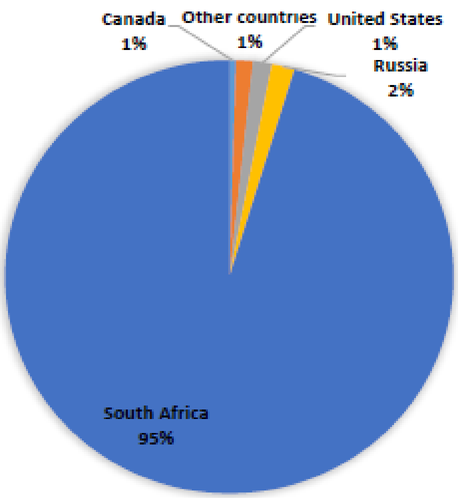
Uncertainties – Support for Infrastructure Deployment

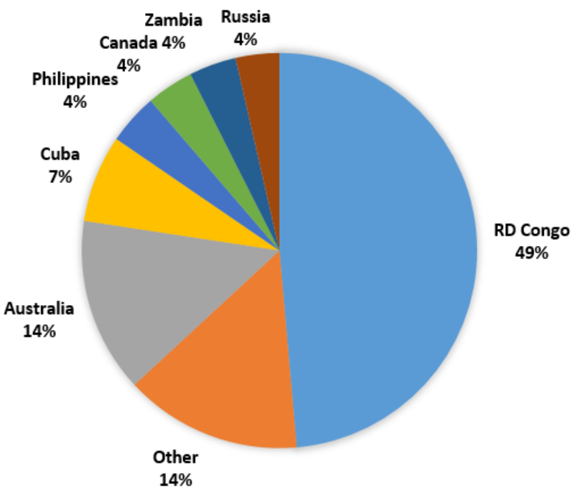
- Refuelling / recharging infrastructure
- Low voltage network
- Built recharging point kerbside flat blocks / lamp posts
- EU refuelling corridors

Uncertainties – Impact of Critical Materials & Supply Chain Risks

- Limited reserves for Cobalt, Lithium and Platinum
- Supply security issues due to concentrated localisation minerals
- Social impacts unacceptable business practices (child labour)







Location of Lithium, platinum and cobalt reserves worldwide

Lessons from Abroad

Country	H2FC uptake as of March 2017		National Incentives and investment		Future Targets	
	Vehicles	Refuelling stations	Vehicles	Refuelling	FC Cars (2020 - 2025 - 2030)	Refuelling stations (2020-2025-2030)
Japan	909 cars	90			40,000-200,000-800,000	160 - 320 - 900
Germany	467 cars, 14 buses	33			100% ZEV by 2040	400 (2023)
China	60 cars, 50 buses	4			3,000 (Shangai)-50,000-1 M	100 - 300 - 1000
US	1,500 cars, 33 buses	33			0-3.3M (ZEV by 8 States)- N/A	100 (California only)
South Korea	100 cars	11			10,000-100,000-630.000	100 - 210 - 520
UK	42 cars, 18 buses	14			100% ZEV by 2040	30 - 150 - N/A

Conclusions

- Favourable policy->lower costs->higher sales->economies of scale->lower costs->higher sales, etc.
- BEVs vs FCEVs -> Each technology is better suited for a different type of operation (Private consumers vs Fleet operators, MaaS, fleet sharing, etc).
- Business strategies should consider criticality of materials and new business models (e.g. MaaS changes end customer)
- BEV -> difficult to build enough power production capacity, smart grids necessary, hydrogen storage could support deployment of lower renewable capacity.
- New battery production capacity arriving by 2020 (mainly in China & USA).
- FCEV -> difficult to deliver low GHG emissions unless CCS in the early transitional period (NG) until green hydrogen can be produced at large scale and cost-efficiently
- Much infrastructure needs to be deployed (recharging / refuelling stations)
- Success depending on requirement to meet climate change goals (1.5-2C scenarios)
- Residual value FCEV likely to be larger than BEV; however, batteries seem to be quite resilient up to 100,000 km or 8/9 years.

Previous Work

- Velazquez Abad, A. and P.E. Dodds, *Conceptualisation of Green Hydrogen Standards.* Renewable and Sustainable Energy Reviews (in preparation), 2018.
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Thank you!

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