Green Emotion - GEM

The Economics of Electric Vehicles

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E&E Seminar

Cambridge, 21st January 2013

Outline

- Statement of the problem
- Quick overview of vehicles
- Structure of Green eMotion and Imperial College activities
  - my tasks within that
  - Other activities – Low Carbon Network Project *I2EV*
- Business models under trial
- The economics of EVs and Plug-in Hybrids (PHVs)
  - contrasts with "Business case"
  - Links with other WPs looking at grid interactions
- Conclusions

Four year project, field trial data slow to arrive

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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: 8ys or 160,000 km, charge time: 7 hrs @ 240 V; charger costs $2,200; DC 500V fast charge in 30 mins ($17,000) **vehicle price UK £31,000***
- Performance 4.73km/kWh = 0.21 kWh/km, 0 -100 km/h in 10 secs
- Range: 117 km (175km Euro test); 75-100km at -7to-1^{o}C with heater and heavy traffic; typically charge 2hrs/night
- 7,500 US sample: av 60km/day; 11 km/trip

*** Reuters op/ed Sep 2012**: GM losing US$49,000 on each Volt built. The Volt is "over-engineered and over-priced"

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Battery Pack – not just a battery

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

Source: Element Energy (2012

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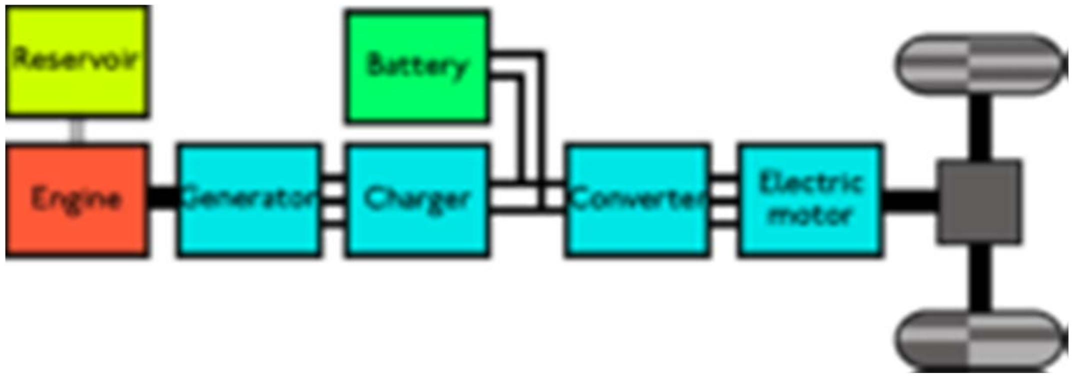
Chevy Volt 2012 PHV (Vauxhall Ampera)

- Engine: 1.4 L 63 kW; Motor: 111 kW; Battery: 16 kHh 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



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Toyota Prius 2012 PHV

- 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 90ft^3 . **Price £33,000** before subsidy
- 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

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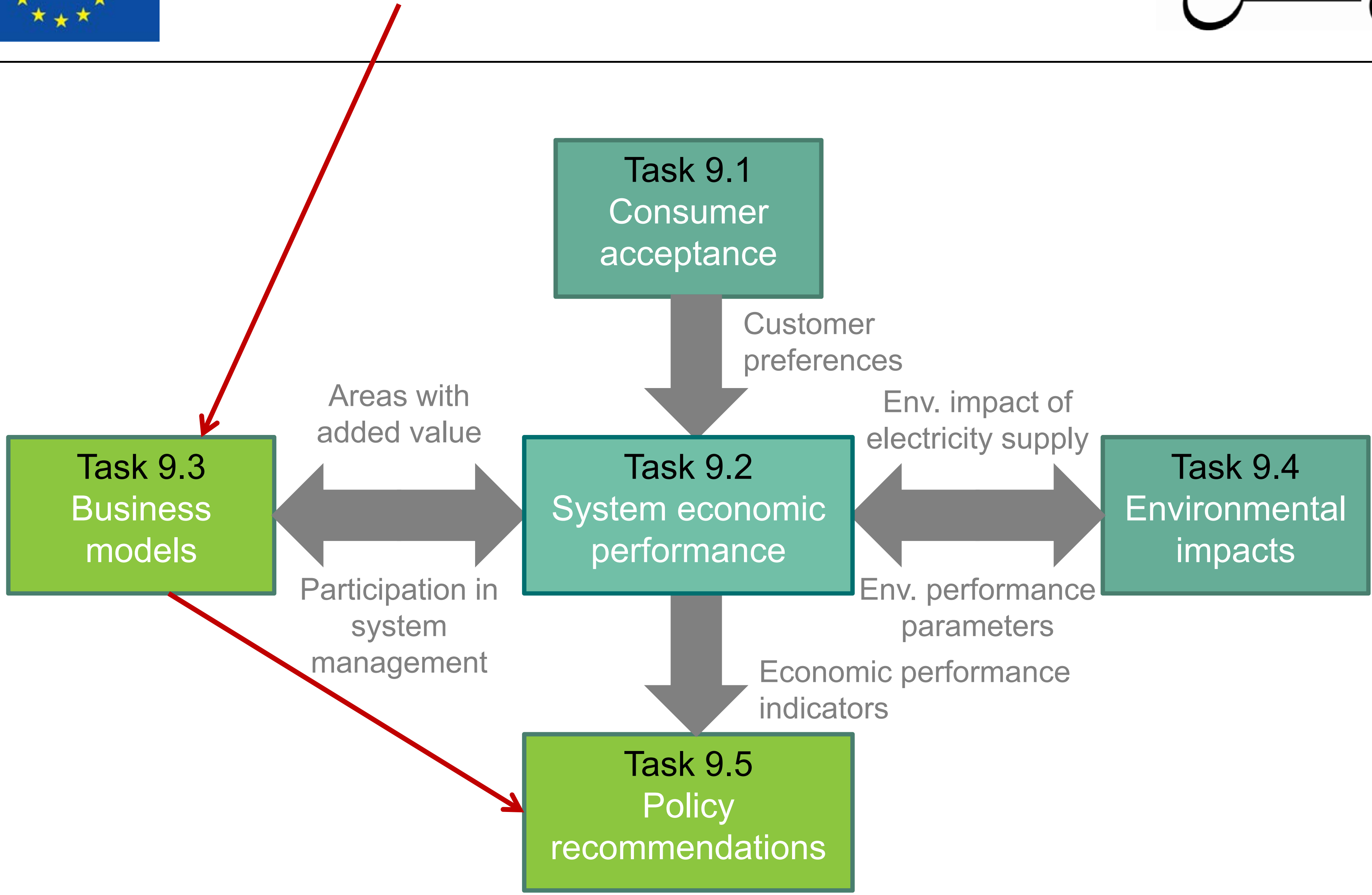
Experience of PHV:

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



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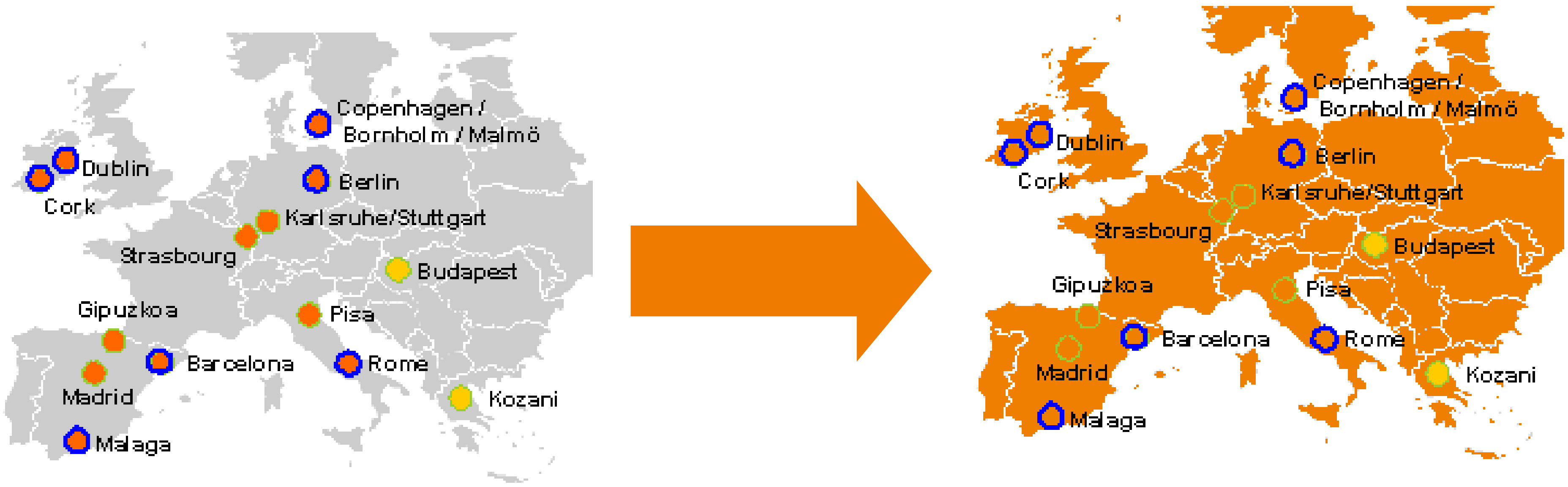
Imperial College London

Task Objective

Identify and analyse the most promising business models for allowing a widespread adoption of electric mobility in Europe.



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Considerations for Business Models Selection

WP1 Business Models (according to DoW):

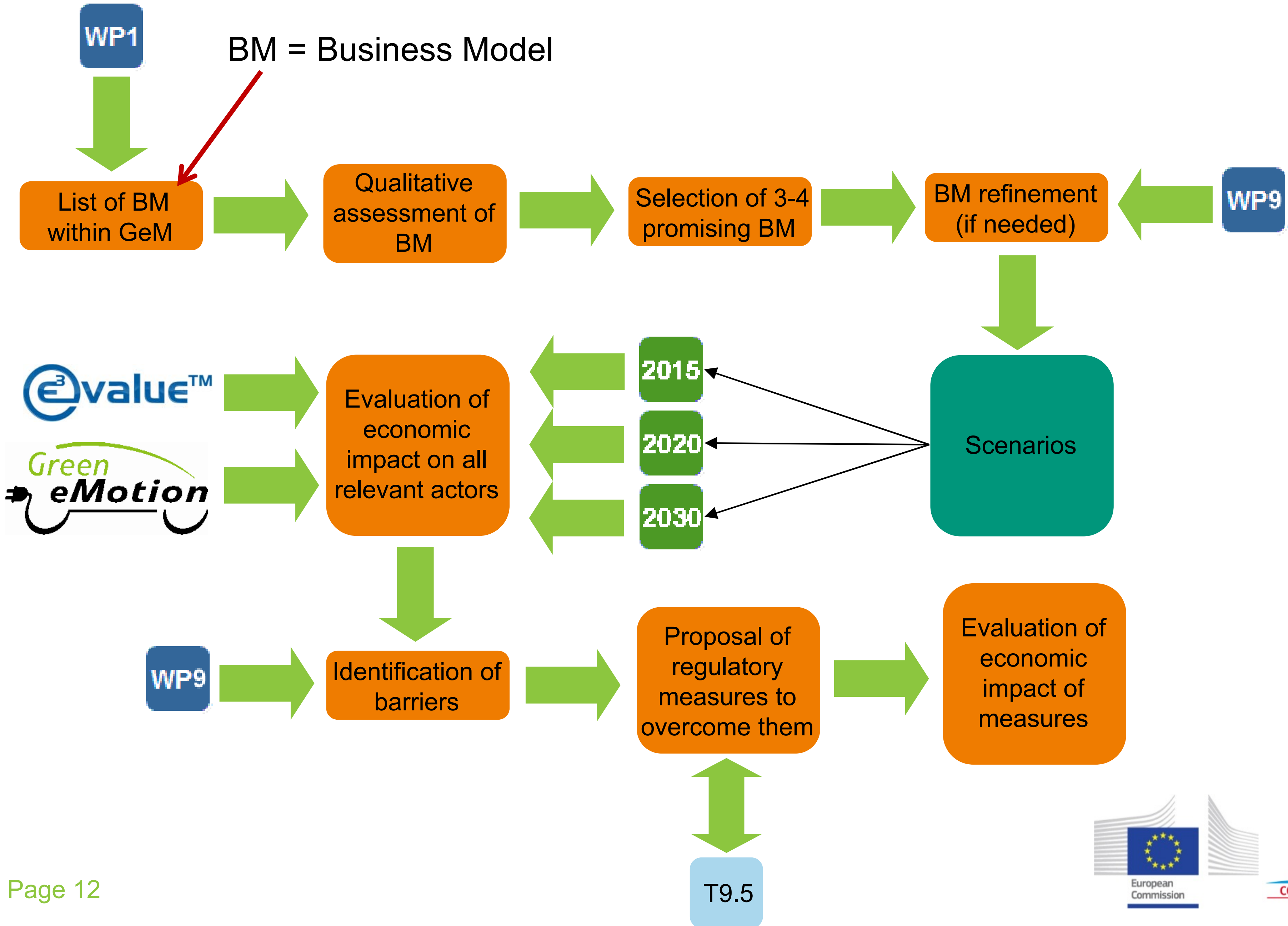
- Barcelona: **e-parking,** for cars + motorbikes
- Berlin: Post payment + **roaming,** public/semi/private, for cars/commercial
- Bornholm: Monthly subscription + roaming, public, cars/bikes/taxis/commercial
- Copenhagen: Subscription + roaming, **battery switch**, cars/commercial
- Copenhague2: Free, private, cars
- Malmoe: Free + roaming, public, cars/bikes
- Ireland: Post payment, public/semi/private, cars/commercial/taxis
- Italy: **Energy retailer**, public/private, cars
- Madrid: **Car renting**, public, cars/commercial
- Malaga: Energy retailer, private, cars
- Strasbourg: Free, public/semi/private, hybrid car
- Stuttgart-Karlsruhe: Energy retailer + roaming, public/semi/private, cars/commercial

Other projects

- Low Carbon Network Project *I2EV – Southern Electric Power Distribution Division*
  - *This project will trial a technology that will allow a cluster of electric vehicles (EVs) to re-charge without stressing the low voltage network. The aim is to test the effectiveness and acceptance by EV customers of an "intelligent socket" that is controlled from the distribution sub-station – ensuring that the load on the feeder is kept within acceptable limits.* **It will use the Nissan Leaf**

This project explores intelligent charging to reduce the electricity cost (to the network and EV owner)

Expected Task Development



Building the Business Model

- 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

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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

Better Place model*

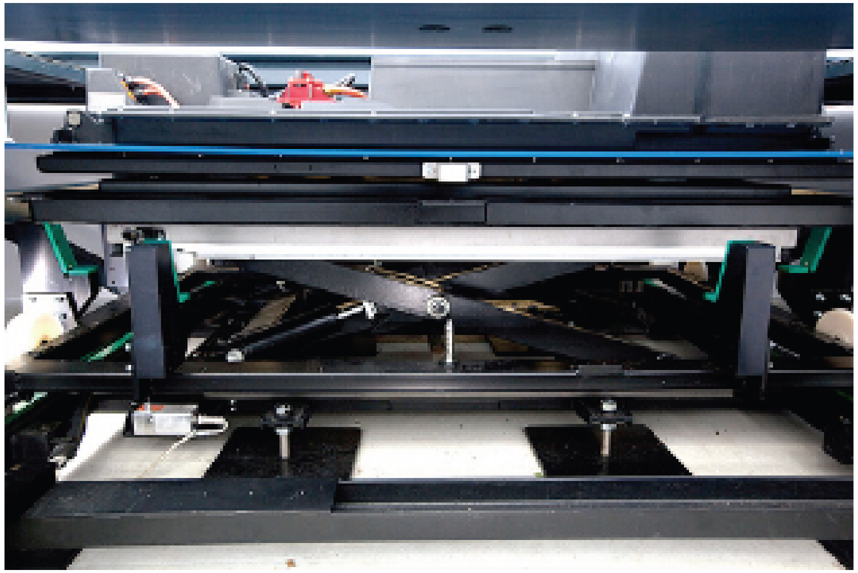
- Better Place (partner Renault) owns batteries
- Plans to install charging points in homes ($2,000 each), work places, and various public locations and offer services and DSM to DNOs.
  - Communication System provides data on battery, charging stations, battery exchange, GPS, etc

* NPC (2012) at http://www.npc.org/FTF_Topic_papers/14Emerging_Electric_Vehicle_Business_Models.pdf

Battery Switch Stations

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

Better Place Battery Switch Stations



BSS Battery Switch In-Progress

Better Place BSS in Ekron, Israel

eVgoSM subscription model

- NRG installed its first Freedom Station in Dallas/Fort Worth on **April 8, 2011**, as part of eVgoSM's network of charging stations.
  - DC Fast charger: delivers 50 miles of charge in 15 minutes 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, (11 already in place in Houston and six installed in Dallas/Fort Worth at **June 2012**)
- 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

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**

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Possible EV developments

- 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

Projecting the future

- 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

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Social cost benefit analysis and the business model

Green eMotion

- 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 CO_2 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

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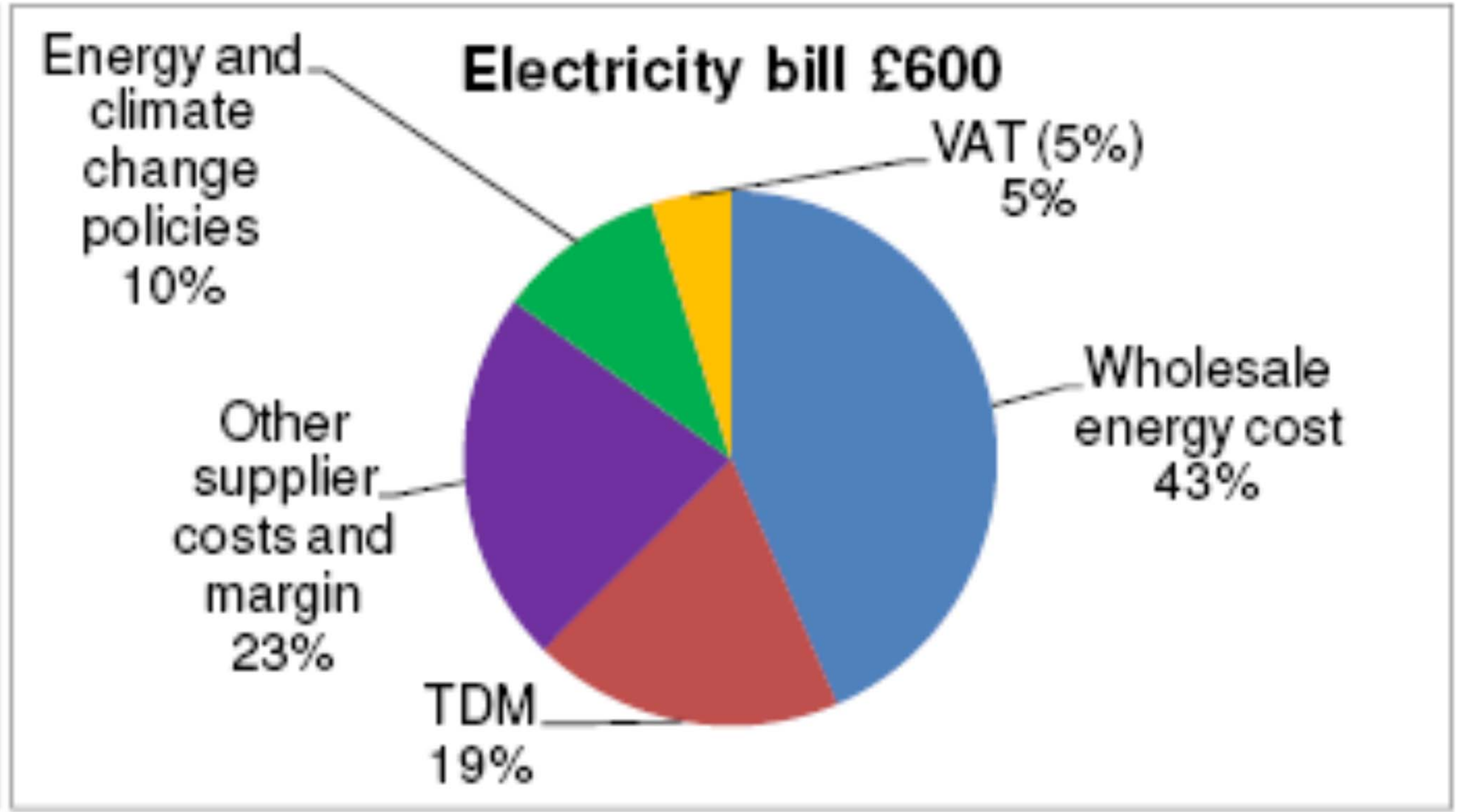
UK average domestic electricity prices include some tax-like charges but under-estimate carbon cost



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

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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

Other data issues

- 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

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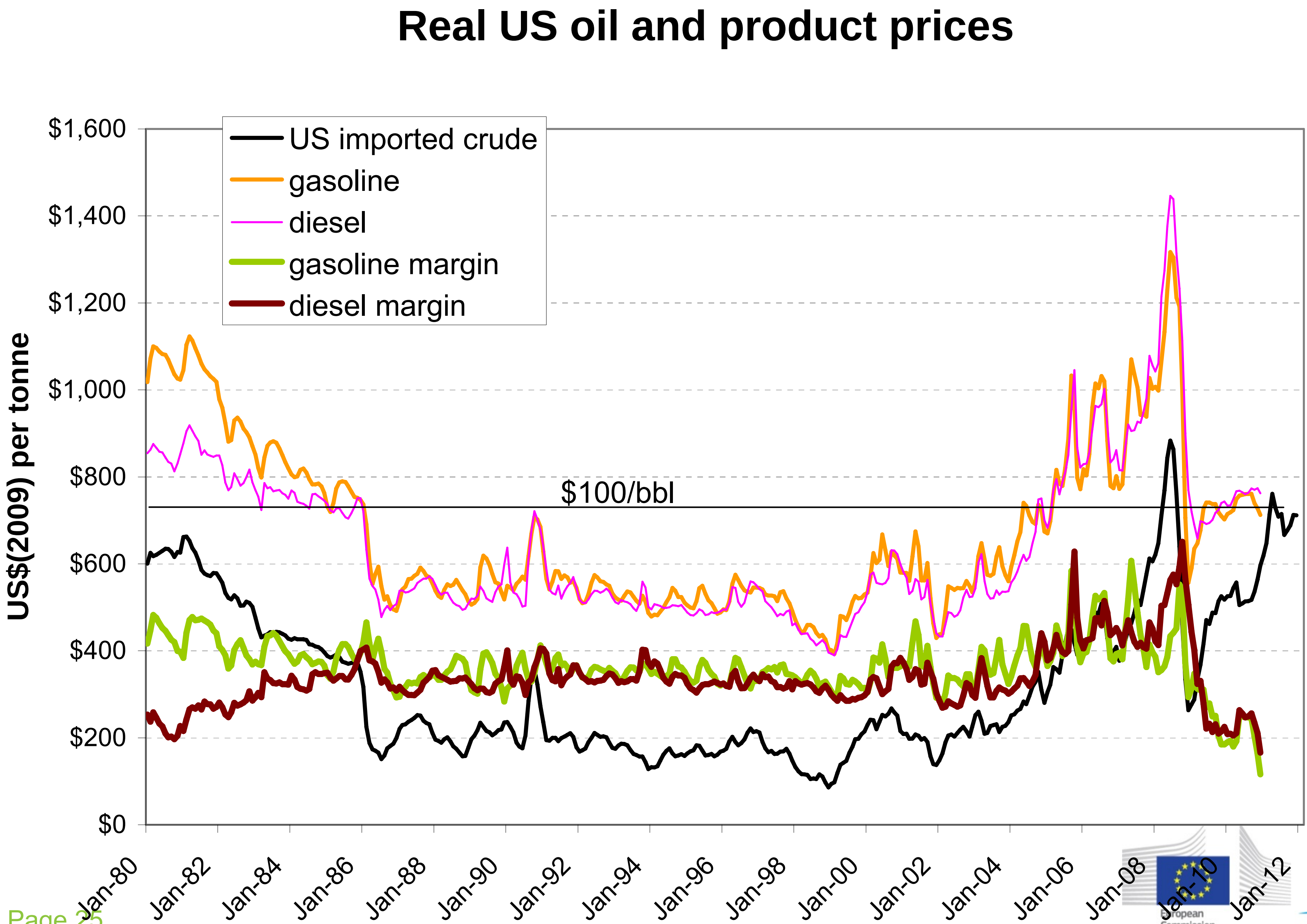
Oil prices are volatile, margins less so



Impact of carbon pricing

- 2020 DECC oil price projections **$(2012)/bbl**

	Low	Med	High
	$95	$125	$150

- energy content; D = 9.7kWh/L; G = 8.8 kWh/L
- pump prices *without any taxes* **€¢/kWh**

Diesel:	3.9	4.2	4.4
gasoline	4.8	5.0	5.3

- Add €50/tonne CO_2 and for **other pollution**

Diesel:	1.38 €¢/kWh	1.48 €¢/kWh
Gasoline:	1.35 €¢/kWh	0.56 €¢/kWh

Efficiency estimates

- IC vehicles where Low is current and high is possible

	Low	Med	High
Diesel:	30%	**35%**	41%
Gasoline	20%	**30%**	37%

- BEVs efficiency allowing for losses in battery

	Low	Med	High
	70%	**75%**	80%

Allows us to estimate target electricity plus battery cost at which BEV running cost = ICV fuel cost

- to which should be added differential maintenance cost

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

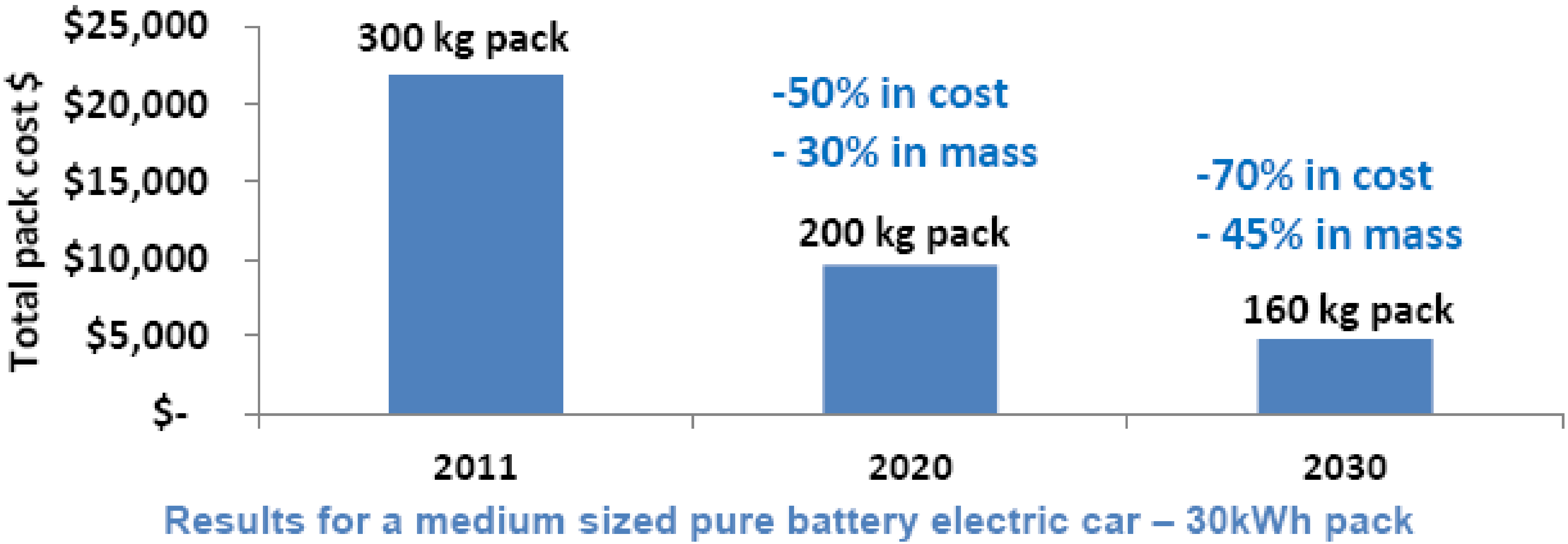
	Low	**Med**	High
Oil price $/bbl	$95	**$125**	$150
CO_2 €/EUA	25	**50**	75

- Target electricity ***plus battery cost* €¢/kWh**

Diesel:	10.4	**14.2**	18.4
Gasoline:	12.4	**17.0**	27.5

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.



Source: Element Energy (2012)

Cell plus packing costs for various BEV types

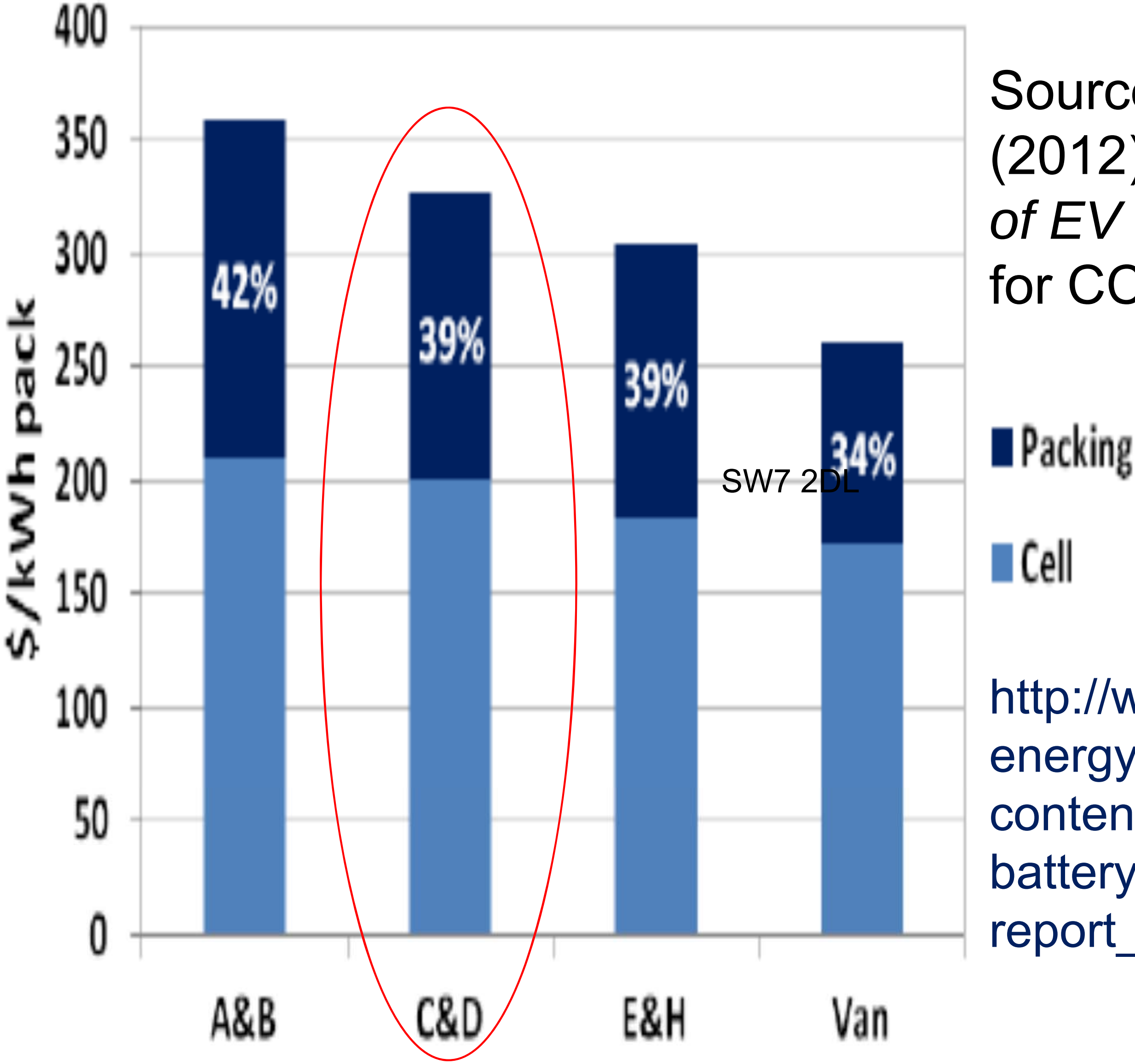


Figure 6-2 Cell and packing cost split in 2020 for the four defined BEV types

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

SW7 2DL

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

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Projected PHEV battery cost

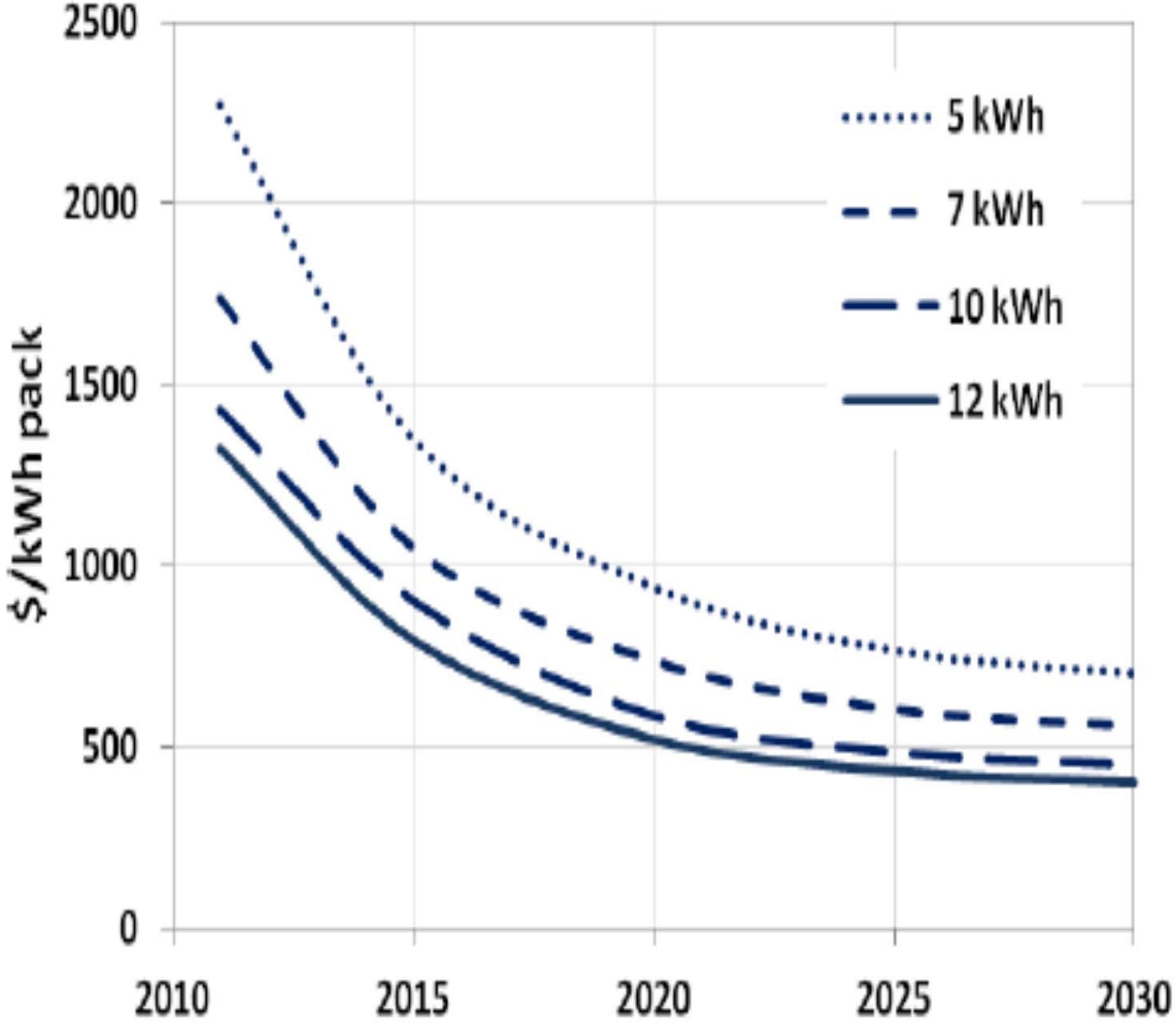

Figure 6-4 PHEV pack cost ($/kWh) for C&D 60kW pack for various pack sizes

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

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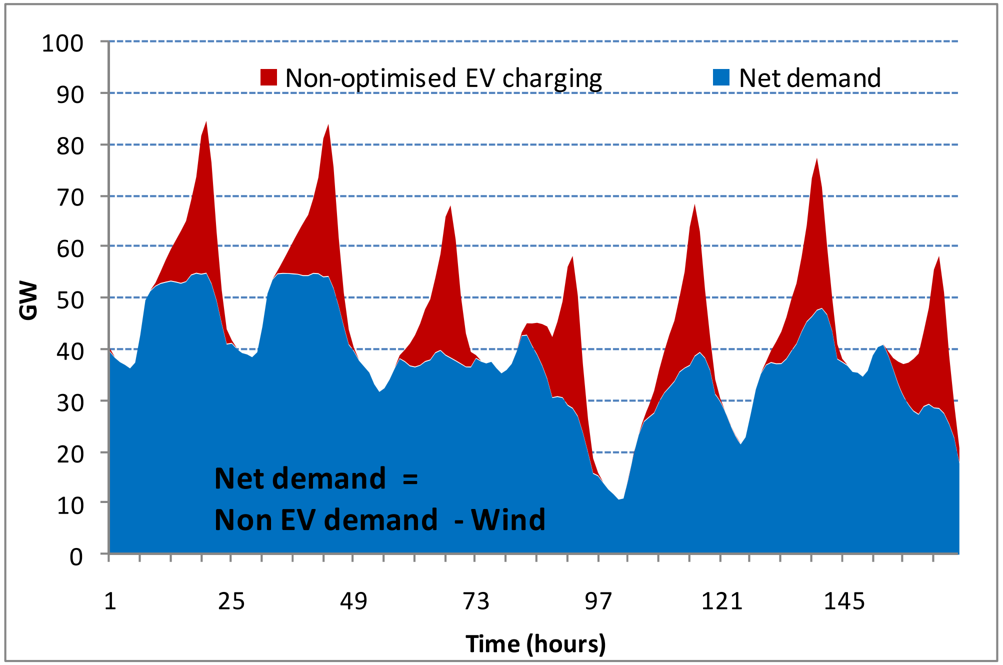
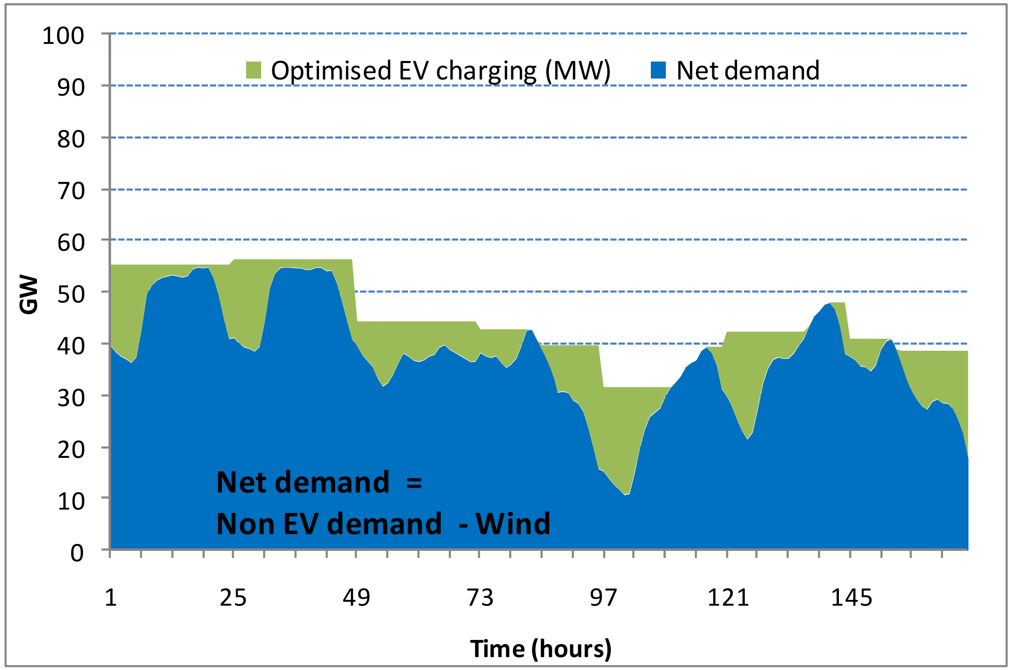
Impact of charging strategies on the need for conventional plant capacity and emissions and prices of electricity





- 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 (revised)

- 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, CO_2 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

Policy implications

- 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

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Conclusions

- 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)
  - 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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Experience of PHV:

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