Economics of Vehicle to Grid

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E4tech perspective:
Strategic thinking in energy

- International consulting firm, offices in UK and Switzerland
- Focus on sustainable energy
- Established 1997, always independent
- Deep expertise in technology, business and strategy, market assessment, techno-economic modelling, policy support...
- Spectrum of clients from start-ups to global corporations
Today

• Energy systems context for vehicle to grid

• New commercial opportunities

• Vehicle to grid economics
Energy system transition: different sources, vectors and uses

ETI 2050 scenario

Electricity: from centralised to intermittent, distributed and digital

Decarbonisation

Generation: nuclear(?), CCS(?), renewables

- Renewable energy is intermittent
- Low carbon generation is more distributed
- Consumers can also be generators
- Digital services connect consumers and generators
- Demand becomes smarter
Change will accelerate

1983

2016

2050

33 years

34 years
New commercial opportunities are being created

• Utilities focusing on capital-intensive generating assets

• New entrants focusing on asset-light ‘smart energy’

• Demand + supply + digital

Source: Company reports and websites. Renewable investment for Centrica not available
Opportunities come from several areas

Stacked Revenue Streams

- Even though National Grid would limit to one service per device, the same device can also be used to sell to DNOs and energy suppliers.
- Imbalance Management & Fault Management are technically feasible but not available today.
- Aggregators could use a geographically distributed asset portfolio to offer services like Constraint Management.
- When aggregated at the domestic level batteries could generate £300 – 600 per year, split between aggregator and homeowner.
V2G utilises a vehicle’s battery as a controllable store/load to provide income

**Income sources for vehicle / home owner**

- **Arbitrage**: ✓
- **Frequency response**: ✓
- **Demand turn-up**: ?
- **STOR**: ?
- **Fault management**: ?
- **Constraint management**: ?
- **Reactive power**: ?
- **Imbalance management**: ?

**Direct benefit**

**Services sold via aggregator**

No income ‘stacking’ assumed as not yet proven

✓ = modelled
Above all else, EVs must provide transportation

- Vehicle must remain available to travel:
  - when driver needs to
  - for as far as they’d normally expect to

- Must not damage battery:
  - No change to charge capability
  - Replacement cost ~£200/kWh

- Economic case only worth considering if drivers convinced of these points

Battery: [http://www.edmunds.com/car-technology/electric-car-battery-basics-capacity-charging-and-range.html](http://www.edmunds.com/car-technology/electric-car-battery-basics-capacity-charging-and-range.html)
EV batteries are well-suited to primary frequency response

- Primary response is the grid’s first line of defence in the event of a frequency deviation

- Lithium-ion batteries well-suited to primary response as:
  - Fast responding (<2 sec)
  - Minimum amount of energy transferred to the grid (<30 sec)
  - Can be switched to charge mode (if >50Hz)

- Service well-remunerated by National Grid
  - Availability payment
  - Use payment

In this example, the frequency level has been set around 49.8 at which point the automatic relay device in the response unit has instructed the unit to activate and operate at full power over 30 seconds until secondary response takes over for 30 minutes.

To evaluate frequency response we used real frequency data from National Grid to estimate revenues...

**Method**

1. Calculate number of vehicles needed in an aggregated vehicle pool

2. Assess when in the day vehicles would be available to provide frequency response

3. Compare the vehicle pool availability with actual demand for frequency response over a year

4. Calculate payments per event and sum over a year spread across fleet

**Assumptions**

- Assume 10 kW power rating for each vehicle – have to reach **10 MW across fleet**
- Average of 60% of vehicles in fleet available for V2G in base case. This is the minimum availability an aggregator would plan for **(1667 vehicles)**
- Assume to be the inverse of an owners’ work pattern (assumed 8am-6pm) so aggregator would only bid to provide V2G **6pm – 8am**
- Second-by-second frequency data from National Grid for 2014.
- Assume aggregator bid accepted for every weekday of the year.
- Price information publically available on National Grid website
- Split between aggregator and vehicle pool (30/70) derived from literature
- Spread over number of vehicles
Main variables affecting frequency response revenues are size of V2G charger and vehicle availability factor.

Frequency response revenue as a function of vehicle availability and size of charger

NB cost of charger not included

23 events identified on weekdays for 2014
We also built an arbitrage model to estimate revenues from vehicle-to-home discharging/charging

- The initial step was to assume technical specifications for battery packs:
  - **Energy capacity per vehicle** – nameplate capacity **10 kWh, 30 kWh, 50 kWh, and 70 kWh**
  - **State of charge** minimum charge of **20%** and a maximum **80%** relative to nameplate capacity
  - **Power capacity** of charger device **10kW**
  - **Round trip efficiency** of charge/discharge **92%**
- Driver specifications and behaviour assumptions are required to understand:
  - **Car available for arbitrage** **6pm to 8am**
  - **Daily driver energy requirement** 18km @ 0.17 kWh/km = **3.06 kWh**
  - **The minimum state of charge** the driver would accept during the night, which is treated as a variable of min. **20%** (always **80% at 8am**)
  - The model assumes consumers can benefit from variable prices. 2014 APX day-ahead prices were used for the arbitrage price signalling. This data is for half-hourly settlement periods for the duration of the year 2014. The model was structured to operate **one discharge/charge cycle between 6pm-8am**.
  - The model identifies the period with the highest price and the adjacent settlement periods which provide the **highest return for discharge**. Similarly the model identifies the lowest price signal and selects the adjacent settlement periods with the next **lowest price for charging** ensuring an 80% charge by 8am. It is assumed that all exported power is used locally.
Battery size and minimum required charge significantly affect an owner’s arbitrage revenue potential

Annual arbitrage revenue potential vs minimum required charge

NBCost of charger not included

State of charge is relative to nameplate capacity. Driver perceives as ‘full to empty’
Main findings

- The total value generated from **primary frequency response** could be significant, however, this is spread across the aggregated fleet and shared with aggregator. For base case (1667 vehicles at 60% availability, 10kW chargers)
  - **£452,000/year** across fleet
  - Only **£190/vehicle/year** to vehicle owner
- Alternatively (not stacked) **arbitrage** could offer the individual owner of a 30kWh vehicle who is prepared to accept min 50% state of charge overnight **£48/year**
- V2G charger implies **additional cost** onboard and offboard vehicle – V2G revenue should cover this
- Frequency response should only minimally affect the performance of the battery as the vast majority of revenue will come from being available to provide response rather than actually discharging or charging
- ‘Stacking revenues’ may lead to more attractive returns although V2G presents unique challenges – stationary storage developers are working on this.
V2G isn’t only about economics

• In Japan vehicle to home backup power unit sold for Nissan and Mitsubishi EVs
  • ~20kWh on full charge (Leaf)
  • Max 6kW AC
  • £1,800-£2,400 after subsidy

• Toyota Mirai fuel cell vehicle offered with Power Take Off in Japan and (TBC) US
  • ~60kWh on full tank
  • Max 9kW AC
  • Est. $1,200
In summary

• Energy system change will be fundamental, creating opportunities for different electricity sector services and actors

• Plugged-in vehicles are well-suited to provide some of these services, without inconveniencing vehicle owners

• Main sources of potential revenue are firm frequency response or arbitrage. Benefits might stack, but less certain

• Additional cost of charger must be covered – UK case currently looks weak

• Economics will vary by country

• Home backup generation is another incentive for V2G in some markets
E4tech – strategic thinking in sustainable energy

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