



Green Emotion - GEM

Opportunities and obstacles to electrifying transport

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Berlin 11th October 2013

- Statement of the problem
 - Quick overview of vehicles
 - Structure of Green eMotion and Imperial College activities
- Business models currently under trial
- The economics of EVs
 - Social cost benefit vs “Business case”
 - The challenge of electricity pricing and cost reduction
- Prospects for 2020 – challenging
- Possible more promising futures
- Commercial and regulatory barriers

Four year project, field trial data slow to arrive



- What are the **characteristics** of EVs?
 - High capital, low running cost
- What does this mean for the opportunities?
 - High utilisation combined with convenient charging
=> taxis, buses and rental models for mass use?
=> or as second cars? Or via PHEVs?
- What are the obstacles?
 - doubtful **social** profitability? How to measure?
 - Business case vs. economic case
- What are the commercial and regulatory barriers?

- Social profitability doubtful before 2020's?
 - Main problems – reducing cost, improving batteries
 - **How far can PHEVs drive technology? What business models might work? What and how to support the transition to mass use?**
- Business case vs. economic case
 - Subsidies may be justified to overcome some barriers
 - Road fuel tax provides considerable subsidy
 - Not sustainable at scale, move to road pricing?
- Commercial and Regulatory barriers
 - Electricity pricing and charging issues
 - Interoperability, roaming, battery exchange

Questions and comparisons



- What are we comparing?
- **Cars only**: Battery Electric Vehicles (BEVs), Plug-in Hybrids (PHVs) with conventional internal combustion vehicles (ICVs)
- What are the main differences?
 - Hold car characteristics constant (size, acceleration, carrying capacity, etc.) then:
 - Battery cost and weight, refuelling time, range, fuel price
- ***Will EVs be attractive (at some scale) by, say, 2020?***
 - With future fuel, electricity and carbon prices
 - And future battery costs and ICV performance?

Need to distinguish economic from business case



Nissan Leaf BEV

- Motor: 80 kW; battery Li-Ion 24 kWh, 300kg, guarantee: 8yrs or 160,000 km, charge time: 4 hrs @ 32 amp; DC 500V fast charge in 30 mins. **Price UK £21,000 (£70/month battery lease for 36 months <12,100km/yr).** Home charger costs US\$2,200
- Performance 5.5km/kWh = 0.18 kWh/km, 0 -100 km/h in 10 secs
- **Range: 200 km** (121km EPA); 7,500 US sample: av 60km/day; 11 km/trip, 68,000 sold to June 2013



Battery Pack – not just a battery



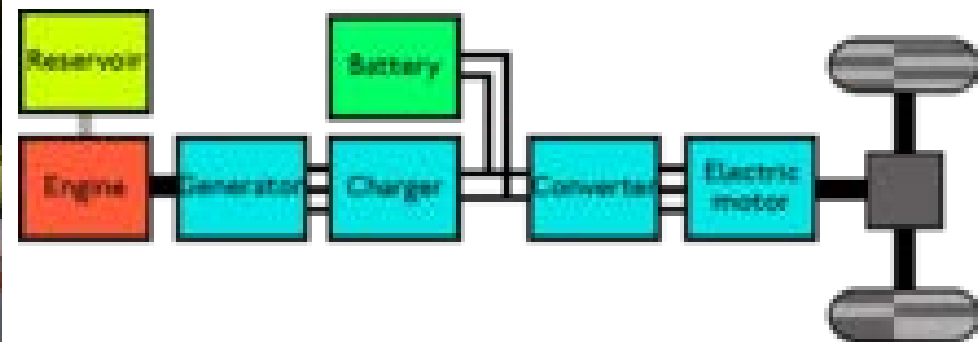
Figure 2-3 Example of a battery pack. Source: Axeon guide to batteries

Source: Element Energy (2012)

Chevy Volt 2012 PHEV (Vauxhall Ampera)



- Engine: 1.4 L 63 kW; Motor: 111 kW; Battery: 16 kWh Li-Ion 10.8kWh available, wt 200kg, guarantee: 8ys or 160,000 km
- 55 kW generator, 0–97 km/h = 9.2secs electric, 9secs both
- Performance 5.9km/kWh = 0.17 kWh/km EV, 20km/L petrol
- 4.7 L/100 km as hybrid. **UK price £34-37,000**
- Range: 55 km EV; 610 km total, charge time: 4 hrs @ 240 V



Toyota Prius 2012 PHEV

- Engine: 1.8 L 73kW; Motor: 60 kW; Battery: 4.5 kw-hr Li-Ion; 42 kW generator, 0 to 100 km/h in 10.7 secs
- Performance 5.5km/kWh = 0.18 kWh/km
- Passenger vol 90ft³ . **Price £22,000**
- combined city/highway rating 4.7 L/100 km as hybrid
- Range: 20 km EV, 860 km total; charge time: 1.5 hrs @ 240 V

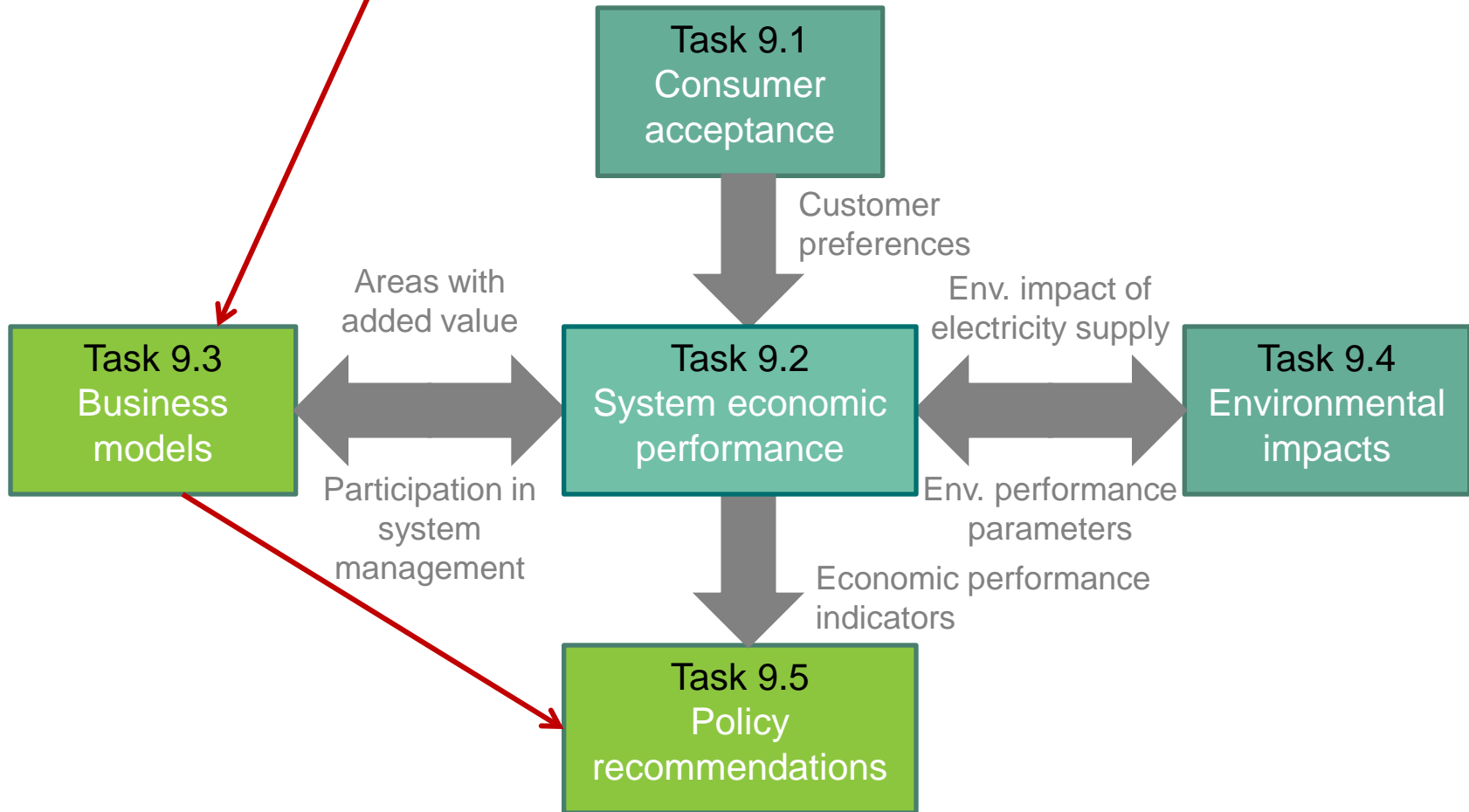


Prius experience after 497,100 miles driven

- 66% of commute trips < 20 km = the expected EV range
- > 33% of participants > 100 km trip at least once a week.
- Prius PHV consumed 36% less fuel than the comparable, best-in-class diesel vehicle, and almost 50% less than the best-in-class petrol vehicle.



My relationship to the ICL WP9 Tasks



- Main obstacles: high capital cost and slow charging
- **Battery switch stations** designed to overcome both
 - as fast as gas station, no need to own battery
 - but infrastructure cost very high and demand very low
=> bankruptcy
- **Home charging** with battery charging stations by road
 - Most trips are short enough to not need road-side charging
 - Probably mainly second cars?
- **Bus trials** planned in Milton Keynes
 - Charge at end of route during change round

Battery exchange versus charging points



- Cost of battery exchange has three elements:
 1. the net cost of the electricity supplied,
 2. the **use cost**, interest + depreciation of battery, and
 3. the **service cost**, i.e. the cost of providing the service (including all the handling and comms charges).
- Compare with cost of owning or renting battery (\$12,000)
 - but still need home charger \$2,000 or access to charging points



Battery Switch Stations

- Battery exchanged at Battery Switch Stations
 - Automated - change takes 4 mins (same as fueling IC V).

Better Place Battery Switch Stations



BSS Battery Switch In-Progress



Better Place BSS in Ekron, Israel

Better Place model



- Israeli-based Better Place start-up (partner Renault) raised \$786m + \$50 m debt, owns batteries
- Planned to install charging points in homes (\$2,000 each), work places, and various public locations and offer services and DSM to DNOs.
 - Communication System provides data on battery, charging stations, battery exchange, GPS, etc
 - Filed for bankruptcy in May 2013



Failed business model



Charging stations

eVgoSM "Freedom Station" with one Level 2 charger (left) and one DC fast charger (right) at a Houston supermarket



Find On the Go Plans

• Starting at \$19/month

- NRG installed its first Freedom Station in Dallas/Fort Worth on **April 8, 2011**, as part of eVgoSM's network of charging stations.
 - Fast charger: delivers 150 miles of charge per hour at 44kW
 - Level 2 charger: delivers up to 25 miles per hour.
 - Plans 70 Freedom Station sites in the Dallas/Fort Worth area and 50 in the Houston area, (17 already in place in Houston and 23 installed in Dallas/Fort Worth at **October 2013**)
- Install a Level 2 (240v) charger at home, avoid \$2,000 for \$59/month for single family; \$69 multi-family
- at work-place from \$29/month – per person, multi purpose use



- A sustainable business case for the long-term requires
 - The economy as a whole benefits
 - => need to use correct prices for evaluation
 - Each agent in the value chain makes a profit
- Medium run will require subsidies
 - to overcome barriers and coordination problems
 - to stimulate demand => higher production => lower long run costs => commercialisation
 - to offset pricing distortions elsewhere:

Carbon not adequately priced, road fuel heavily taxed

- Initially BEVs as niche product
 - second car, limited local use, range not critical
 - charging at home/work, some outlets
- Plug-in Hybrids (PHVs) as bridging technology
 - stimulates battery and control development
 - removes range anxiety as charging outlets expand
- Eventually BEVs competitive as sole vehicle
 - cost-effective against ICVs
 - adequate charging infrastructure developed
 - various business models – rental, battery swap, etc



- Carbon, electricity and oil **prices will change**
- Scenarios consistent with decarbonising imply high C prices
- High BEV penetration **requires road tax changes**
 - road fuel tax very high, pays for roads
 - gives high advantage to EVs at present
 - notionally replace by road pricing for all vehicles
- **ICVs will improve**
 - under tightened emissions/efficiency standards
 - substantial improvements possible (weight, engine)

BEV competitiveness is a moving target

Social cost benefit analysis and the business model



- Social cost benefit analysis requires the use of **efficient, not market prices**
 - For road fuel this is **exclusive of road fuel excise duty** (88 €/L for UK diesel), but **plus the CO₂ and air pollutant costs**
 - For electricity prices it is the nodal spot price with the scarcity price of any transmission and distribution networks
- => Domestic efficient electricity prices for controllable EV charging times can be low: 5 €/kWh or less
- **But** peak prices might be 45 €/kWh (fast charging outlets)
 - The **subsidy** is the difference between the required market price for profitability and the efficient price



Data requirements



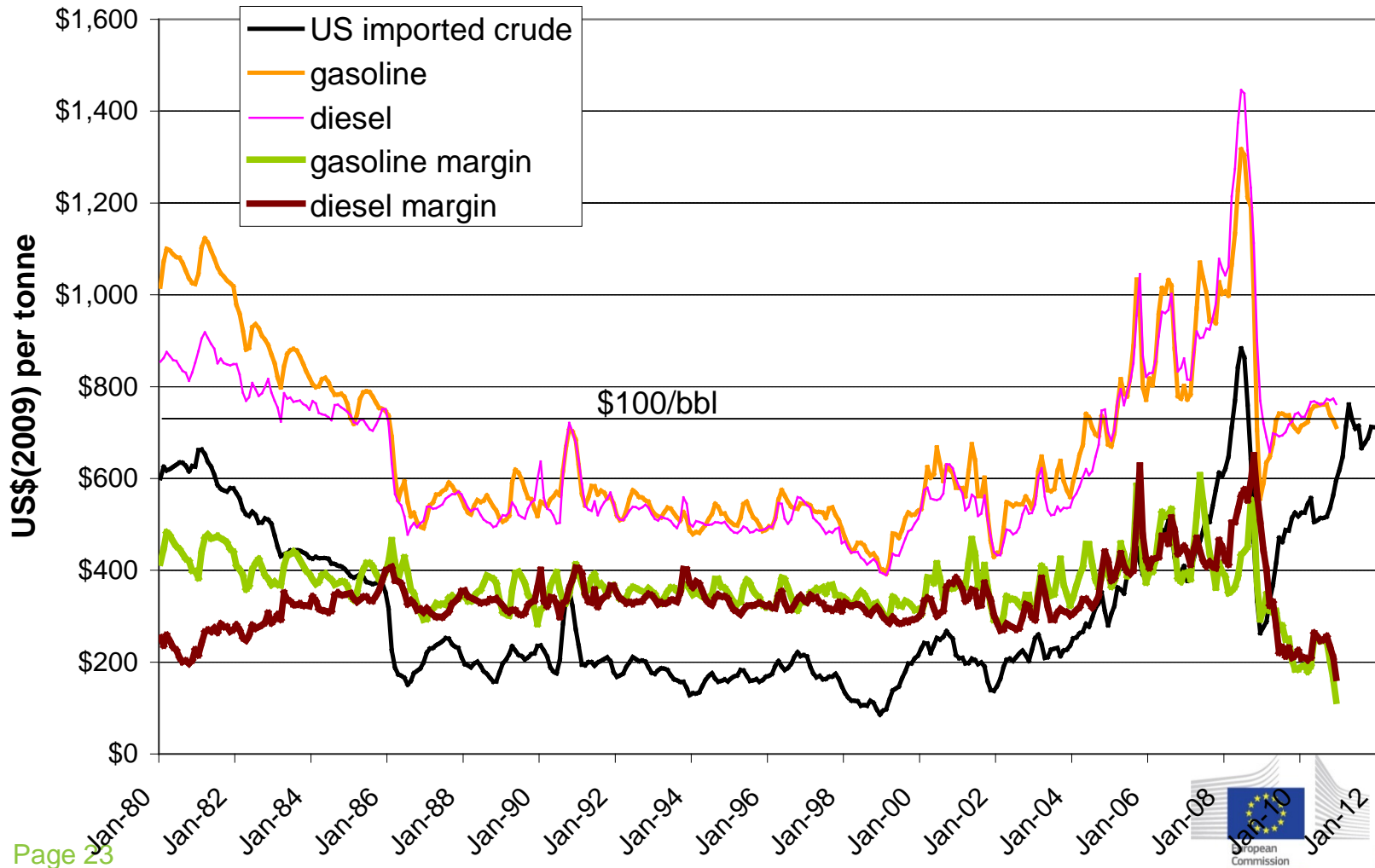
- Need to specify oil, carbon and electricity **prices**
 - several scenarios, take from EU Roadmap?
 - Need **margins** from oil to pump for gasoline, diesel
 - then add CO2 cost + other corrective charges => **“fuel cost”**
 - Project **fuel efficiency of ICVs** in 2015, 2020, 2025
 - for comparable size and power
 - calculate “fuel cost” per km for different C prices
 - Calculate break-even running cost per km of BEVs
 - electricity + battery interest + depreciation separately
- => target electricity and battery costs rel to C price**

- Assumes equality of BEVs and ICVs of same size
- But BEVs and ICVs differ in other respects
 - that affect consumer willingness to pay
 - For BEVs: range anxiety vs reduced maintenance costs and increased functionality
 - varies according as main or second car and driving pattern
- Balance between purchase and operating costs
 - possibly different tax treatment

Need information on willingness to pay for different vehicle types of similar power

Oil prices are volatile, margins less so

Real US oil and product prices



Target electricity + battery cost

- Varying oil and C price *together* and assuming all efficiencies are *negatively correlated* with fossil fuel costs and 2020 pollution costs are 50%, 75% and 100% of 2000 levels

2012 prices

	Low	Med	High
Oil price \$/bbl	\$95	\$125	\$150
CO₂ €/EUA	25	50	75

- Target electricity *plus battery cost* €/kWh

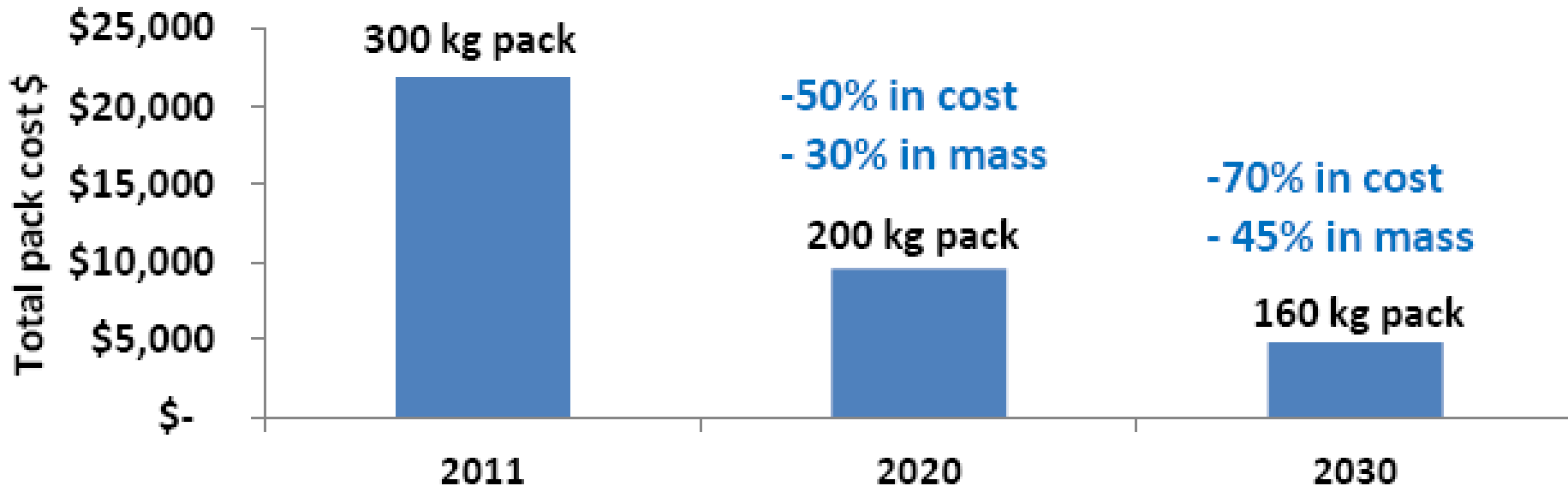
Diesel:	10.4	14.2	18.4
Gasoline:	12.4	17.0	27.5

- EVs are **socially profitable** if competitive against ICVs, based on true economics costs and benefits
- => conduct all SCBAs at **efficient, not market, prices**
- => Main corrections to **fuel, carbon and electricity prices**
- EV Economics depend on battery cost, carbon & oil price and the local price of electricity at CP
 - The carbon price is more potent than the oil price
 - Efficient electricity prices vary enough to make EVs either economic or costly

Current and projected PHEV battery cost



2011: \$800/kWh for pack; 100 Wh/kg, \$21,000 range = 150km
2030: possibly 300Wh/kg, \$6,400 for a range of 250km.

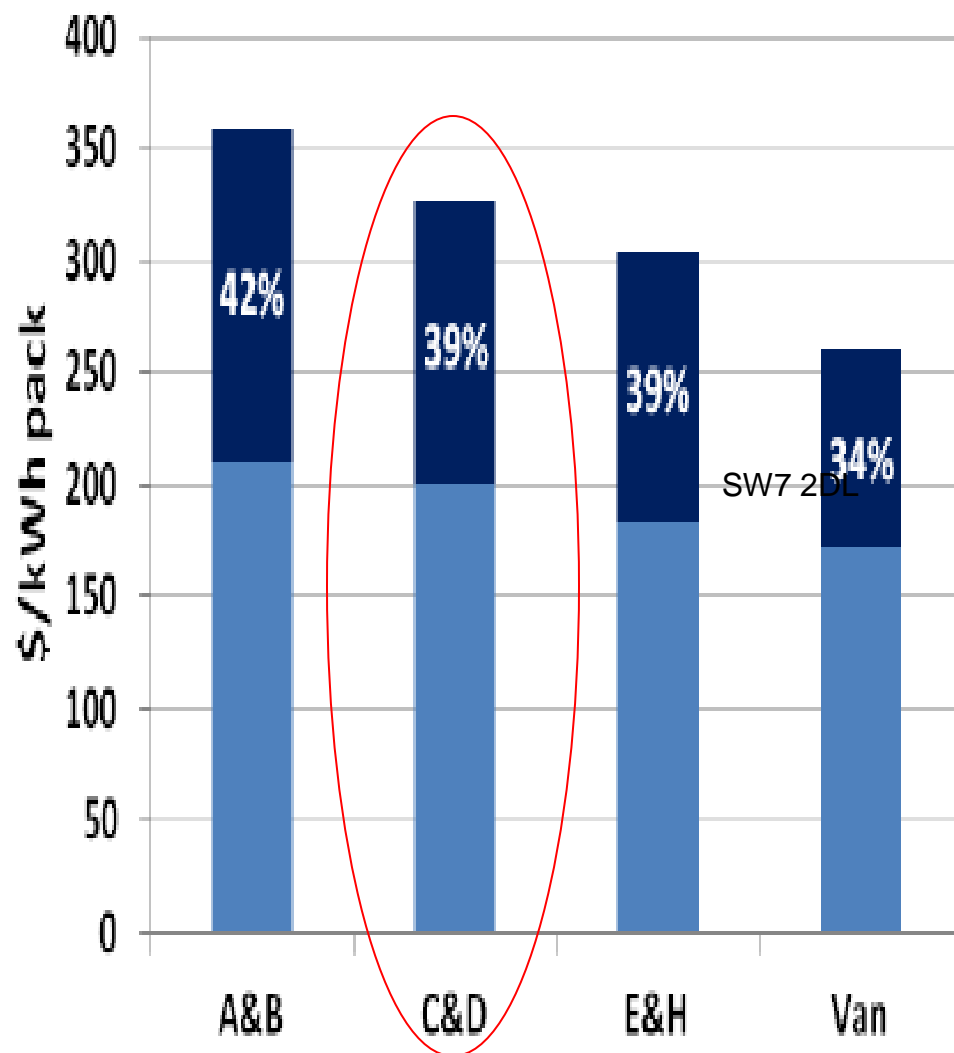


Results for a medium sized pure battery electric car – 30kWh pack

Source: Element Energy (2012)



Cell plus packing costs for various BEV types



Source: Element Energy (2012) *Cost and performance of EV batteries for CCC at*

■ Packing
■ Cell

http://www.element-energy.co.uk/wordpress/wp-content/uploads/2012/06/CCC-battery-cost_-Element-Energy-report_March2012_Finalbis.pdf

Figure 6-2 Cell and packing cost split in 2020 for the four defined BEV types



Projected PHEV battery cost

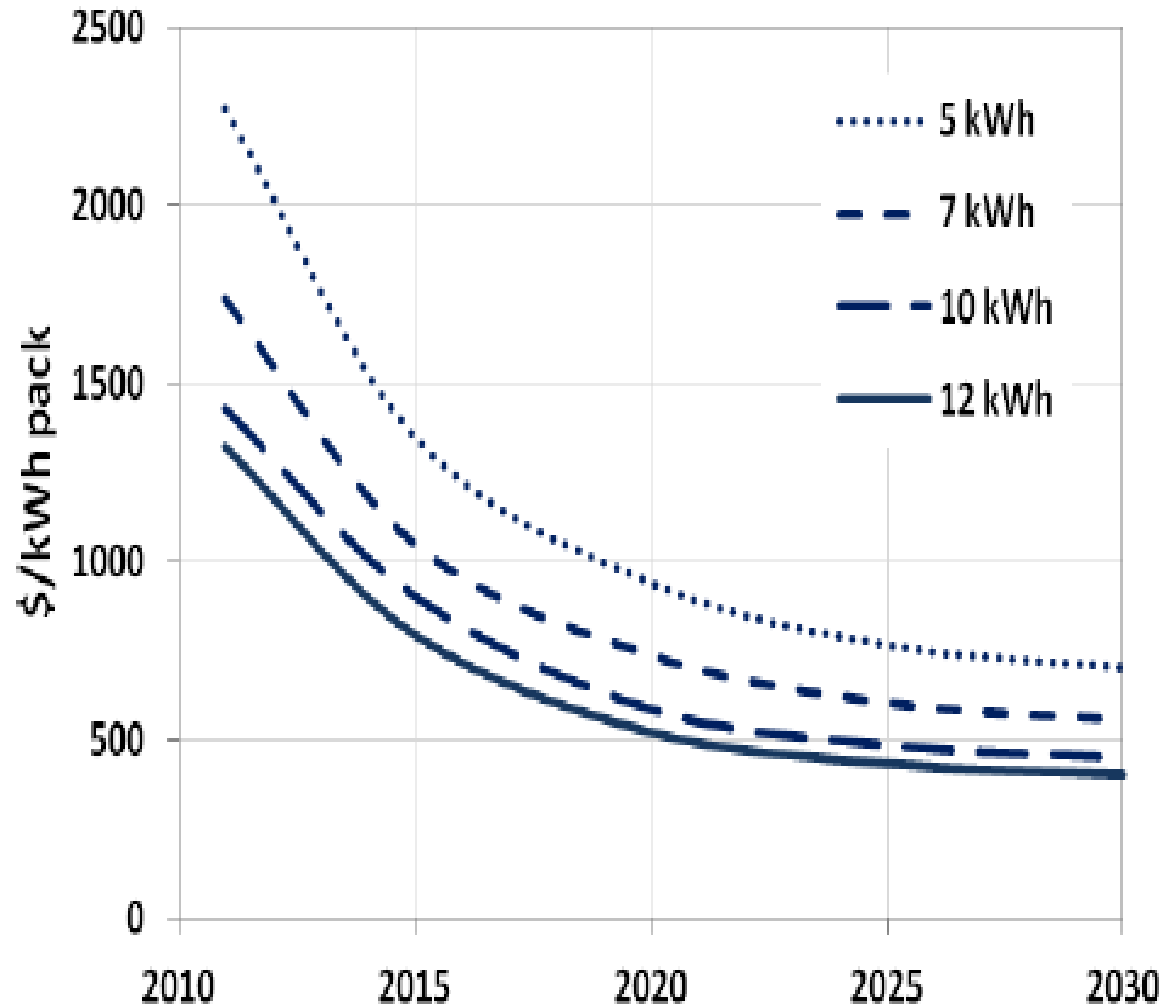


Figure 6-4 PHEV pack cost (\$/kWh) for C&D 60kW pack for various pack sizes

Example of battery costs (revised)



- Suppose battery costs /kWh

	2020 L	2020 H
	\$350	\$500
	€280	€400

- Consider three cycle lifetimes:

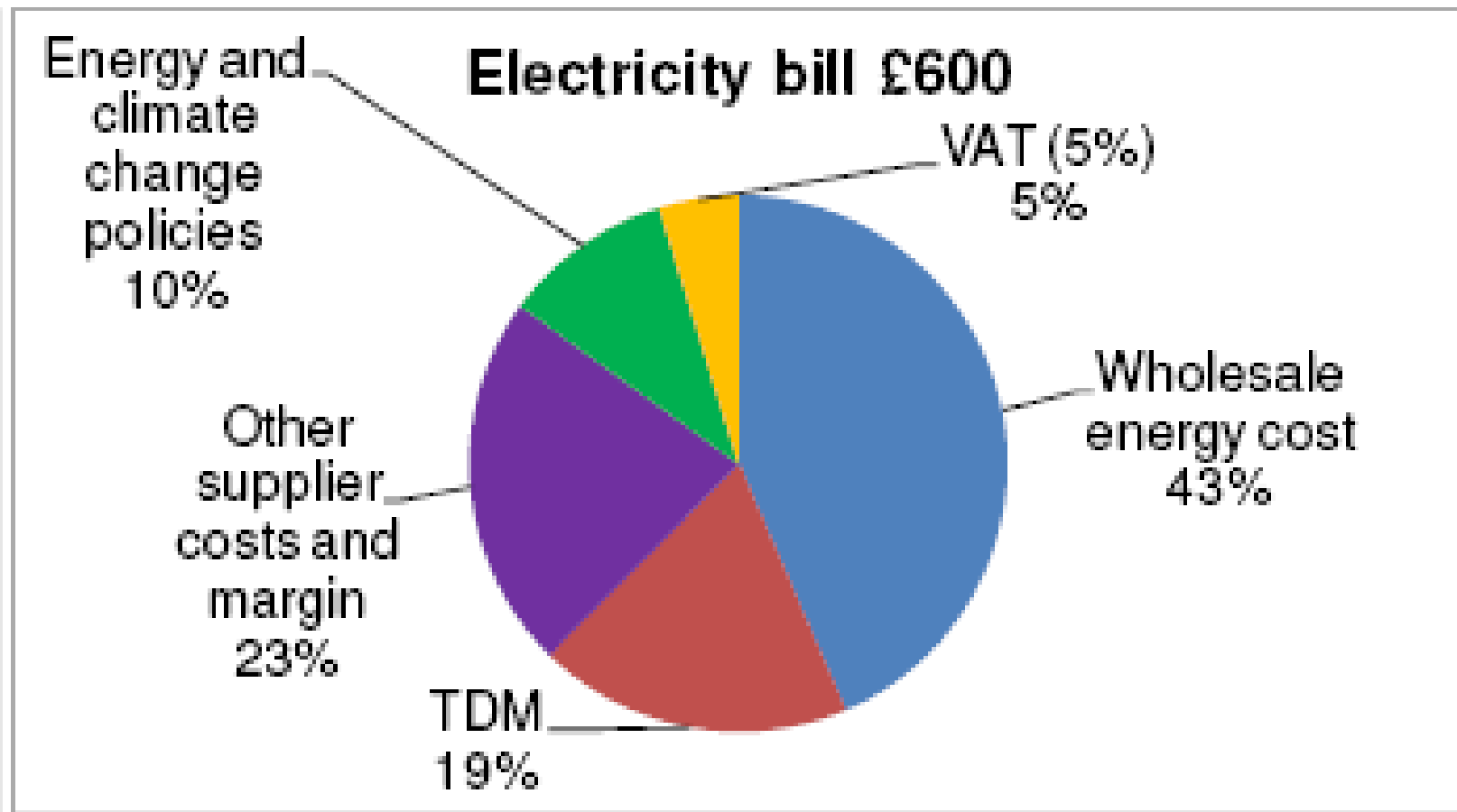
	2,000	2,500	3,000
Years	8	10	12

- Ignoring discounting, this translates into **€/kWh**

2020L:	€14	€11.2	€9.3
2020H:	€20	€16	€13.3

Cf target electricity + battery cost **€15 (€10-28)/kWh**

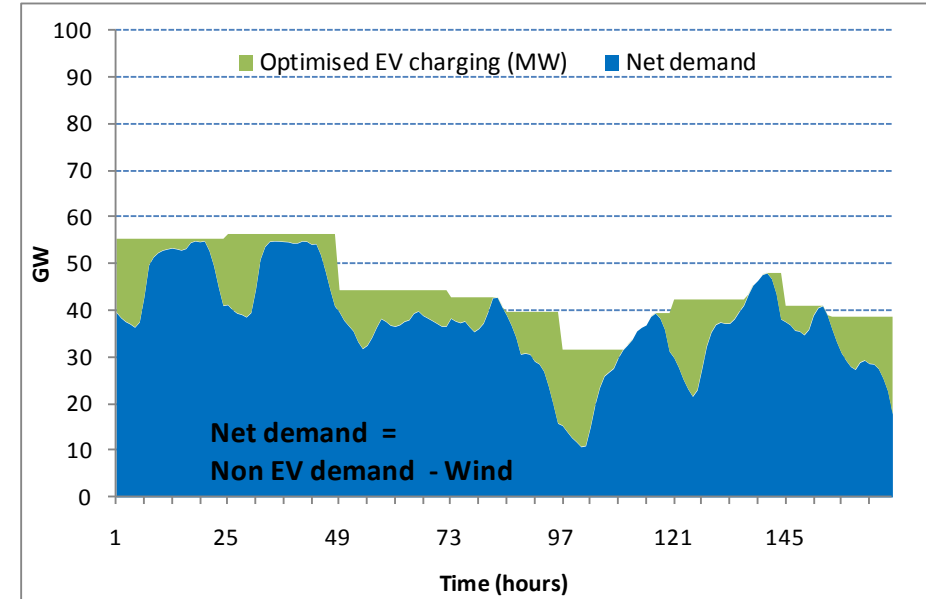
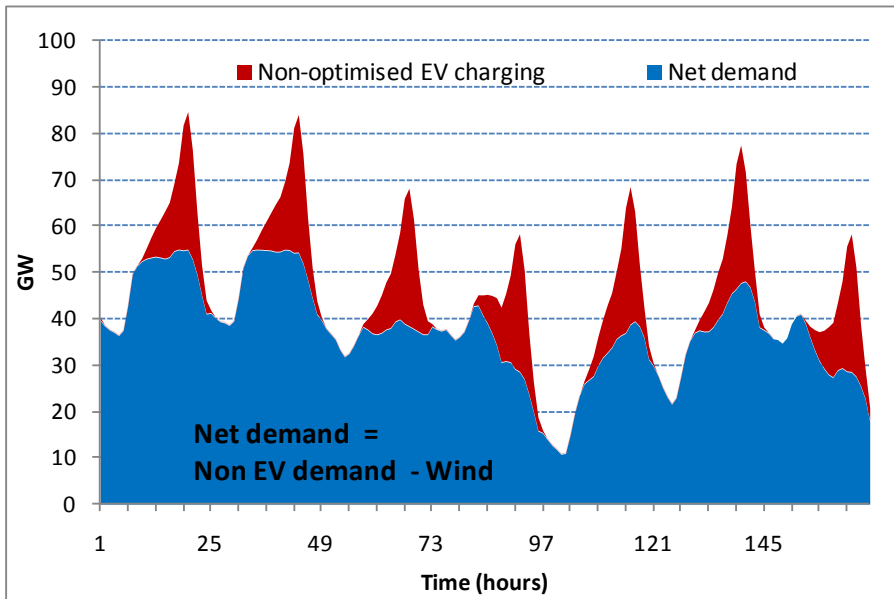
UK average domestic electricity prices include some tax-like charges but under-estimate carbon cost



Price is forecast to rise from 14.9p/kWh to 18.3p/kWh by 2020 and 20.1p/kWh by 2030



Impact of charging strategies on the need for conventional plant capacity and emissions and prices of electricity



- Calculate delivered electricity price (including same price of carbon) assuming **efficient charging strategy**
 - Including cost of extra generation, transmission, distribution assets
 - which with efficient charging could be zero
 - and spot price of power, lower if wind at the margin

Preliminary conclusions

- BEV Economics depend on battery cost, carbon & fuel cost and the local price of electricity at CP
 - Carbon + pollution tax element < current fuel excises
 - Battery cost and life are critical determinants
- At 2,500 cycles battery should last 10 years and might cost **€11-16/kWh** by 2020
- At \$125/bbl, CO₂ at €50/EUA, modest ICV efficiency gain, possibly competitive at **€14-17/kWh (D or G)**
- So could pay **€1-6/kWh** for charging

***BEVs viable only with higher oil and carbon prices
or cheaper batteries?***

Work back to current supports



- **If** there is a **viable economic case** for BEVs by e.g. 2020
- examine existing support via road fuel tax exemption
 - correct for efficient pricing of electricity
 - may need extra support until pricing improves
 - Is this sufficient to cover difference in BEV – ICV cost?
- estimate support needed to make vehicles viable at some earlier date – e.g. 2015?
 - offer this as capital rebate on battery? Subsidies to charging points (including in home)
 - Then compute business case with these subsidies



- ICT rapidly developing
=> finding suitable rental vehicles simpler?
- Problem is delivery and recovery after trip
=> Solution – **driverless delivery and recovery?**
 - Intermediate solutions: ZIP car model at charging points
 - Rental locations have a variety of models with differing ranges
 - BEVs, PHEVs, extended range EVs, etc
 - Can optimise charging to minimise variable cost

Who should build charging infrastructure?



- Some charging pole (CP) business models site-specific
 - Offices, supermarkets, parking at shopping centres
 - Benefits accrue to users (both sides – company and worker, shop and customers)
=> provide stand-alone cost recovery
 - => Various viable ownership models including site owner
- En-route CPs have less clear business model
 - Likely to be underused as charging slow(ish)
 - Likely to be commercially risky
 - Could be treated as regulated/subsidized infrastructure

Case for and against DNO ownership

Arguments for

- DNOs can optimise site of CPs given network constraints
 - Can internalise DSM with low transaction costs
- DNO may be able to justify this as a regulated business
 - Financed by club access fees with roaming agreements
 - C.f. cross-border tariffication for EU transmission

Arguments against

- DNOs have no special transport expertise
- Vertically integrated incumbent advantage blocks competition
- Restricts market area when long-distance routes needed

- Parking with CPs – option of slow/controlled cheap charging
 - Can offer DSR and hence discounted charging
 - “Fuel stations” – offer rapid charging at any time of day
 - Little/no scope for DSR => high uniform charge price
 - Possibly varying by time-of-day
 - Concerns over low use – more as emergency service?
 - “Fuel station + rental facility”
 - Can offer DSR for its rental fleet and do some internal DSM
- => cheaper business model for CP?

- BEV economics depend on costs of battery, carbon & road fuel and local cost of electricity at CP
 - Carbon + pollution tax element < current fuel excises
 - Battery costs and cycle lives are critical determinants
- ⇒ **conduct all SCBAs at efficient prices**
- ⇒ Main corrections to fuel, carbon and electricity prices
- ⇒ **Economics look doubtful even by 2020 without subsidy or much higher C and oil price**
- Consider possible contract designs between DSOs, aggregators and EV owners

- Many **interesting questions to research**
- On **battery performance** – what is the potential in power density, hence size and range, and cost?
- On **network management** – how can charging be managed to deliver cheap low-C power without more investment?
- For the **Distribution Service Operator** – how to access frequency control and demand side response (LCNF projects)
- On **driving behaviour** – what would reduce range anxiety? Or is the BEV just the second car?
- On **business models** – own or rent/lease; own or swap battery?



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