V2G GLOBAL ROADTRIP:
AROUND THE WORLD IN 50 PROJECTS

Lessons learned from fifty international vehicle-to-grid projects.
THIS REPORT PROVIDES A GLOBAL REVIEW OF V2G PROJECTS, TEASING OUT LESSONS LEARNED FOR THE UK AND BEYOND

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READY FOR A CROSS-CONTINENTAL ADVENTURE?
A SUMMARY OF LANDMARK V2G PROJECTS FROM AROUND THE GLOBE.

Vehicle-to-grid (V2G) technology is booming. Across the world, pioneering V2G projects are delivering cutting-edge insights through learning by doing.

But whilst most projects have published individual outcomes, no one before has ventured to systematically capture lessons learned – and apply these to the UK and beyond. This is a problem. By focusing only on activity at home, we risk repeating mistakes that others have already learned; and we risk missing out on early successes too.

So this report is a round-the-world road trip of landmark V2G projects. It is jointly commissioned by leading network operator UK Power Networks and innovation agency Innovate UK, both at the forefront of V2G demonstration. It’s an ambitious exploration, made possible only through the pan-industry support from contributors, and the records of intrepid explorers who have charted part of the way with early comparative reviews.

Our goal is to equip Distribution System Operators (DSOs) and market participants with the latest intelligence on where the value of V2G lies and what the challenges are. Please join us: pack your bags and off we go!

Vehicle-to-grid (V2G): Technology enabling bi-directional energy transfer from/to plug-in electric vehicles. This is distinct from ‘dumb’ one-way charging and ‘V1G’ or ‘smart’ charging where the rate and time of charge can be varied. Potential of V1G is considered in literature elsewhere.
As electric vehicle (EV) penetration increases, Distribution System Operators (DSOs) face new challenges in operating their networks. But with challenge comes opportunity. Vehicle-to-grid (V2G) technology enables bi-directional energy transfer from and to EVs, exploiting the storage potential of the batteries they contain. V2G promises to better integrate EVs whilst offering additional forms of flexibility at a local level.

Seeking to learn from wider experience on V2G, and maximise national innovation benefits, UK Power Networks and Innovate UK have together commissioned a global review of this technology.

This report is a round-the-world roadtrip of landmark V2G projects. We’ve ventured to equip DSOs and market participants with the latest global V2G intelligence and where the challenges lie.

**OUR JOURNEY**

1. **Mapping the journey:** Every good roadtrip begins with a plan. So we started with a grand mapping exercise – reviewing the literature and contacting leading experts to form a definitive project list. Our criteria for inclusion was physical deployment of V2G technology for a specific use case. This excluded experimental research and narrow technology demonstration.

2. **Stop-offs on the way:** We scheduled ‘stop-offs’ with ten must-see landmark projects – holding interviews to understand the customer offer, service readiness and operational findings.

3. **Our journal:** All of this travel prompted reflection. We logged what we learned – and teased out the transferability to the UK.

It’s been an ambitious exploration, made possible only through the support of contributors on the way – for which we are very grateful. Here’s what we found.

There are 50 V2G projects globally, of which 25 are in Europe, 18 in North America, and 7 in Asia. Asian participation has been more focused on vehicle-to-home and vehicle-to-building (V2H/B) services and contributing as a manufacturing partner than deployment.

Almost all projects had a technical element (98%). Few focused on social aspects (27%). This reflects the sector’s fledging status and early teething problems with V2G charger technology. Interviewees emphasised the need for greater focus on user behaviour going forward.

**RENAULT NISSAN MITSUBISHI DOMINATE MARKET**

Although 12 vehicle manufacturers (OEMs) have participated in V2G projects, Renault Nissan Mitsubishi clearly dominates. This arguably reflects the legacy of the Fukushima disaster, and the successful integration of V2G within the CHAdeMO protocol (see p10).

**DC SOLUTIONS DOMINATE**

DC solutions have dominated to date with DC chargers featured in 93% of projects. However there remains significant interest in AC with more AC compatible vehicles expected over the coming years.
**EXECUTIVE SUMMARY**

**ONLY 10 V2G PROJECTS ARE PROVIDING DISTRIBUTION SERVICES – BUT UK DSOs CAN LEARN FROM V2G’S TRACK RECORD IN PROVIDING OTHER SERVICES**

**DISTRIBUTION SERVICES PROVIDED IN 10 PROJECTS**

Services provided to Distribution System Operators (DSOs) are under-represented in global V2G projects – though this appears to reflect lack of DSO service maturity more than inherent V2G capability. Time-shifting and frequency response have been focus areas due to their high value.

**DSOS CAN LEARN FROM V2G's TRACK RECORD IN OTHER SERVICES**

A Service Readiness Level (SRL) summarises the techno-commercial readiness of V2G systems to provide a particular service in the UK. From our review of projects globally, distribution-level services have a low SRL of 3. Lessons learned from higher SRLs for other services should help accelerate roll-out. However, a key difference with distribution services is the location specificity required, which complicates the aggregate statistical approach taken to guarantee availability and performance.

<table>
<thead>
<tr>
<th>SERVICE</th>
<th># OF PROJECTS GLOBALLY*</th>
<th>1. RESEARCHED</th>
<th>2. TESTING</th>
<th>3. PROVEN</th>
<th>4. COMMERCIAL ANYWHERE</th>
<th>5. COMMERCIAL (SIMILAR UK)</th>
<th>6. COMMERCIAL COMPETITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arbitrage</td>
<td>4</td>
<td>FRANCE, DENMARK</td>
<td>NL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reserve</td>
<td>2</td>
<td>FRANCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freq Resp.</td>
<td>16</td>
<td>FRANCE</td>
<td>NL</td>
<td>USA</td>
<td>DENMARK</td>
<td></td>
<td>Expected in UK shortly</td>
</tr>
<tr>
<td>DSO Services</td>
<td>10</td>
<td>DENMARK</td>
<td>UK, NL, (DE)</td>
<td>US</td>
<td></td>
<td></td>
<td>Expected in US 18/19</td>
</tr>
<tr>
<td>Time Shifting***</td>
<td>23</td>
<td>KOREA</td>
<td></td>
<td>USA, UK</td>
<td>JAPAN (Expected in US 18/19)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Multiple selections permitted  
**Full definition of SRL on slide 11  
***For energy users

**10 LANDMARK PROJECTS ARE ESPECIALLY INTERESTING**

1. Denmark, 2016  
   “Parker” World’s first fully commercial vehicle-to-grid hub: Nuvve

2. Germany, 2018  
   “Re-redisplay” Unique redispatch approach: TenneT

3. Netherlands, 2014  
   “Cityzen Smart City”, Innovative DSO services trial: Alliander

4. Netherlands, 2014  
   “Smart Solar Charging” Distinctive AC approach: LomboXnet

5. France, 2017  
   “Grid Motion” Delivering cutting-edge customer insights: Groupe PSA

6. Korea, 2014  
   “Korean V2G” Preparing Korea for EV roll out: KEPCO, Hyundai

7. Japan, 2012  
   “M-tech Labo” Pioneering vehicle-to-building model: Mitsubishi Motors Corp.

8. US, 2012  
   “JUMPSmart MAUI”, V2G via V2H with 80 chargers on island of Maui: Hitachi

9. US, 2017  
   “INVENT” 50 chargers with innovative EMS: Nuvve and UC San Diego

10. UK, 2018  
    “Network impact” DNO-led study of V2G network impact: Northern Powergrid

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EXECUTIVE SUMMARY

SO WHAT? LESSONS FROM OUR ROADTRIP

FOR NETWORK OPERATORS

1. ADAPT INTERCONNECTION STANDARDS & PROCESSES: The EV community does not expect special treatment. But along with other distributed energy providers—such as domestic demand-side response—it expects requirements and costs to be proportionate to asset size.

2. CLARIFY THE VALUE OF DSO SERVICES: Global projects have tended to focus on other non-DSO services only because the value and service specification of other services have, to date, been clearer.

3. DESIGN SERVICE SPECIFICATIONS WITH V2G IN MIND: in particular, consider the:
   i. response time required (with V2G able to provide a response within 2 seconds)
   ii. duration the service needs to be provided for (with a balance between power and length of service), and;
   iii. availability and performance levels provided by fundamentally less controllable assets.

4. MATURE THE HARDWARE: Few bidirectional chargers and vehicles (particularly AC) are commercially available at present, with performance challenges and high costs. A greater range and maturity of technology is expected in the coming years.

5. TARGET SERVICES WHERE V2G ADDS VALUE: Smart charging (V1G) is sufficient for many services. However, V2G offers unique value in these scenarios: (1) for services where location matters; (2) locations with surplus solar capacity; (3) markets with high peak pricing or charges; and/or (4) for longer duration services. Yet even here, V2G charger cost reduction is essential for economic viability.

6. SEGMENT USER BEHAVIOUR: Customers have typically been a secondary consideration to date. Yet customers are diverse (families, fleets, car-share schemes and/or school buses all featured in this review). This diversity aids V2G and 24/7 service provision but means segmentation of customers is more useful than averages. Innovations should target mobility-as-service models.

FOR INDUSTRY

FOR GOVERNMENT

Support and enable Network Operators and Industry to achieve the above, to unlock the potential of V2G
Vehicle-to-grid (V2G) technology could potentially be one of the most important technological innovations to hit the electricity network since distributed renewable energy became commercially viable. It could eventually millions of mobile energy assets can be deployed in an instant to prop up local networks and contribute to the national transmission system.

Earlier this year Innovate UK announced a series of large-scale V2G demonstrator projects. UK Power Networks is part of consortia that won a total of £11 million for five different projects, from a trial of 1,000 V2G fleet vehicles to helping a bus garage in London become the country’s first clean green electric facility of its type. We have jointly commissioned this report, an international summary of V2G, to ensure that our activity is fully informed by lessons learned abroad.

The road to V2G isn’t going to be easy. Significant technical challenges remain. The cost of bi-directional chargers is still prohibitive. And with a nascent market, electricity networks need to move quickly to enable the potential to be realised.

Yet the government’s commitment to V2G demonstrator projects shows there is political will and strong interest from across the industry. The opportunity is waiting to be taken, the ambitious in the industry will reap the rewards.

The energy system is undergoing a pivotal change. Renewable generation is consistently increasing and demand loads are becoming active agents in the power system. Ubiquitous use of two way communication and closer interaction between assets and players on the grid will allow smarter interactions.

One thing seems certain – consumers will play a key role in driving the change as their energy needs for warmth, light, power and, increasingly, mobility change.

At InnovateUK, we’re excited about V2G’s potential role in this future energy system. We have been pleased to award funding to 21 vehicle-to-grid projects, to pay for research and design and development, with the aim of exploring and trialling both the technology itself and commercial opportunities. This represents almost £30 million in government funding.

Yet in order for us to effectively support businesses to develop and realise the potential of new ideas, it’s also important that we remain abreast of the wider global context. We hope that the findings of this report help inform innovation in the UK, learning lessons to boost productivity and economic growth.

Through such innovation, consumers will move from being on the edge of the energy system to being at its heart. Now that’s an exciting prospect indeed.
Every good roadtrip begins with a plan. What projects are out there? We survey the literature and contact leading experts to form a definitive list.
A LITERATURE REVIEW REVEALED 50 V2G PHYSICAL PROJECTS DELIVERING CLEAR USE CASES. EUROPE AND NORTH AMERICA ARE CLEAR HOTSPOTS OF ACTIVITY.

Before embarking on our road-the-world trip, we need to map out what’s out there. Through a combination of literature review, targeted discussions and LinkedIn promotion, we identified 50 projects that met the threshold criteria for inclusion. The literature review excluded 8 V2G demonstrator projects (and 13 research and feasibility studies) recently funded by Innovate UK, as documented in Appendix 1. A full project list is provided in Appendix 1, and sources logged in Appendix 2.

Our criteria for project inclusion in list was for projects to have physical deployment of V2G technology for a specific use case. The list excludes desk-based studies, experimental research and narrow technology demonstration. Collecting detailed data on projects is challenging: This is in stark contrast to the often detailed data available for stationary storage projects on the global NREL database, and the data compilation on renewables projects conducted by Trade Associations.

Note: Details are based on a review of public domain sources; however, we note that these datapoints are not always clear, and it is common for a project’s number of chargers and trialled services to evolve over time.
MOST PROJECTS HAVE HAD A TECHNICAL FOCUS – WITH USER BEHAVIOUR ONLY BEING EXPLORED MORE RECENTLY. JAPANESE OEMS HAVE DOMINATED THE MARKET.

HALF OF PROJECTS ARE IN EUROPE

50 V2G PROJECTS GLOBALLY

OF WHICH
25 ARE IN EUROPE (50%)
18 ARE IN NORTH AMERICA (36%)
7 ARE IN ASIA (14%)

There are 50 V2G projects globally, of which 25 are in Europe, 18 in North America, and 7 in Asia. In Europe, Northern European states dominate with the Netherlands, Denmark, UK and Germany the market leaders. Activity in the US is primarily in California, Hawaii and Delaware. Project data shows that Asian participation has been more focused on contributing as a manufacturing partner than being a home for deployment, with a few notable exceptions.

RENAULT NISSAN MITSUBISHI DOMINATE MARKET

Although 12 vehicle manufacturers (OEMs) have participated in V2G projects, Renault Nissan Mitsubishi clearly dominate. This arguably reflects the legacy of the Fukushima disaster, and the successful integration of V2G within the CHAdeMO protocol (see p10).

SOCIAL ISSUES OFTEN OVERLOOKED

Almost all projects had a technical element (98%). Few focused on social aspects (27%). This reflects the sector’s fledging status and early teething problems with V2G charger technology. Interviewees emphasised the need for greater focus on user behaviour going forward.

DC SOLUTIONS FEATURED IN 93% PROJECTS

DC solutions have dominated to date with DC chargers featured in 93% of projects. However there remains significant interest in AC, with more AC compatible vehicles expected over the coming years.
V2G HAS BEEN TECHNICALLY DEMONSTRATED FOR OVER A DECADE. THE SECTOR’S CHALLENGE HAS BEEN IDENTIFYING A Viable COMMERCIAL MODEL

PRE 2012 – THE EARLY YEARS

- V2G was pioneered at the Uni of Delaware by Prof. Willett Kempton in 1990s, leading to the first real world test of frequency response with seven vehicles in the PJM* market in 2008.
- In 2011, the Fukushima disaster in Japan spurred Japanese OEMs and market participants to develop bidirectional capability. This led to the development of the CHAdeMO protocol and set the scene for the larger deployments to come.

2012~2015 MAJOR PROJECTS DEMONSTRATE TECHNICAL VIABILITY OF V2G IN RANGE OF MARKETS

- Grid to wheels project in US proves EVs can provide FR services to PJM*
- JumpSMARTMaui installs 80 centrally-controlled V2H chargers, helping manage evening peaks on Maui
- German lighthouse project INEES demonstrates technical viability of V2G using 20 Volkswagen UP and 40 SMA bi-directional chargers
- Commercial LEAF to home service launched in Japan – over 4000 sold by 2017

2016 – 2018 SEARCH FOR THE RIGHT COMMERCIAL MODEL TO UNLOCK SCALE

- Since 2016 market searching for scalable commercial model.
- Viability has been hindered by a lack of competitive hardware
- Frequency response prices have declined in the UK reducing value available to V2G projects targeting this revenue stream
- One highlight has been Parker providing commercial frequency response in Denmark (although deployment in the Danish market has been limited by high taxes on EVs).

THE FUTURE!

- More chargers and more cars! The rise of AC?
- First commercial offers being announced in California and the UK
- Greater focus on DSO services as the value and service specification becomes clear
- Integration of V2G into broader mobility offers

FOOTNOTE: More chargers and more cars! The rise of AC?
- First commercial offers being announced in California and the UK
- Greater focus on DSO services as the value and service specification becomes clear
- Integration of V2G into broader mobility offers

FOOTNOTE: A number of V2G projects across Europe have scaled back on their ambitions on number of chargers. The reasons are multiple, including:

- Technical: Technical testing problems in Phase I deployment, e.g. bugs with chargers, leading to budget reallocations.
- Economic: Prohibitively high cost of chargers, and diminishing returns to learning from deploying more (uncompetitive) chargers.
- Social: Challenges in securing customers willing to participate in scheme

*PJM is a regional transmission organization (RTO) in the USA that coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia
IN ADDITION TO IDENTIFYING PROJECTS, WE DEVELOPED THREE METRICS OF README LEVEL TO ASSESS GLOBAL V2G TRACK RECORD

PROJECT GOAL
To help assess the techno-commercial readiness of V2G systems to provide various services in the UK we have developed three indicators of maturity, called ‘readiness levels’. The readiness levels reviewed are:

- **Technology Readiness**: focused specifically at chargepoint technology
- **Market Readiness**: focused on the openness of the market reviewed to V2G.
- **Service Readiness**: focused on the ability of V2G to provide a specific system service

Each is now discussed in more detail.

### Technology Readiness Level (TRL)

TRL is a tool developed by NASA and used by a range of other organisations (e.g. European Commission) for monitoring technology support from basic research through to system demonstration for a range of conditions, and is commonly applied in the innovation space. In this report, we use TRL to describe the maturity of V2G chargepoint technology.

<table>
<thead>
<tr>
<th>TRL Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic principles observed</td>
</tr>
<tr>
<td>2</td>
<td>Technology concept formulated</td>
</tr>
<tr>
<td>3</td>
<td>Experimental proof of concept</td>
</tr>
<tr>
<td>4</td>
<td>Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)</td>
</tr>
<tr>
<td>5</td>
<td>Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)</td>
</tr>
<tr>
<td>6</td>
<td>System prototype demonstrated in operational environment (industrially relevant environment in the case of key enabling technologies)</td>
</tr>
<tr>
<td>7</td>
<td>System complete and qualified</td>
</tr>
<tr>
<td>8</td>
<td>Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies)</td>
</tr>
<tr>
<td>9</td>
<td>Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies)</td>
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</tbody>
</table>

### Market Readiness Level (MRL)

A country’s procurement readiness for V2G, focusing on the openness of demand response markets from distributed assets, including any regulatory barriers.

<table>
<thead>
<tr>
<th>MRL Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>Score taken directly from ‘DSR enabled energy markets’ categorisation in Cenex (2018) or if market not covered qualitative assessment by Everoze and EVConsult. Specific regulatory barriers identified through interviews.</td>
</tr>
<tr>
<td>MEDIUM</td>
<td></td>
</tr>
<tr>
<td>HIGH</td>
<td></td>
</tr>
</tbody>
</table>

### Service Readiness Level (SRL)

We have adapted the TRL metric into a Service Readiness Level for the UK as follows:

The techno-commercial readiness of V2G systems to provide a particular service in the UK.

<table>
<thead>
<tr>
<th>Service Readiness Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEASIBLE</td>
<td>Service theoretically feasible</td>
</tr>
<tr>
<td>TESTED/ TESTING</td>
<td>Demonstrated that system can technically provide the service (i.e. proof of concept trial)</td>
</tr>
<tr>
<td>PROVEN</td>
<td>Demonstrated in small-scale commercial trial (most likely with Gov. support and funding)</td>
</tr>
<tr>
<td>COMMERCIAL ANYWHERE</td>
<td>Service being procured commercially from V2G, in any market not necessarily similar or applicable to the UK</td>
</tr>
<tr>
<td>COMMERCIAL (SIMILAR TO UK)</td>
<td>Service being procured commercially from V2G in market that is not vertically integrated</td>
</tr>
<tr>
<td>COMMERCIAL COMPETITION</td>
<td>Service being procured commercially from V2G in market that is not vertically integrated, with some degree of competition from V2G providers</td>
</tr>
</tbody>
</table>
STOP-OFFS ON THE WAY

Right, so we’re off! Time to see the must-see landmark projects! We shortlist 10 showcase projects and marvel at what’s been achieved, taking Dashboard Snapshots along the way.
WE SELECTED 10 LANDMARK PROJECTS FOR DETAILED REVIEW ON OUR GLOBAL V2G ROADTRIP. THESE ARE FEATURED ON THE FOLLOWING SLIDES.

1. PICKING OUR LANDMARK PROJECTS

The projects on the following 10 slides have been shortlisted as landmark must-see projects, based on the following criteria:

- Focus on DSO services (where possible)
- Breadth of customer offer and geography
- Project maturity, with a preference for projects where clear learnings and direction for future development and implementation can be extracted
- Applicability to UK.

2. DEVELOPING DASHBOARDS

We developed Project dashboards to enable systematic comparison of projects. They were populated based on literature review and following targeted interviews with project representatives.

OUR JOURNEY: KEY LANDMARKS

1. Denmark, 2016 “Parker” World’s first fully commercial vehicle-to-grid hub: Nuve, p15
2. Germany, 2018 “Re-dispatch” Unique redispatch approach: TeneT, p16
3. Netherlands, 2014 “City-zen Smart City”, Ground-breaking DSO services trial: Alliander, p17
4. Netherlands, 2014 “Smart Solar Charging” Distinctive AC approach: LomboXnet, p18
9. US, 2017 “INVENT” 50 chargers with innovative EMS: Nuvve and UC San Diego, p23
10. UK, 2018 “Network impact” DNO-led study of V2G impact on network: Northern Powergrid, p24
SERVICES ARE CHARACTERISED BASED ON THEIR TECHNICAL PARAMETERS

The table below characterises the services provided by V2G systems, in a way that strikes a balance between standardisation and presenting market-specific features.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>DEFINITION</th>
<th>OPTIONS</th>
</tr>
</thead>
</table>
| **Beneficiary**| The party that benefits from the service.                                  | ▪ TSO: Transmission System Operator  
▪ DSO: Distribution System Operator  
▪ TPI: Third Party Intermediary (an actor participating in energy markets)  
▪ Consumer: Onsite energy consumer, behind-the-meter |
| **Service**    | A defined technical product provided to System Operators, Networks Operators, utilities or consumers | ▪ Frequency response – fast acting service seeking to keep system frequency within specified limits  
▪ Reserve – slower acting service provided over a longer duration  
▪ Arbitrage – buying energy at low prices and selling at high prices  
▪ Distribution services – services to the DNO or DSO, typically involving constraint management or voltage control  
▪ Time shifting for energy users – shifting when customers use energy thereby reducing charges and/or increasing self consumption |
| **V2G**        | Type of service provided                                                   | ▪ V2G: Vehicle-to-grid. Vehicle provides services to regional network or national system  
▪ V2B: Vehicle-to-building. Vehicles are integrated into (non-residential) building energy management, providing behind the meter services  
▪ V2H: Vehicle to home. Vehicle provides services to home with chargers behind the meter  
▪ V1G: commonly referred to as ‘Smart Charging’, the vehicle only supports uni-directional charging (no exports) and provides services by altering its charging load. |
| **When to act**| When service is provided                                                  | ▪ Pre-fault: before a fault is experienced on a system, for instance frequency response with a tight trigger frequency  
▪ Post-fault: after a fault has occurred |
| **Triggering Action** | The mechanism through which a response is triggered | ▪ Grid frequency: e.g. frequency hits set threshold such as 49.9Hz  
▪ Back office control signal: e.g. event beneficiary sends signal to vehicle that triggers a response  
▪ Other local signal: to be defined  
▪ N/A – scheduled: Service is contracted to commence at a pre-agreed time |
| **Response speed** | The time to provide full response after receiving trigger | Subject to service specification but typically:  
▪ Seconds for frequency response  
▪ Minutes for reserve  
▪ N/A - scheduled |
| **Duration of service** | For how long service is required                                           | Subject to service specification but typically:  
▪ < 1 hour for frequency response  
▪ Minutes to hours for reserve  
▪ 1-4 hours for peak shaving & constraint management |
PARKER

Landmark commercial deployment of V2G in Danish frequency response market – engaging multiple fleets, vehicles & locations.

Project sought to test ability of electric vehicles to provide grid services using real world fleets. Identified and addressed barriers to commercialisation. Compared capability of different cars. Follows from Edison and Nikola projects. Linked to ACES project on Bornholm.

DTU Elektro/PowerLabDK (Project lead), NUVVE (Aggregator), Nissan, Groupe PSA, Mitsubishi Motors (Car OEMs), Insero (Other), Frederiksberg Forsyning (Host and Fleet), Enel (Charger), Mitsubishi Corp (Tech)

2016-18

PARTNERS

SERVICE FOCUS

COMMERCIAL

TECHNICAL

SOCIAL

PROJECT VALUE

DKK 14,731,471 (financed by ForskEL)

SERVICE PROVISION

TSO

V2G?

WHEN TO ACT

TRIGGERING ACTION

RESPONSE SPEED

DURATION OF SERVICE

STATUS

DSO

Constraint management

Trading on day-ahead / intraday

TPI

Constraint management

Trading on day-ahead / intraday

CUSTOMER SNAPSHOT

50 units

ENEL 10kW DC charger

CUSTOMER OFFER

Monthly fee which includes charger

USER BEHAVIOUR

Every fleet is different.

Customers have access to app on phone to indicate what state of charge they would need at what point in the day.

Some users don’t want to use the app, so then a schedule is put in for them.

Important to understand customer schedule.

ARCHITECTURE

App informs Nuvve of drivers’ preferences and charge required. This resource is then matched to grid and market signals to provide service.

For V2G CHAdEMO protocol is being used.

BATTERY USAGE FOR V2G: 30% to 95%

Main Daily Market is FCR-N in DK2. Project accessed market through Energinet participation, & now have commercial contracts with customers. Key regulatory barriers identified include i) long duration freq. bids – service required often exceeded kWh capacity requiring lower kW bids ii) two way energy loss - (discharging at power levels lower than the rating of the charging equipment can result in low efficiency and high losses. Efficiency of 90%+ expected in future. iii) battery degradation impact (see INVENT slide for further details)

MARKET

Commerically available

OPERATIONAL SNAPSHOT

USER BEHAVIOUR

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**SERVICE PROVISION**

**PARTNERS**
- TenneT
- The Mobility House
- Nissan

**PROJECT VALUE** Corporate funding + TenneT

**SERVICE**
- TSO constraint management

**BENEFICIARY**
- TSO

**PROJECT FOCUS**
1. TECHNICAL

**TECHNOLOGY**
- EVTEC bidirectional charging technology is mature, but not yet in series production.

**MARKET**
- High. Active demand side response market. Non-vertically integrated market. Regulatory barriers include that storage not yet a regulatory category, creating 'double-charging' problem – i.e., it can be charged at both producer and consumer. Necessity for each vehicle to be individually registered as a power plant.

**OPERATIONAL SNAPSHOT**

**CUSTOMER SNAPSHOT**
- Potential commercial value is very high. In 2017, 5.5TWh of renewables was curtailed in Germany, at a cost of €1.4bn. Network upgrades to manage this could cost €18bn. 5.5TWh could charge ~2m EVs for one year.

**SEGMENT**
- COMMERCIAL
  - TSO’s service cars, driving ~150km/day + 2 HQ cars.

**CHARGING LOCATION**
- WORK
  - At substations & at HQ office. Multiple across north & south Germany.

**VEHICLE**
- Nissan LEAF & ENV200, 40kWh.

**BATTERY USAGE FOR V2G:** Permission from Nissan to drop State of Charge (SoC) to 35%

**CUSTOMER OFFER**
- Field service fleet is expected to provide mobility services in a relatively routine, scheduled manner during standard working hours. Assets will be plugged in and available overnight.

**ARCHITECTURE**
- The Mobility House (TMH) provide load and energy management software, communication & control technology. TMH bundles V2G assets together and continuously reports availability (kWhs) to TSO. TenneT sends a request to TMH, which can be accepted or rejected. One key objective to maximise comm’s system learning through utilising multiple distributed locations.

**AVAILABILITY & PERFORMANCE**
- Data available from 2019.
- One performance challenge that will be probed is the ability of V2G to respond to a diversity of constraint scenarios, reflecting the diversity of wind conditions. This can range from sudden storms (lasting hours) through to 2-3 day weather cycles.

**READINESS LEVEL**
- 2

**PLUG-IN TIME**
- 0hrs

**USER BEHAVIOUR**
- Not a primary focus of project – focusing on TSO-owned fleet vehicles with a routine driving behavior at first.

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**PROOF OF CONCEPT**
- Not a primary focus of project – focusing on TSO-owned fleet vehicles with a routine driving behavior at first.
**2014-19 CITY-ZEN**

Small-scale commercial trial of DSO service, engaging diverse customers: commercial, individual & car-sharing

---

### SERVICE PROVISION

<table>
<thead>
<tr>
<th>DSO</th>
<th>TPI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraint managers &amp; Power quality</td>
<td>Imbalance and energy trading</td>
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<tr>
<td>V2G</td>
<td>V2G</td>
</tr>
<tr>
<td>Pre-fault</td>
<td>When spreads are high</td>
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<tr>
<td>Forecast on USEF platform</td>
<td>During market peak/valleys</td>
</tr>
<tr>
<td>Within minutes/hours</td>
<td>Settlement Period – 15 mins</td>
</tr>
<tr>
<td>Minutes-hours</td>
<td>Minutes-hours</td>
</tr>
<tr>
<td>Testing ongoing</td>
<td>Testing ongoing</td>
</tr>
</tbody>
</table>

### BENEFICIARY

- Project adopts the Universal Smart Energy Framework (USEF) platform. All stakeholders can access forecast system needs day-ahead, hour-ahead or on the spot.
- AVAILABILITY & PERFORMANCE
  - Pleased with response time; only marginally slower than stationary batteries. Biggest challenge was with availability of assets for usage (i.e. plug-in time plus appropriate State of Charge - SoC). This was particularly problematic given the small scale of the pilot (4 chargers), meaning that during some periods, storage was not available.

---

### CUSTOMER SNAPSHOT

**SEGMENT**

- HOUSEHOLD & COMMERCIAL

**CHARGE POINT**

- 4 DC V2G chargers, 10 kW, MagnumCap

**VEHICLE**

- 2 Mitsubishi Outlander, 2 Nissan EV200 (mini an), 1 Nissan LEAF

**CUSTOMER OFFER**

- Customers paid flat rate of 10 Euro cents/hour of plug-in time (subsidised by public funding)

---

### OPERATIONAL SNAPSHOT

**BATTERY USAGE FOR V2G:**

- Minimum SoC of 20-30%. When car arrives at chargepoint, immediately bring down to 45% SoC.

**USER BEHAVIOUR**

- Commercial customer well-engaged; this is believed to partly be due to their strong green credentials at management level and emphasis on resilience, and maximising PV self-consumption.
- Payment of 10Eur cent/hr helps engagement but is subsidised; concerns if payment is at (lower) market rates.

---

### READINESS LEVEL

- **SERVICE**
  - Level: 2
  - Status: Slow Starter amendments required initially in chargepoint; new chargepoint is demonstrated in operational environment.

- **TECHNOLOGY**
  - Level: DSO is engaging proactively with V2G, and this is expected to create new revenue opportunities. Barriers include legacy solar subsidy regime, and unclear grid acceptance requirements.

- **MARKET**
  - Level: DSO is engaging proactively with V2G, and this is expected to create new revenue opportunities. Barriers include legacy solar subsidy regime, and unclear grid acceptance requirements.

---

**SERVICE PROVIDER**

- Project would like to re-engage with V2G, and this is expected to create new revenue opportunities. Barriers include legacy solar subsidy regime, and unclear grid acceptance requirements.
2014-2019
SMART SOLAR
CHARGING

Pioneering AC V2G project with 22 chargers installed as part of city car share scheme and solar in Lombok neighbourhood.

The core focus of this project is developing an AC standard for V2G, and developing a system that facilitates and speeds up the rollout of electric vehicle charging infrastructure and solar power. Follow on project is seeking to scale up to 1000 chargers across region of Utrecht.

PROJECT VALUE
Supported by a grant from ERFD

PARTNERS
Lomboxnet
Last Mile Solutions
Stedin
Renault
ElaadNL

PROJECT FOCUS
1. TECHNICAL
2. COMMERCIAL
3. SOCIAL

SERVICE PROVISION

CUSTOMER SNAPSHOT

SEGMENT
CITY CAR SHARE SCHEME

CHARGING LOCATION
PUBLIC

VEHICLE
22 Renault Zoe (40kWh)

OPERATIONAL SNAPSHOT

USER BEHAVIOUR
Insights expected at end of 2019
With present amount (22) of 22 kW unidirectional charging stations we see on average:
- 10% occupied and charging;
- 50% occupied and NOT charging

BATTERY USAGE FOR V2G:
Small amount (1%) of battery is used. Maybe more later if results show that degradation is small.

ARCHITECTURE
Public charge points (directly connected to the low voltage grid) in a neighbourhood with high uptake of solar energy.

V2G services will be delivered through USEF framework

AVAILABILITY & PERFORMANCE
Insights expected at end of 2019
End 2018 the first prototypes of the Renault Zoe car with bidirectional capabilities will arrive in Utrecht. Testing will start in 2019. Results are expected at the end of 2019.

SERVICE
Constraint management
Pre-fault
Forecast on USEF platform
Within minutes/hours
Minutes-hours
Researched

TECHNOLOGY
V2G
Pre-fault
Forecast on USEF platform
Within minutes/hours
Minutes-hours
Researched

MARKET
DSO

DSO is engaging proactively with V2G, and this is expected to create new revenue opportunities. Barriers include legacy solar subsidy regime, and unclear grid acceptance requirements. Dutch grid is not ready for storage.

"We are developing a scalable system to facilitate the rollout of EV charging and solar power with an AC standard."
- Robin Berg, Lomboxnet

"ElaadNL cooperation of DSOs"
**GRID MOTION**

Large scale, privately funded demonstration of V1G and V2G – targeting frequency response, arbitrage and more

**PARTNERS**
- Groupe PSA (Car OEM)
- Direct Energie (Market access)
- Enel (Charger)
- Nuvve (Aggregator)
- Proxiserve (Installation)
- DTU (Research)

**PROJECT VALUE**  
PRIVATELY FUNDED

**SERVICE**
- **TSO**
  - Frequency Response
  - V2G
  - Pre-fault
  - Grid frequency
- **TPI**
  - Trading on day-ahead / intraday
  - V2G
  - Price differential - Bid/Offer called
    - Bid/Offer called
    - < 15 minutes
    - 15 min blocks
  - Researched – plan to test
- **ENERGY USER**
  - Reduction Time of Use Charges
  - V2H/B
  - Peak charges
  - Scheduled
  - Subject to charges (hours)

**SERVICE PROVISION**

**CUSTOMER SNAPSHOT**

**SEGMENT**  
Commercial fleet on airport grounds (airport supplier)

**CHARGING LOCATION**  
Enel 10 kW DC, V1G is using bidirectional Nuvve 18 kW AC chargers

**VEHICLE**  
15 Peugeot iOn or Citroen C-ZERO

**CUSTOMER OFFER**  
Free charger

**OPERATIONAL SNAPSHOT**

**ARCHITECTURE**
App informs Nuvve of drivers’ preferences and charge required. This resource is then matched to grid and market signals to provide service.

For V2G CHAdeMO protocol is being used. Residential V1G chargers are bidirectional AC but limited number of vehicles with AC compatibility at present.

**AVAILABILITY & PERFORMANCE**
Battery min/max usage is dependent on specific model of car.

**REACTIVITY**

**LEVEL**
- **SERVICE** 1
- **TECHNOLOGY** 9
- **MARKET** 9

**READINESS LEVEL**
FRANCE

**DSR market well developed. Market is not vertically integrated. Regulatory barriers exist relating to introduction of diverse, distribution level kW-scale resource i.e. minimum participation limits to trade and access frequency market; end-users cannot sell energy.**

**TSO**

**TPI**

**ENERGY USER**

**CUSTOMER**

**OFFER**

Mix of driver types and plug-in behaviour. Fleet use is 24/7 although with greater use during day.

**PROJECT WEBPAGE**

**PROJECT FOCUS**

1. TECHNICAL
2. SOCIAL
3. COMMERCIAL

**PARTNERS**

**PROJECT VALUE**
PRIVATELY FUNDED

**SERVICE**
- Frequency Response (V2G)
- Pre-fault (V2G)
- Grid frequency (V2G)

**OPERATIONAL SNAPSHOT**

**USER BEHAVIOUR**
Too early in project to provide learning

**BATTERY USAGE FOR V2G (30-95%)**

**AVAILABILITY & PERFORMANCE**

**MARKET**

**DSR market well developed. Market is not vertically integrated. Regulatory barriers exist relating to introduction of diverse, distribution level kW-scale resource i.e. minimum participation limits to trade and access frequency market; end-users cannot sell energy.**

**WE NEED MORE EFFICIENT INTERCONNECTION STANDARDS**
- Paige Mullen, Nuvve
KOREAN V2G

KEPCO project laying technical groundwork for EV roll out in Korea

Project is part of a broader Vehicle Grid Integration programme seeking to smooth roll out of EVs in Korea. V2G work has focused on development of bidirectional DC chargers and interface protocol, with tested testing various chargers. Hyundai Mobis were first to have bidirectional charger approved.

KEPCO LEAD

HYUNDAI EV

MOBIS (Charger), I&C (IT), PNE (Charger), KDN (EMS), Nemo (Business Model)

PARTNERS

PROJECT FOCUS

1. TECHNICAL

PROJECT VALUE

Private Funding

SERVICE PROVISION

ENERGY USERS

Time-shifting for energy users

V2G

Peak

Market signals

< 10 seconds

1 – 4 hours

Tested

SERVICE

V2G

WHEN TO ACT

TRIGGERING ACTION

RESPONSE SPEED

DURATION OF SERVICE

STATUS

CUSTOMER SNAPSHOT

No real customers - researchers conducting V2G programme

SEGMENT

COMMERCIAL (research centre)

CHARGING LOCATION

COMMERCIAL (research centre)

CHARGE POINT

2 x AC 6.6kW charging / 3.3kW discharging

1 x 10kW DC

VEHICLE

2 Hyundai (28kWh 1xAC, 1xDC)

1 ITeng (20kWh AC)

CUSTOMER OFFER

N/A

PLUG-IN TIME

0hrs discharge 24hrs charge

OPERATIONAL SNAPSHOT

USER BEHAVIOUR

No real users. Full control of EVs on simulated user usage patterns with full availability. (Technical Lab Test)

AVAILABILITY & PERFORMANCE

Response within 10 seconds achieved. 3 tested EVs responded to various types of DR signals with more than 95% accuracy.

ARCHITECTURE

Currently central management system operated by V2G service provider, but could be installed at a local site for distribution line monitoring and EV control.

BATTERY USAGE FOR V2G (30-100%)

"V2G can help shave summer and winter peaks"

- Mr Son, Chan, KEPRI
**2010-13**

**M-TECH LABO**

Early V2B trial using 5 iMiEVs, reducing peaks by 12.7% at Mitsubishi Motors’ office – together with second life battery.

**PARTNERS**

- Mitsubishi Corp: lead
- Mitsubishi Motors: OEM
- Mitsubishi Electric: EHS
- Tokyo Institute of Tech: Advisory

**PROJECT VALUE**

66% Government funded

**SERVICE**

- **Energy Users**: Peak shaving, V2B
- **When to Act**: Scheduled
- **Triggering Action**: Forecast
- **Response Speed**: N/A
- **Duration of Service**: 3 hours (1pm-4pm)
- **Status**: Tested

**User Behaviour**

5 drivers using the vehicles ‘normally’, typically plugging in when arriving at work.

Leaving time is entered by employees to indicate time window for V2B services.

**Customer Offer**

Mitsubishi Motors’ employees selected, to simplify consumer engagement.

**Operational Snapshot**

- **Architecture**
  - The system consists of a 20kW photovoltaic system, 5 electrically-dischargeable EVs and 80kWh used rechargeable batteries collected from EVs. Electric vehicle Integration System (EIS) aggregates data and information of available dischargeable capacity and hours of each EV while still allowing the EV to be used as a means of transportation.

**Availability & Performance**

- 30-50kWh/day discharged for the peak hours (1-4pm) from the EVs and the used batteries to the facilities.
- Shaved peaks by 12.7% on average.
- No performance issues over 1 year period. No noticeable impact on battery degradation.

**Market**

- **Readiness Level**: L
  - EV uptake still low, so difficult market. Market is undergoing liberalisation. V2B achievable, but V2G faces substantial barriers
Deployed 80 V2H chargers which demonstrated discharge in response to grid signals over the 6-9pm peak period, thereby helping manage distribution system loads and frequency events.

The project was part of major broader smart grid project seeking to integrate renewable energy, electric vehicles, energy storage, and controllable loads in Maui, Hawaii.

The project was lead and funded by Hitachi, NEDO, and the State of Hawaii, the County of Maui, Maui Electric Company, and Hawaiian Electric Company. Maui Economic Development Board Inc. University of Hawaii Maui College.

**PARTNERS**

**PROJECT FOCUS**

1. **TECHNICAL**

2. **SOCIAL**

3. **COMMERCIAL**

**SERVICE PROVISION**

<table>
<thead>
<tr>
<th>DSO/TSO (same organisation on Maui)</th>
<th>DSO/TSO (same organisation on Maui)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak reduction</td>
<td>Frequency response*</td>
</tr>
<tr>
<td>Yes through peak reduction at home</td>
<td>Yes through peak reduction at home</td>
</tr>
<tr>
<td>Forecast based on system req.</td>
<td>Change in frequency</td>
</tr>
<tr>
<td>Backoffice control signal</td>
<td>Control signal from DSO</td>
</tr>
<tr>
<td>&lt; 4 secs</td>
<td>&lt; 4 secs</td>
</tr>
<tr>
<td>3 hours (6-9pm)</td>
<td>2 hours)</td>
</tr>
<tr>
<td>Proven</td>
<td>Proven</td>
</tr>
</tbody>
</table>

*Service provided in the demonstration project led by Hawaiian Electric that followed JUMPSmartMaui

**CUSTOMER SNAPSHOT**

- **SEGMENT**
  - INDIVIDUAL

- **CHARGING LOCATION**
  - HOME

- **CHARGE POINT**
  - 6kW Hitachi DC

- **VEHICLE**
  - Nissan LEAF

- **CUSTOMER OFFER**
  - Free charger provided, with no other economic incentive. Participants involved due to environmental or community interest reasons.

**OPERATIONAL SNAPSHOT**

- **USER BEHAVIOUR**
  - 80 families using the vehicles 'normally', typically plugging in on return from work. This meant limited diversity and restricted when V2G could be provided.
  - Families often used other DC fast chargers, which meant only plugged in on average every other day.
  - Trial ran in 2013-2014 with V1G which made it easier to introduce V2G as good data on driving patterns had already been recorded.

- **ARCHITECTURE**
  - Energy control via autonomous, decentralized system. Hitachi developed integrated Demand Management System (DMS), with localised autonomous DMS. EV charging utilised these DMS with EV Control Centre to create a charging schedule so as to fill up the gap between the estimated power generated by renewable energy and load of the next day. It then takes account of each EV's connection status to the normal charger and the desired charge end time to instruct the charge start time to each EV. ChaDeMo protocol used.

- **BATTERY USAGE FOR V2G: 30-95%**

- **AVAILABILITY & PERFORMANCE**
  - Export limited to 1kW, although 6kW modelled. Interconnection standards were onerous and Hawaii specific. (These have now been replaced with US-wide UL certificate which is helpful). Forecast of vehicle behaviour in aggregate was challenging.
  - Lack of incentive to plug in may have reduced how often people plugged in when they got home, particularly when they could charge using the public fast charging stations.
  - Complicated to get new users interested. Significant and targeted recruitment campaign, with jargon free branding, marketing material and one to one visits.

**MARKET**

- **SERVICE**
  - Commercially available

- **TECHNOLOGY**
  - Commercially available

- **MATERIAL**
  - Commercially available

- **MARKET**
  - Commercially available

**PROJECT WEBPAGE**

**READINESS LEVEL**

- **SERVICE**
  - B (in trial)

- **TECHNOLOGY**
  - B (in trial)

**CUSTOMER SNAPSHOT**

- **SEGMENT**
  - INDIVIDUAL

- **CHARGING LOCATION**
  - HOME

- **CHARGE POINT**
  - 6kW Hitachi DC

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**MARKET**

- **SERVICE**
  - Commercially available

- **TECHNOLOGY**
  - Commercially available

- **MATERIAL**
  - Commercially available

- **MARKET**
  - Commercially available
**2017-2020**

**INVENT**

Large scale trial on UCSD campus, with multiple vehicle types and chargers, supporting move towards commercial deployment in California

**PARTNERS**
- Large scale trial on UCSD campus, with multiple vehicle types and chargers, supporting move towards commercial deployment in California
- **TSO / DSO**
  - Demand Response / Peak reduction
    - V2G
    - Stress event called by TSO/DSO
    - Stress event called by TSO/DSO
    - Alerts usually issued day ahead
  - Frequency regulation
    - V2G
    - Continuous response to signal
    - Grid frequency (AGC signal)
    - < 4 seconds
  - Energy Users
    - Reduction of demand charges
    - V2H/B (although can be stacked)
    - Peak charge periods (kW)
    - Approach of unusual load peak

**PROJECT VALUE**
- $7.9 million – part funded by CA Energy Comm.

**SERVICE PROVISION**

**SPORT**
- Mitsubishi, BMW & Nissan
  - OEMs
- UCSD
  - Research
- Nuve, Hitachi
  - Operators

**TECHNOLOGY**
- AC chargers UL listed and commercially available DC chargers have been operated thoroughly in testing environment and commercially available.

**MARKET**
- Value streams available in DSO and TSO level demand response markets and behind-the-meter applications (V2B).

**OPERATIONAL SNAPSHOT**

**USER BEHAVIOUR**
- There is a challenge to predicting what capacity you can provide to the market, particularly when there are only a small number of cars (only above 100 can you really start to use statistics).
- ‘Real world’ issues include: (1) unexpected damage to project vehicles, (2) drivers’ varying personal schedules and (3) optimizing plug-in time by assigning convenient parking locations to project drivers.

**ARCHITECTURE**
- Nuve GIV™ aggregation platform.
- Exploring interaction with advanced solar forecasting, integration with building energy management systems and response to TSO & DSO-level demand response markets.
- Platform has been providing frequency regulation to TSOs since 2009.

**AVAILABILITY & PERFORMANCE**
- Challenges are: 1) Availability of cars 2) EVSE reliability 3) Adapting system to local requirements, 4) Market Access Paths 5) Battery Degradation – V2G does cause some additional degradation but much smaller than that experienced through driving behaviour (and particularly regenerative braking). Potential damage depends on service, with full charge/discharge cycles being the worst. Car manufacturers may move towards certifications to make it a requirement to be an approved aggregator or charger.

**CUSTOMER SNAPSHOT**
- Trial is in collaboration with UCSD’s Triton Ride Program which operates a fleet of EVs that safely transport students around campus at night.
- Collaboration also with UCSD’s solar forecasting lab for integration into services provision as well as with other stationary storage projects located on campus.

**Plug-in time**
- 0hrs
- 24hrs

**Plug-in locations**
- Free charger, parking and electricity

**Vehicle**
- 9 AC Nuve PowerPorts (18 kW)
- 9 DC Hitachi (6 kW)
- 30+ TBD (Phase 2/3)

**Charge point**
- 9 Mitsubishi Outlanders (12 kWh) ; 7 Nissan LEAFs (24-30 kWh); 9 Chevy Bolts/BMW i3s/Daimler Smart/Model 3/LEAF; 30 + TBD (Phase 2/3)

**Customer offer**
- Predominantly workplace charging during day, with university fleet charging at night.

**Project webpage**
- "We are making commercial offers in California"  - Marc Trahand, Nuve
2017-20
NETWORK IMPACT OF
GRID-INTEGRATED VEHICLES

DNO project aiming to understand impacts and interconnection process for V2G-enabled EVs on the distribution network.

NPG is monitoring installation of chargers commercially installed by Nuvve. Scope also includes investigation of commercial options for connection offers and customer usage behaviour. Initially 1000 charge points were planned but this has been reduced to 19.

PARTNERS
- Northern Power Grid
- Nuvve
- Newcastle Uni.

PROJECT FOCUS
1. TECHNICAL
2. COMMERCIAL

PROJECT VALUE £375k NIA funding to NPG

SERVICE PROVISION

SERVICE
- DSO
- V2G
- WHEN TO ACT
- TRIGGERING ACTION
- RESPONSE SPEED
- DURATION OF SERVICE
- STATUS

DSO
- TBC (testing to see what DSO services could be offered by the vehicles and the impact of this on the network. This is to help shape DSO service and new market specifications)

SERVICE readiness level 2

TECHNOLOGY
- Chargepoint has been demonstrated in operational environment

MARKET
- High – active demand response market, supportive TSO and DSO environment, strong competition between aggregators. However interconnection process is slow.

OPERATIONAL SNAPSHOT

USER BEHAVIOUR
- Too early to say

ARCHITECTURE
- Dispatched via Nuvve’s aggregator platform.
  - Control input will be determined by the service that they are seeking to test.

BATTERY USAGE FOR V2G: tbc but assumed to be 35-95%

AVAILABLE & PERFORMANCE
- Interconnection process in UK (G59 and 83 currently) is one of most complicated globally, taking ~6 months to connect due to requirement to undertake network impact assessment. This project will seek to make recommendations to streamline this process, most likely through type certification.

CUSTOMER SNAPSHOT

SEGMENT
- COMMERCIAL (NPG fleet)

CHARGING LOCATION
- WORK (NPG offices)

VEHICLE
- Nissan NV200s and possible Nissan LEAFs

CUSTOMER OFFER
- Given fleet vehicles of NPG, customer offer has not been major focus.

PLUG-IN TIME
- 0hrs
- 24hrs

“Through this project we hope to gain the evidence to streamline the interconnection process in the UK”
- Paige Mullen, Nuvve
This time away has prompted some reflection. We log what we’ve learned – and the implications for the UK.
THERE ARE ONGOING UK REFORMS ON MULTIPLE FRONTS (GOV’T, REGULATOR, SYSTEM AND NETWORK OPERATORS) TO ADDRESS V2G TECH & MARKET BARRIERS

UK CONTEXT

So, we’ve mapped out V2G projects globally and visited ten landmark projects: there’s plenty to log in our Journal and bring back home. But before we can tease out the lessons learned for the UK, we need to be aware of UK-specific market conditions.

The UK benefits from important commitment from government, the regulator, system operators and network operators to remove barriers to entry to V2G roll-out.

The chart on the right summarises some notable features of the market landscape. Its purpose is not to be comprehensive, since a detailed market review would constitute a report in itself*. Instead, the purpose is to prime our analysis covered on the following pages.

*NSee Cenex report listed in Appendix 2.

NORTHERN IRELAND

The observations on this page largely refer to England, Wales & Scotland only. The market and regulatory context in Northern Ireland (NI) is distinct from that in GB, due to collaboration across the Island of Ireland. For instance, the procurement of system services in NI is run jointly with the RoI under the DS3 programme.
EVs CAN PROVIDE FAST AND FLEXIBLE BIDIRECTIONAL ENERGY FLOW, YET THE HARDWARE REMAINS COMMERCIAL IMMATURE

OUR JOURNAL

Just as the development of V2G is on a journey from purely technical studies and demonstrator trials through to widespread commercial deployment to a large number of customers; this Journal follows the same path. We begin with the lessons learned for technical aspects, primarily focused on the hardware itself. We then consider the critical interface between technical and regulatory issues, before looking at commercial models. We consider insights into potential V2G customers before concluding with where V2G can add unique value. In all of the above we consider key learnings for the UK sector.

TECHNICAL

Fast and flexible bidirectional power flow has been demonstrated in a range of markets and a range of applications:

▪ **Fast** – the Parker project has shown that vehicles can respond in less than 2 seconds, faster than traditional forms of frequency response.

▪ **Flexible** – vehicles can provide a flexible service that can be tailored to the specific market application. This ranges from peak reduction in Hawaii, frequency response in Denmark and constraint management for the TSO in Germany.

Yet the hardware remains immature:

▪ **Chargers** – few bi-directional chargers are commercially available, with performance being a concern cited by many projects. Costs are high (e.g. over 5 times V1G enabled chargers), although there is significant scope for cost reduction if mass scale can be achieved.

▪ **Vehicles** - few V2G-enabled vehicles are commercially available, with Japanese manufacturers dominating the market. The range of vehicles is expected to increase over the next couple of years. As more vehicles come to market, the differences in capabilities (already considered by the Parker and INVENT projects) will become more visible.

Efficiency losses – The Parker project found that efficiency losses were significant when discharging at a rate lower than the rated power of the equipment.

AC / DC debate is live. DC ChaDeMo solutions dominate the market at present but there is significant interest in AC solutions (Smart Solar Charging, INVENT, Kepco).

The marginal degradation cost of V2G activities should be considered: However, the magnitude of this degradation cost appears much smaller than that caused by differences in driving behaviour (and particularly regenerative braking). Potential damage depends on the nature of the service, with full charge/discharge cycles being the worst. Car manufacturers may move towards certifications to make it a requirement to be an approved aggregator or charger.

Make slow starters mandatory: A key finding of the City-zen project (Amsterdam) is that it is crucial to ensure that grid stability does not interfere with the charger. Having incurred problems with this early in their project, the City-zen team recommend that grid acceptance standards are amended to make it mandatory for ‘slow starters’ to be incorporated into all V2G chargers. Slow starters limit the inrush of voltage, making the power quality more stable. The cost of incorporating this technology is reported to be low.

LEARNINGS FOR THE UK

▪ Support hardware development*

▪ Be flexible on AC/DC

▪ Consider slow-start charging technology

*Current Innovate UK focus area.
REGULATIONS NEED TO BE ADAPTED FOR A DECENTRALISED, BEHIND-THE-METER AND INHERENTLY LESS CONTROLLABLE SET OF ASSETS.

REGULATION

The energy system is heavily regulated – and this regulation is not well suited to flexibility assets which are decentralised, behind-the-meter and less controllable.

Specific examples include:

Interconnection standards

▪ Onerous interconnection requirements were repeatedly flagged in interviews (Grid Motion, France; JumpSMARTMAui, USA; Parker, Denmark). As an example, in Denmark nuvve were initially given an 89 page wind farm connection guide!

▪ A key challenge for providers is that interconnection standards are country-specific, meaning the system has to be adapted every time.

▪ The EV community does not expect special treatment. But along with other distributed energy providers – such as domestic demand-side response – it expects requirements to be proportionate to asset size.

▪ The interconnection process in the UK (G59 and G83 currently) is one of the most complicated globally, taking ~6 months to connect due to requirement to undertake a network impact assessment. The NPG project seeks to make recommendations to the ENA to help streamline this process. This would put the UK at the forefront globally.

Energy charges and settlement

▪ High cost of settlement meters: To demonstrate that an asset has provided a service, settlement meters are required. Different meters are often required for different services and these meters are often designed for much larger utility scale assets. This means proportionally high costs for V2G providers.

▪ Double-charging: In Germany V2G flexibility providers must pay energy levies on both production and consumption as storage is not yet a separate regulatory entity. This is also an issue in Netherlands and Denmark. The UK is more advanced in this area with Ofgem making various regulatory changes including adding storage as specific term within electricity licenses.

▪ System services: energy tariffs are lower when providing a system service. This leads to the challenge of ‘baselining’ or distinguishing between imports that are used to charge the car for mobility, and those imports used by the car to provide a service. In the UK, NGET’s Power Responsive goes some way to addressing this (though not fully).

Service specifications are particularly important and need to be defined with this technology class in mind. Three specifications emerge as crucial:

1. Response time – although EVs can respond rapidly (<2 secs), stand alone batteries are currently faster. Implementation of slow-start charger technology (see previous page) could slow EV response time further.

2. Duration - The Parker project noted that the amount of power that could be bid in as a service often had to be less than the charger capacity to ensure that the vehicle could provide a service over the full duration defined within the service specification. Reducing the duration could therefore allow a greater power response to be provided. To fully access the potential EV resource, service specifications need to be better aligned with what can be delivered or aggregators need to blend with other resources.

3. Availability – DSOs are used to their assets (grid infrastructure) providing extremely high levels of reliability (99.9%+). This is challenging if EVs are to play a significant role in deferring grid reinforcement or expansion costs. Availability and performance issues need to be carefully considered within service and contract specifications for such works.

LEARNINGS FOR THE UK

▪ Use NPG project to streamline interconnection process

▪ Design service specifications with V2G in mind, in particular response time (current min of 2 secs), duration (linked to power requirements) and availability
### COMMERCIAL

**V2G provision of DSO services are underrepresented globally** with 10 projects exploring DSO services. Projects have generally focused on time-shifting and/or frequency response due to the higher value available.

This appears to reflect lack of DSO service maturity more than inherent V2G capability. Interviews suggest that the reason why DSO services have been overlooked is that to date (a) the market value is unclear and (b) the service specification and route to market are not normally well understood.

As a result, DSO services currently have a relatively low SRL of 3. The SRL summarises the techno-commercial readiness of V2G systems to provide a particular service in the UK. An SRL of 3 means DSO services have been proven (in the SmartMAUI project in the US), with testing ongoing in the UK (NPG) and Netherlands (City-zen project). Also notable is the Re-dispatch project in Germany which is providing constraint management, albeit to the TSO. An SRL of 4 is in sight with tenders expected in Hawaii towards the end of this year.

**V2G DSO services can benefit from developments on other services.** The Parker project in Denmark demonstrates that V2G can provide a commercial service while meeting demanding technical standards for speed of response, availability and performance.

### Location is more of a priority for DSO services.**

Frequency response is location agnostic, while DSO Services are location specific. This is both an opportunity and a challenge for V2G – an opportunity as there are likely to be vehicles in almost all locations; a challenge as there will only ever be a limited number of vehicles within a specific area making a statistical approach to forecasting difficult. This suggests a key role for aggregators in blending assets to reduce availability risk. V2G providers are also likely to have significant amounts of data that could help DSOs manage their network.

**DSO services and V2G therefore have potential to mature together.**

### LEARNINGS FOR THE UK

DSOs need to clarify the value of services, define in which locations services are required and define service specifications with V2G in mind.

<table>
<thead>
<tr>
<th>SERVICE</th>
<th># OF PROJECTS GLOBALLY*</th>
<th>SERVICE READINESS LEVEL (SRL***)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1. RESEARCHED</td>
<td>2. TESTING</td>
</tr>
<tr>
<td><strong>ARBITRAGE</strong></td>
<td>4</td>
<td>FRANCE, DENMARK</td>
</tr>
<tr>
<td><strong>RESERVE</strong></td>
<td>2</td>
<td>FRANCE</td>
</tr>
<tr>
<td><strong>FREQ RESP.</strong></td>
<td>16</td>
<td>FRANCE</td>
</tr>
<tr>
<td><strong>DSO SERVICES</strong></td>
<td>10</td>
<td>DENMARK</td>
</tr>
<tr>
<td><strong>TIME SHIFTING</strong>*</td>
<td>23</td>
<td>KOREA, USA, UK</td>
</tr>
</tbody>
</table>

*Multiple selections permitted **Full definition of SRL on page 11 ***For energy users

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**ONLY 10 V2G PROJECTS ARE PROVIDING DISTRIBUTION SERVICES – BUT UK DSOS CAN BENEFIT FROM V2G’S TRACK RECORD IN PROVIDING OTHER SERVICES**
A big question is around lowest min SoC acceptable to users (How low can you go?). The answer is determined by both user acceptance and battery warranties. This review has suggested that vehicles are typically managed within the 25-95% SoC range, although this is vehicle and service dependent. It is less clear how comfortable customers are with this.

Car-sharing helps dodge the dual consumer concern of range and battery degradation. The City-zen project (Amsterdam) has engaged a car-sharing company, with good results. The downside is lower plug-in time compared with individually owned vehicles. Plug-in time is hugely variable; however, the project’s experience has been that the shared car’s plug-in time at the V2G charger is ~60%, though they believe that this might be increased with greater V2G charger availability.

This raises the bigger question of how V2G fits in with the future of mobility. From leased vehicles, to car sharing, to electric vehicles and, in due course, to autonomous vehicles, mobility is undergoing a profound transformation. The most advanced projects are part of this trend. For instance, Smart Solar Charging and City-zen are focused on car-sharing schemes, while in Denmark Nuvve are using V2G to reduce the monthly fee paid by customers for all of their mobility needs.

CUSTOMERS

Our global review shows social considerations typically come second in V2G project activity. This is a problem given that V2G potential depends on user acceptance, with drivers defining the constraints which V2G providers work within. A lack of focus on user acceptance is also noted within academic literature [Sovacool et al, 2018].

Consumer types and mobility behaviours are diverse. Project dashboards covered a range of customers including families, fleets and car-share schemes, even school busses for three US-based projects. Each customer will have their own mobility patterns and behaviours that need to be clearly understood. Averages will only tell part of the story with segmentation more useful.

This diversity adds value to V2G. In Denmark, the Parker project has been able to achieve 24/7 response only through diversity in the types of commercial fleets contracted (e.g. utility vehicles, port vehicles, municipality vehicles). Similarly JumpSMARTMaui noted that they could only provide frequency response during evenings due to the specific customer category.

Data is important. On the JumpSMARTMaui project, Hitachi had two years of V1G trial data on driving pattern data at an individual household level which made it easier to subsequently introduce V2G. This project also flagged the importance of understanding other charging options locally, with families having the option of using DC fast chargers locally, meaning they only plugged in at home every other day on average.

But, Warning! Consumers do not always behave how you expect. The customers are real people who take unplanned trips, may have vehicles that break, or are crashed into. They may not want to always connect their EV when at home or at work, with plug-in times typically lower than parking times. This is a real challenge. Mitigations include close to real time bidding of services, some allowance for lower availability and / or aggregation with other assets.

LEARNINGS FOR THE UK

- Embrace diversity in consumer types, data will help
- Integrate V2G into mobility-as-a-service schemes (e.g. car rental or sharing schemes etc.)
- Address social considerations for future projects, within the context of broader changes in mobility.
V2G CAN ADD UNIQUE VALUE, PARTICULARLY AS PART OF BLENDED ASSETS. BUT PROPORTIONATE STANDARDS AND CHARGER COST REDUCTION ARE NEEDED

UNIQUE VALUE OF V2G

Many of the services in this report can also be provided by smart charging (V1G). A key challenge for V2G is how and when it can add unique value over and above V1G. This review has identified the following as key areas of added value:

- **Services where location matters.** The Redispatch project in Germany is seeking to manage transmission constraints across the country. This is managed through seeking different service profiles from the highly distributed V2G fleet depending on the location.

- **Locations with surplus solar capacity.** V2G is a useful complement to solar at a range of scales. For instance at a site level, V2G can help increase local consumption at near solar projects, with export from vehicles if a building is able to use the additional power. At a system level, V2G can help manage the ‘duck curve’ issue so prevalent in California (and potentially an issue in the UK in due course), with vehicles managing the morning to midday solar ramp-up through charging, and evening solar ramp-down through discharging. This helps explain why INVENT, City-zen and Smart Solar Charging are so focused on the interaction with solar. However, legacy solar subsidies can make this difficult (i.e. as seen via the City-zen project).

- **High time of use or peak import tariffs.** In areas with significant time of use or peak charges, V2G can make a significant impact. This is a key focus of nuvve’s commercial offer in California.

- **Longer-duration services.** Smart charging can only provide frequency response for the period of time when the vehicle is charging. In contrast, due to its bi-directional nature, V2G can provide frequency response until the point at which the SoC needs to be returned to the required level for the customer. Naturally this depends on flexibility within the service specification to allow management of state of charge for any periods of sustained asymmetric frequency behaviour. Previous studies by nuvve suggest revenue from V2G can be a multiple of 8-15x that from V1G for provision of frequency response services.

But even in these scenarios, economic viability will only be achieved when wider economic conditions are met:

- **Pilots essential to achieve scale:** Large scale demonstration projects are needed to unlock markets. This bodes well for the UK given 8 demonstration projects funded by Innovate UK (see Appendix 1).

- **Proportionate interconnection standards:** These must be appropriate for these diverse, distributed and less controllable assets.

- **Charger cost reduction essential:** Representatives of M-tech Labo (Nagoya) emphasise that economical feasibility of V2G ‘needs further penetration of EV, cost reduction of V2X chargers and standardization.’ Bi-directional chargers are not yet mass-scale products. This clearly limits the ability to achieve scale.

Finally, it is important **not to consider V2G in isolation.** In practice V2G will be blended with a range of other assets such as demand side response and batteries. As Hitachi note: ‘EVs are very fast and flexible, and when combined with other resources, can be very valuable to the grid’

LEARNINGS FOR THE UK

- Focus on when and where V2G can add value
- Support aggregation of V2G with other technologies (into Virtual Power Plants)
APPENDICES

1. Project list
   - Global
   - Innovate UK

2. Sources
<table>
<thead>
<tr>
<th>#</th>
<th>Project Name</th>
<th>Country</th>
<th>Start Year</th>
<th>No. Chagers</th>
<th>Service Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vehicle-to-Grid (V2G) Pilot Project</td>
<td>Hong Kong</td>
<td>2011</td>
<td>1</td>
<td>Small scale proof of concept trial in Hong Kong</td>
</tr>
<tr>
<td>2</td>
<td>M-tech Labo</td>
<td>Japan</td>
<td>2010</td>
<td>5</td>
<td>Early V2B trial using 5 iMiEVs, reducing peaks by 12.7% at Mitsubishi Motors’ office – together with second life battery</td>
</tr>
<tr>
<td>3</td>
<td>Osaka business park</td>
<td>Japan</td>
<td>-</td>
<td>-</td>
<td>Small scale trial for V2B, with little information available publicly</td>
</tr>
<tr>
<td>4</td>
<td>Toyota Tsuho / Chubu Electric / Nuve</td>
<td>Japan</td>
<td>2018</td>
<td>-</td>
<td>Expected to be first ever V2G (as opposed to V2B) project in Japan. Government-funded trial announced in 2018</td>
</tr>
<tr>
<td>5</td>
<td>V2G Aggregator project</td>
<td>Japan</td>
<td>2018</td>
<td>-</td>
<td>Government-funded project just announced to build V2G system and test business models in Japan</td>
</tr>
<tr>
<td>6</td>
<td>Leaf to home</td>
<td>Japan</td>
<td>2012</td>
<td>4000+</td>
<td>Commercially available vehicle-to-home product in Japan with over 4000 units sold (press release 2017).</td>
</tr>
<tr>
<td>7</td>
<td>Korean V2G</td>
<td>Korea</td>
<td>2015</td>
<td>3</td>
<td>KEPCO project laying technical groundwork for EV roll out in Korea</td>
</tr>
<tr>
<td>8</td>
<td>Elia V2G</td>
<td>Belgium</td>
<td>2018</td>
<td>2</td>
<td>Leading Belgium project evaluating a mix of V2G and V1G to provide FCR services to TSO Elia.</td>
</tr>
<tr>
<td>9</td>
<td>Parker</td>
<td>Denmark</td>
<td>2016</td>
<td>50</td>
<td>FR, DSO. The aim of the Parker project is to validate that series-produced electric vehicles as part of an operational vehicle fleet can support the power grid by becoming a vertically integrated resource, providing seamless support to the power grid both locally and system-wide.</td>
</tr>
<tr>
<td>10</td>
<td>ACES</td>
<td>Denmark</td>
<td>2017</td>
<td>50</td>
<td>FR, DSO. The ACES project intends to holistically investigate technical and economic system benefits and impacts by large scale electric vehicles integration in Bornholm, augmented by real usage patterns, grid data and field testing for across continents replicability</td>
</tr>
<tr>
<td>11</td>
<td>Suwilahti pilot</td>
<td>Finland</td>
<td>2017</td>
<td>1</td>
<td>Finland first two-way public charger in connection with a solar plant and electrical storage facility.</td>
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<tr>
<td>12</td>
<td>Grid Motion</td>
<td>France</td>
<td>2017</td>
<td>15</td>
<td>FR, R, A. Large scale, privately funded demonstration of V1G and V2G in France – targeting frequency response, arbitrage and more. Seeking to open up French market</td>
</tr>
<tr>
<td>13</td>
<td>Redispatch V2G</td>
<td>Germany</td>
<td>2018</td>
<td>10</td>
<td>CM German trial with 10 electric vehicles, with uni- and bi-directional capability. Seeking to prove ‘dispatchability’ of Evs to manage network constraints, reduce curtailment and reduce upgrades.</td>
</tr>
<tr>
<td>14</td>
<td>Honda, Offenbach</td>
<td>Germany</td>
<td>2017</td>
<td>1</td>
<td>TS Honda are testing V2B application on a building with on-site solar.</td>
</tr>
<tr>
<td>15</td>
<td>INEEs</td>
<td>Germany</td>
<td>2012</td>
<td>40</td>
<td>FR German ‘lighthouse’ project which demonstrated the real world technical feasibility of V2G through the use of 20 SMA bi-directional inverters and modified Volkswagen UP vehicles.</td>
</tr>
<tr>
<td>16</td>
<td>Vehicle-to-coffee</td>
<td>Germany</td>
<td>2015</td>
<td>1</td>
<td>TS The Mobility House’s office is powered in part from Nissan LEAF in practical demonstration of vehicle to office concept.</td>
</tr>
<tr>
<td>17</td>
<td>Genoa pilot</td>
<td>Italy</td>
<td>2017</td>
<td>2</td>
<td>- Two car trial testing V1G and awaiting definition of regulatory framework for V2G in Italy</td>
</tr>
<tr>
<td>#</td>
<td>PROJECT NAME</td>
<td>COUNTRY</td>
<td>START YEAR</td>
<td>NO. CHARGERS</td>
<td>SERVICE SUMMARY</td>
</tr>
<tr>
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<td>----------------</td>
</tr>
<tr>
<td>18</td>
<td>SEEV4City</td>
<td>Netherlands, Norway, UK, Belgium</td>
<td>2016</td>
<td>13</td>
<td>DSO, TS - Large-scale Northern European trial delivering 5 pilots in 4 countries. Pilots include: Loughborough Living Lab - single residential household with solar also installed; Amsterdam Arena - Up to 200 uni- and bidirectional connected EVs will be part of the smart energy system; City depot of Kortrijk - single Nissan LEAF van providing V2B with onsite solar; Leicester City Hall - Vehicle to business trial with four vehicles at present; Vulkan Real Estate Building Oslo - innovative EV parking garage seeking to deploy V2G in next phase.</td>
</tr>
<tr>
<td>19</td>
<td>City-Zen Smart City</td>
<td>Netherlands</td>
<td>2014</td>
<td>4</td>
<td>DSO, A - Small-scale commercial trial of DSU service, engaging diverse customers: commercial, individual &amp; car-sharing</td>
</tr>
<tr>
<td>20</td>
<td>Smart Solar Charging</td>
<td>Netherlands</td>
<td>2015</td>
<td>22</td>
<td>A, DSO, FR - Pioneering AC V2G project with 22 chargers installed as part of city-car share scheme and solar in Lombok. Now seeking to scale up to 1000 chargers across region of Utrecht.</td>
</tr>
<tr>
<td>21</td>
<td>NewMotion V2G</td>
<td>Netherlands</td>
<td>2016</td>
<td>10</td>
<td>FR - First V2G project in NL to provide Frequency Control Reserve (FCR) services to TSO TenneT with chargers at homes, offices and public locations.</td>
</tr>
<tr>
<td>22</td>
<td>Amsterdam Vehicle2Grid</td>
<td>Netherlands</td>
<td>2014</td>
<td>2</td>
<td>TS - Small scale domestic trial looking at feasibility of V2H installations in Amsterdam.</td>
</tr>
<tr>
<td>23</td>
<td>Solar-powered bidirectional EV charging station</td>
<td>Netherlands</td>
<td>2015</td>
<td>1</td>
<td>TS - Research project developing integrated EV charger and solar PV inverter, designed for solar car port applications.</td>
</tr>
<tr>
<td>24</td>
<td>Hitachi, Mitsubishi and Engie</td>
<td>Netherlands</td>
<td>2018</td>
<td>1</td>
<td>TS - One V2G charger installed at Engie office in order to increase self consumption of on-site generation from solar PV. A stationary energy battery system also on site.</td>
</tr>
<tr>
<td>25</td>
<td>Porto Santo</td>
<td>Portugal</td>
<td>2018</td>
<td>1</td>
<td>Project seeking to make Porto Santo a fossil-free island through the use of EVs to stabilize the grid. At present just V1G.</td>
</tr>
<tr>
<td>26</td>
<td>GrowSmarter</td>
<td>Spain</td>
<td>2015</td>
<td>6</td>
<td>TS - 6 V2G chargers installed at Endesa facility and used for Time shift, Power balancing and Power quality support.</td>
</tr>
<tr>
<td>27</td>
<td>Zem2All</td>
<td>Spain</td>
<td>2012</td>
<td>6</td>
<td>At this time largest real world V2G trial in world, forming part of wider e-mobility trial in Malaga.</td>
</tr>
<tr>
<td>28</td>
<td>Nissan Enel UK</td>
<td>UK</td>
<td>2016</td>
<td>100</td>
<td>- Large-scale trial proposed in UK by Enel and Nissan seeking to connect one hundred V2G units. Current status not clear and this trial may have become one of latest Innovate UK projects.</td>
</tr>
<tr>
<td>29</td>
<td>The Network Impact of Grid-Integrated Vehicles</td>
<td>UK</td>
<td>2018</td>
<td>16</td>
<td>DSO - DNO-run project aiming to understand the negative and positive impacts of V2G-enabled EVs on the distribution network.</td>
</tr>
<tr>
<td>30</td>
<td>Hitachi - Isle of Scilly Smart Island</td>
<td>UK</td>
<td>2017</td>
<td>-</td>
<td>Wide-ranging smart-grid programme on island network. V2G element appears relatively small at present.</td>
</tr>
<tr>
<td>31</td>
<td>ITHECA</td>
<td>UK</td>
<td>2015</td>
<td>1</td>
<td>FR - Micro-grid demonstration project at Aston University which installed UK’s first ever V2G charger.</td>
</tr>
<tr>
<td>32</td>
<td>EFES</td>
<td>UK</td>
<td>2013</td>
<td>4</td>
<td>FR, TS - Cenex led project developing V2G technology and software for residential and commercial applications, with installation of 3 V2G chargers at residential and commercial properties.</td>
</tr>
<tr>
<td>33</td>
<td>IREQ</td>
<td>Canada</td>
<td>2012</td>
<td>1</td>
<td>DSO, TS - Technology demonstration of back up supply and export to the grid for an assembled electric test vehicle and charging station.</td>
</tr>
<tr>
<td>34</td>
<td>Powerstream pilot</td>
<td>Canada</td>
<td>2013</td>
<td>-</td>
<td>Small scale, microgrid proof-of-concept trial incorporating V2G in phase 2.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>#</th>
<th>PROJECT NAME</th>
<th>COUNTRY</th>
<th>START YEAR</th>
<th>NO. CHARGERS</th>
<th>SERVICE</th>
<th>SUMMARY</th>
</tr>
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<tbody>
<tr>
<td>35</td>
<td>NYSERDA</td>
<td>USA</td>
<td>2016</td>
<td>5</td>
<td>-</td>
<td>6 Nissan LEAF vehicles used to provide bi-directional grid services on the CUNY Queens College campus</td>
</tr>
<tr>
<td>36</td>
<td>JumpSmartMaii</td>
<td>USA</td>
<td>2012</td>
<td>80</td>
<td>DSO, FR</td>
<td>Deployed 80 V2H/B chargers which demonstrated discharge, in response to grid signals, over 6-9pm peak period thereby helping manage distribution system loads and frequency events.</td>
</tr>
<tr>
<td>37</td>
<td>BlueBird School Bus V2G</td>
<td>USA</td>
<td>2017</td>
<td>8</td>
<td>FR, TS</td>
<td>8 Bluebird electric school buses deployed at the Rialto Unified School District providing ancillary services and energy management services.</td>
</tr>
<tr>
<td>38</td>
<td>US Air Force</td>
<td>USA</td>
<td>2012</td>
<td>13</td>
<td>FR, R, TS</td>
<td>Small-scale V2G pilot completed by the US Department of Defence leading to a large-scale testing and evaluation programme on 6 DoD installations.</td>
</tr>
<tr>
<td>39</td>
<td>NRG Evg0, UCSD</td>
<td>USA</td>
<td>2015</td>
<td>9</td>
<td>-</td>
<td>Evg0 partnership with UC San Diego testing use case and interconnection standards with range of auto manufacturers on the UCSD campus (which also has solar PV and stationary storage).</td>
</tr>
<tr>
<td>40</td>
<td>KIA Motors, Hyundai Technical Center Inc., UCI</td>
<td>USA</td>
<td>2016</td>
<td>6</td>
<td>TS</td>
<td>UC Irvine partnered with KIA/Hyundai to demonstrate V2G control software, understand charging behaviour and assess impact on the grid.</td>
</tr>
<tr>
<td>41</td>
<td>NREL Integrate / living lab</td>
<td>USA</td>
<td>Not known</td>
<td>3</td>
<td>-</td>
<td>Use cases for V2G assessed for one vehicle and one school bus using grid simulator and on-site solar.</td>
</tr>
<tr>
<td>42</td>
<td>US DoD – Fort Carson</td>
<td>USA</td>
<td>2013</td>
<td>5</td>
<td>TS</td>
<td>A V2G grid services demonstration was performed at Fort Carson. This was part of the three-phase SPIDERS programme that sought to demonstrate the practicality and benefits of creating secure microgrid architecture across three DoD installations.</td>
</tr>
<tr>
<td>43</td>
<td>Grid on wheels</td>
<td>USA</td>
<td>2012</td>
<td>15</td>
<td>FR, TS</td>
<td>First, real world field test of V2G technology with 15 vehicles providing frequency response services over two year period and range of driving patterns.</td>
</tr>
<tr>
<td>44</td>
<td>Fiat-Chrysler V2G</td>
<td>USA</td>
<td>2009</td>
<td>-</td>
<td>FR, TS</td>
<td>Large scale demonstration with 140 PHEVs, a portion of which were fitted with bi-directional charging capability, to test V2H and V2G capability.</td>
</tr>
<tr>
<td>45</td>
<td>Clinton Global Initiative School Bus Demo</td>
<td>USA</td>
<td>2014</td>
<td>6</td>
<td>FR, TS</td>
<td>Project seeking to improve economic viability of electric school buses through V2G and V2B trials in two school districts.</td>
</tr>
<tr>
<td>46</td>
<td>Distribution System V2G for Improved Grid Stability for Reliability</td>
<td>USA</td>
<td>2015</td>
<td>2</td>
<td>DSO, TS</td>
<td>EPRI project seeking to assess the value of, and barriers to, V2G at the distribution level, including whether these benefits can be monetised and quantified.</td>
</tr>
<tr>
<td>47</td>
<td>UCLA WinSmartEV</td>
<td>USA</td>
<td>Not known</td>
<td>1</td>
<td>DSO, TS</td>
<td>Research project seeking to achieve maximum power flow from vehicles, while addressing response time and control, for a variety of applications including reactive power, voltage regulation and distributed storage.</td>
</tr>
<tr>
<td>48</td>
<td>Massachusetts Electric School Bus Pilot</td>
<td>USA</td>
<td>2015</td>
<td>-</td>
<td>-</td>
<td>Pilot project to test deployment of three electric school buses in cold weather environments in US.</td>
</tr>
<tr>
<td>49</td>
<td>INVENT</td>
<td>USA</td>
<td>2017</td>
<td>50</td>
<td>FR, DSO, TS</td>
<td>Nuvve seeking to deploy V2G technology on 50 UC San Diego electric vehicles, in project part funded by California Energy Commission.</td>
</tr>
<tr>
<td>50</td>
<td>Torrance V2G School Bus</td>
<td>USA</td>
<td>2014</td>
<td>2</td>
<td>FR, TS</td>
<td>Department of Energy funded project which retrofitted 2 school buses.</td>
</tr>
</tbody>
</table>

# LIST OF UK DEMONSTRATOR PROJECTS FUNDED BY INNOVATE UK IN 2017 V2G COMPETITION

In 2017, Innovate UK launched a competition for real-world demonstrators in V2G systems. The Table below documents the 8 successful projects. Further funding was awarded to V2G feasibility studies and collaborative R&D.

## PROJECT OVERVIEW

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Category</th>
<th>Lead Applicant</th>
<th>Corporations</th>
<th>SME</th>
<th>Research / Consulting</th>
<th>Academia</th>
<th>Local Authorities</th>
<th>Additional Applicants/Partners</th>
<th>FUNDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMARTHUBS Demonstrator</td>
<td>Smart Hub: Integration of V2G charger, battery and PV controller into a smart hub</td>
<td>Flexisolar</td>
<td>Turbo Power Systems</td>
<td>Flexisolar</td>
<td>Infrastructure/Aggregator: Turbo Power Systems, Flexisolar, (Flexisolar), PowerStar</td>
<td>Infrastructure/Aggregator: Turbo Power Systems, Flexisolar, (Flexisolar), PowerStar</td>
<td>36</td>
<td>2,241,214</td>
<td>1,386,000</td>
</tr>
<tr>
<td>eFuture</td>
<td>Mixed: Validation of stacked V2G services in diverse scenarios</td>
<td>Nissan Motor (GB)</td>
<td>Nissan Motor (GB)</td>
<td>National Grid Northern Power Grid UK Power Networks eON</td>
<td>Imperial College London</td>
<td>Newcastle University</td>
<td>Vehicles/Automotive: Nissan Infrastructure/Aggregator: Nuvve Energy operators: National Grid, Northern PowerGrid, UK Power Networks Academia: Imperial College London, Newcastle University</td>
<td>36</td>
<td>9,864,302</td>
</tr>
</tbody>
</table>

APPENDIX 2 SOURCES EXCLUDING PROJECT-SPECIFIC SOURCES, WHICH ARE INCLUDED ON PROJECT DASHBOARDS

FORMATION OF GLOBAL LIST OF PROJECTS

Literature Review
In addition to the links provided within Appendix 1:

- Amsterdam University of Applied Sciences/SEEV4-City (2018) A V2G Repository: 18 European Vehicle2Grid Projects
- ENA (2018) Online Smarter Networks Portal
- Elaad.nl (2018) Our Projects
- NREL (2017) Vehicle-Grid Integration: A global review of opportunities and issues
- Mobility House (2018) Vehicle-to-Grid (V2) Technology Map
- NREL (2015) Multi-Lab EV Smart Grid Integration Requirements Study
- SEEV4-City (2018) Summary of the State-of-the-Art report

Targeted discussions with representatives of
- Cenex
- IEA
- IREC
- NREL
- Mobility House
- Nuve
- NRCan

Other sources consulted during the course of the study

- Energy Networks Association (2018) Open Networks Project: DSO service requirements – definitions
- Leitat (2018) Demystifying TRLs for Complex Technologies
- Nemo (2018) Website – e-mobility.eu
- Nuve & DTU (2018) Project report: Integration of new technology in the ancillary service markets

Plus, core project team of Everoze, EVConsult, Innovate UK and UK Power Networks.
Journey over…or just the beginning?

We hope you’ve enjoyed this global roadtrip of V2G projects – and that it helps promote awareness of the lessons learned from pioneering pilot projects.

Our parting message is this: there’s been much made of the need for cross-vector exchange of knowledge on V2G – strengthening the links between transport and power sectors. But through our work, we’ve uncovered a need for much more cross-country learning too. This report is our small contribution, but we sense there’s much more to come...

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This document is issued by Everoze Partners Ltd in accordance with proposal UKPN001-P-01-A dated 4 June 2018 and associated proposal contract MAA-20180277 dated 19 July 2018.


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