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V2G GLOBAL ROADTRIP:
AROUND THE WORLD IN 50 PROJECTS

Lessons learned from fifty international vehicle-to-grid projects.

UK Power Networks
Delivering your electricity

Innovate UK

An Everoze & EVConsult report jointly commissioned by UK Power Networks and Innovate UK

October 2018

THIS REPORT PROVIDES A GLOBAL REVIEW OF V2G PROJECTS, TEASING OUT LESSONS LEARNED FOR THE UK AND BEYOND

UK Power Networks Delivering your electricity

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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.*

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EXECUTIVE SUMMARY

THERE ARE 50 VEHICLE-TO-GRID PROJECTS GLOBALLY WITH PHYSICAL DEPLOYMENT OF CHARGERS, OF WHICH OVER HALF ARE IN EUROPE

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.

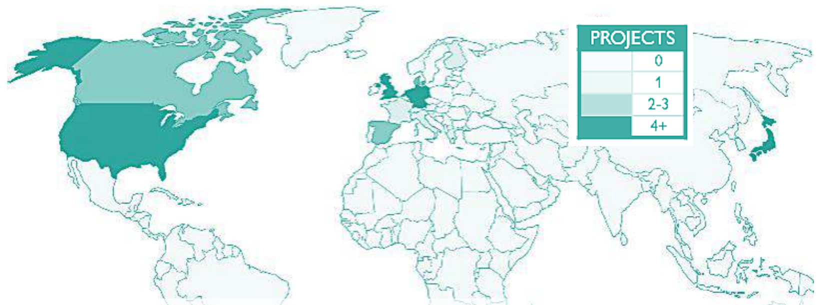
This report is a round-the-world roadtrip of landmark V2G projects. We've ventured to equip DSOs and market participants with the latest global V2G intelligence and where the challenges lie.

OUR JOURNEY

1. **Mapping the journey:** Every good roadtrip begins with a plan. So we started with a grand mapping exercise – surveying 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.

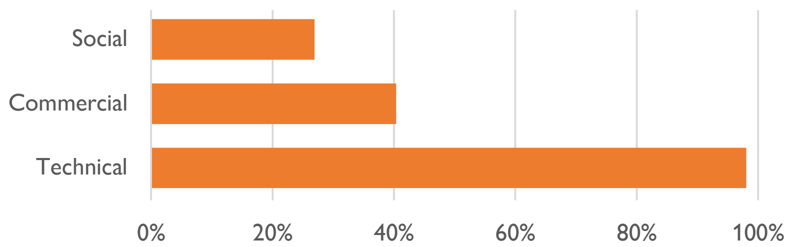
It's been an ambitious exploration, made possible only through the support of contributors on the way – for which we are very grateful. Here's what we found.

HALF OF PROJECTS ARE IN EUROPE



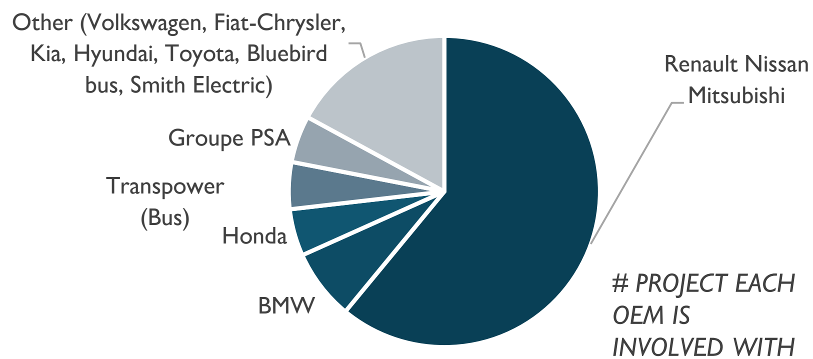
There are 50 V2G projects globally, of which 25 are in Europe, 18 in North America, and 7 in Asia. Asian participation has been more focused on vehicle-to-home and vehicle-to-building (V2H/B) services and contributing as a manufacturing partner than deployment.

SOCIAL ISSUES OFTEN OVERLOOKED



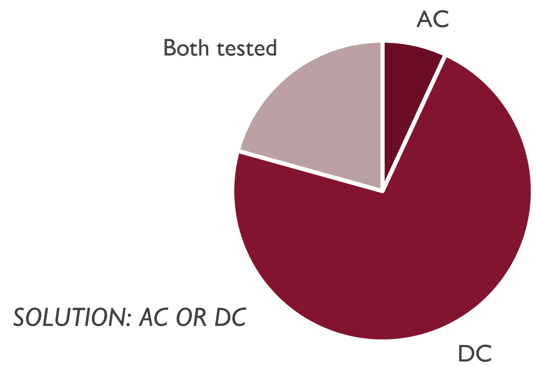
Almost all projects had a technical element (98%). Few focused on social aspects (27%). This reflects the sector's fledging status and early teething problems with V2G charger technology. Interviewees emphasised the need for greater focus on user behaviour going forward.

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 *locational specificity* required, which complicates the aggregate statistical approach taken to guarantee availability and performance.

SERVICE	# OF PROJECTS GLOBALLY*	SERVICE READINESS LEVEL (SRL**)					
		1. RESEARCHED	2. TESTING	3. PROVEN	4. COMMERCIAL ANYWHERE	5. COMMERCIAL (SIMILAR UK)	6. COMMERCIAL COMPEITION
ARBITRAGE	4	FRANCE, DENMARK	NL				
RESERVE	2	FRANCE					
FREQ RESP.	16	FRANCE	NL	USA		DENMARK	Expected in UK shortly
DSO SERVICES	10	DENMARK	UK, NL, (DE)	US	Expected in US 18/19		
TIME SHIFTING***	23		KOREA	USA, UK	JAPAN (Expected in US 18/19)		Expected in UK shortly

*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 (p15)
2. Germany, 2018 **"Re-dispatch"** Unique redispatch approach: TenneT (p16)
3. Netherlands, 2014 "**City-zen Smart City**", Innovative DSO services trial: Alliander (p17)
4. Netherlands, 2014 "**Smart Solar Charging**" Distinctive AC approach: LomboXnet (p18)
5. France, 2017, "**Grid Motion**" Delivering cutting-edge customer insights: Groupe PSA (p19)
6. Korea, 2014 "**Korean V2G**" Preparing Korea for EV roll out: KEPCO, Hyundai (p20)
7. Japan, 2012 "**M-tech Labo**" Pioneering vehicle-to-building model: Mitsubishi Motors Corp. (p21)
8. US, 2012 "**JUMPSmart MAUI**", V2G via V2H with 80 chargers on island of Maui: Hitachi (p22)
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 network impact: Northern Powergrid (p24)

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.

FOR INDUSTRY

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 GOVERNMENT

Support and enable Network Operators and Industry to achieve the above, to unlock the potential of V2G

THIS REPORT IS JOINTLY COMMISSIONED BY UK POWER NETWORKS AND INNOVATE UK

INTRODUCTION

This report is commissioned as part of the TransPower portfolio, which explores vehicle-to-grid technology as one of several smart solutions capable of reducing reinforcement costs due to electric vehicle uptake.

The TransPower portfolio consists of UK Power Networks' activities contributing to several Innovate UK vehicle-to-grid (V2G) competition projects. TransPower is funded by the Network Innovation Allowance.

Under TransPower, UK Power Networks is evaluating the technical, commercial and customer proposition of V2G technology to the distribution network. The portfolio will investigate network impact and flexibility services for several different vehicle customer segments from domestic, to commercial and public charging through demonstrator trials and collaborative research and development.

FORWORDS

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.

THAZI EDWARDS
LOW CARBON TECHNOLOGY & ELECTRIC VEHICLE PROJECTS
UK POWER NETWORKS

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.

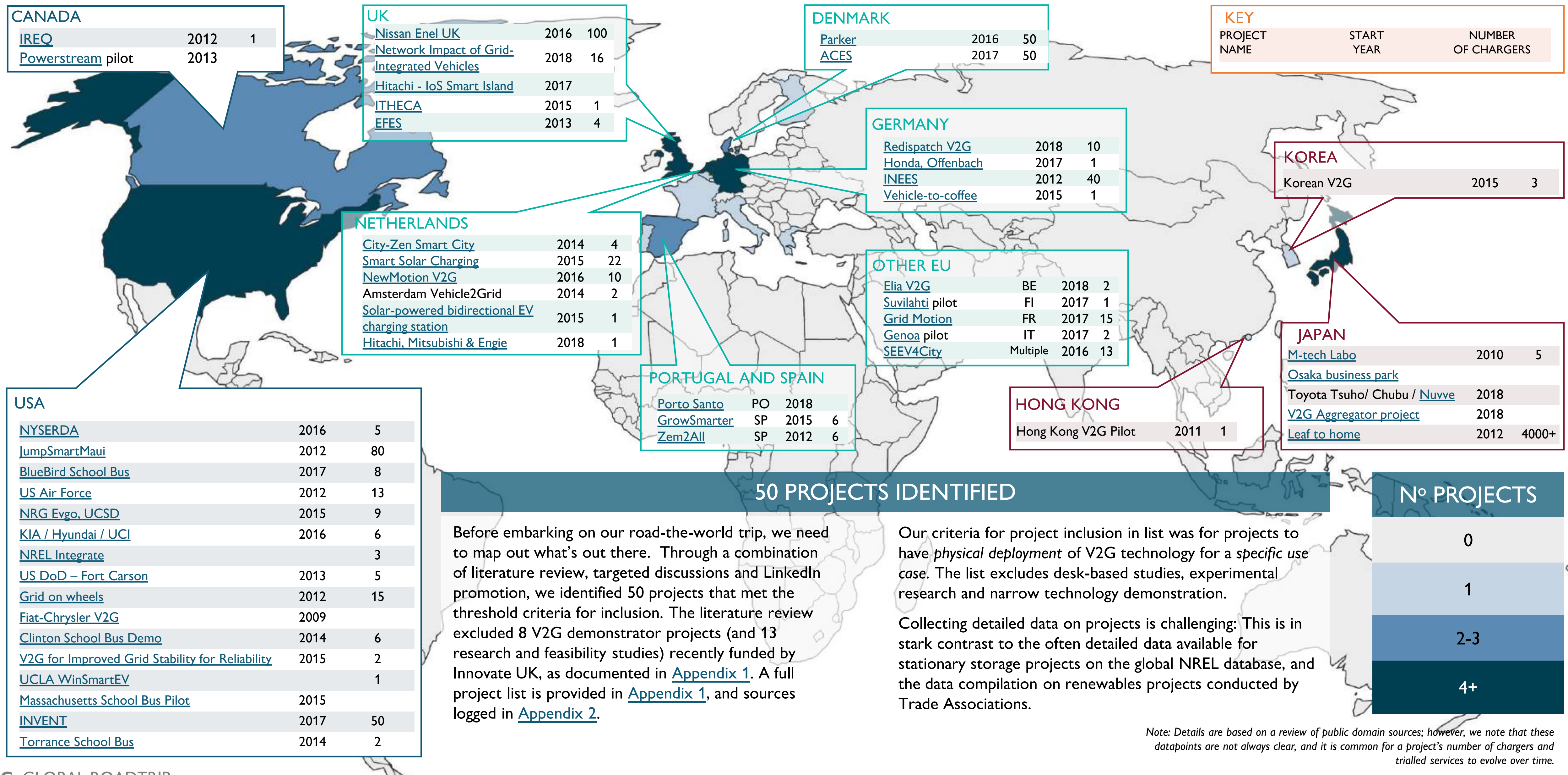
MARCO LANDI
INNOVATION LEAD
INNOVATE UK

CHAPTER 1

MAPPING OUT OUR JOURNEY

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



KEY

PROJECT NAME	START YEAR	NUMBER OF CHARGERS

CANADA

IREQ	2012	1
Powerstream pilot	2013	

UK

Nissan Enel UK	2016	100
Network Impact of Grid-Integrated Vehicles	2018	16
Hitachi - IoS Smart Island	2017	
ITHECA	2015	1
EFES	2013	4

DENMARK

Parker	2016	50
ACES	2017	50

GERMANY

Redispatch V2G	2018	10
Honda, Offenbach	2017	1
INEES	2012	40
Vehicle-to-coffee	2015	1

KOREA

Korean V2G	2015	3

NETHERLANDS

City-Zen Smart City	2014	4
Smart Solar Charging	2015	22
NewMotion V2G	2016	10
Amsterdam Vehicle2Grid	2014	2
Solar-powered bidirectional EV charging station	2015	1
Hitachi, Mitsubishi & Engie	2018	1

OTHER EU

Elia V2G	BE	2018	2
Suvilahti pilot	FI	2017	1
Grid Motion	FR	2017	15
Genoa pilot	IT	2017	2
SEEV4City	Multiple	2016	13

JAPAN

M-tech Labo	2010	5
Osaka business park		
Toyota Tsuho/ Chubu / Nuvve	2018	
V2G Aggregator project	2018	
Leaf to home	2012	4000+

PORTUGAL AND SPAIN

Porto Santo	PO	2018	
GrowSmarter	SP	2015	6
Zem2All	SP	2012	6

HONG KONG

Hong Kong V2G Pilot	2011	1

USA

NYSERDA	2016	5
JumpSmartMaui	2012	80
BlueBird School Bus	2017	8
US Air Force	2012	13
NRG Evgo, UCSD	2015	9
KIA / Hyundai / UCI	2016	6
NREL Integrate		3
US DoD – Fort Carson	2013	5
Grid on wheels	2012	15
Fiat-Chrysler V2G	2009	
Clinton School Bus Demo	2014	6
V2G for Improved Grid Stability for Reliability	2015	2
UCLA WinSmartEV		1
Massachusetts School Bus Pilot	2015	
INVENT	2017	50
Torrance School Bus	2014	2

50 PROJECTS IDENTIFIED

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.

Nº PROJECTS

0
1
2-3
4+

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%)

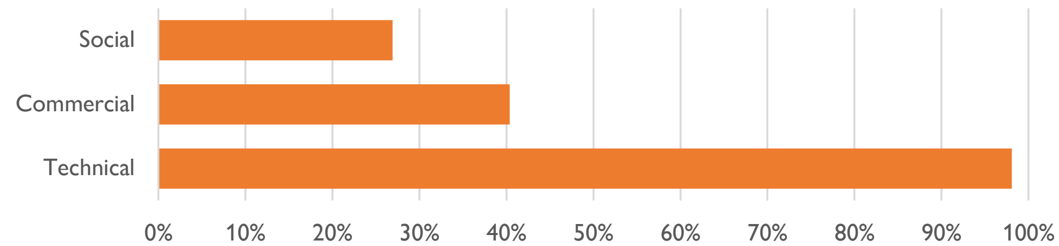
18 ARE IN NORTH AMERICA (36%)

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.

SOCIAL ISSUES OFTEN OVERLOOKED

PROJECT FOCUS – MULTIPLE SELECTIONS PERMITTED



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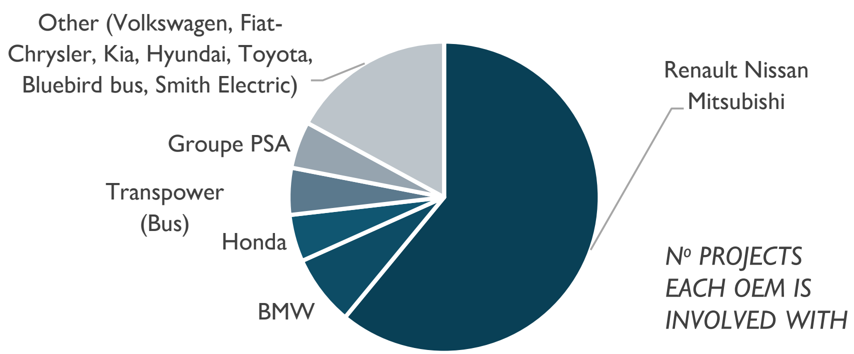
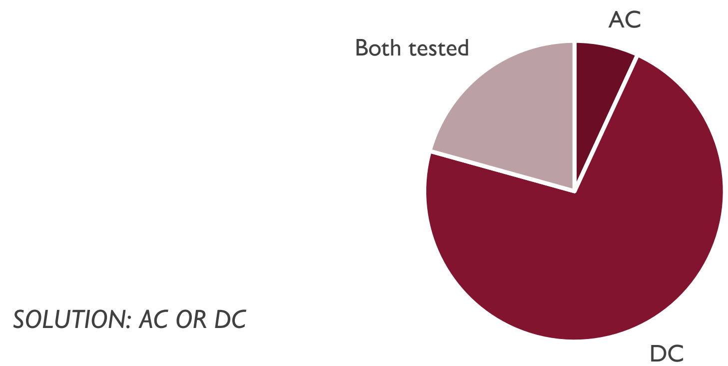


Although 12 vehicle manufacturers (OEMs) have participated in V2G projects, Renault Nissan Mitsubishi clearly dominate. This arguably reflects the legacy of the Fukushima disaster, and the successful integration of V2G within the CHAdeMO protocol (see p10).

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

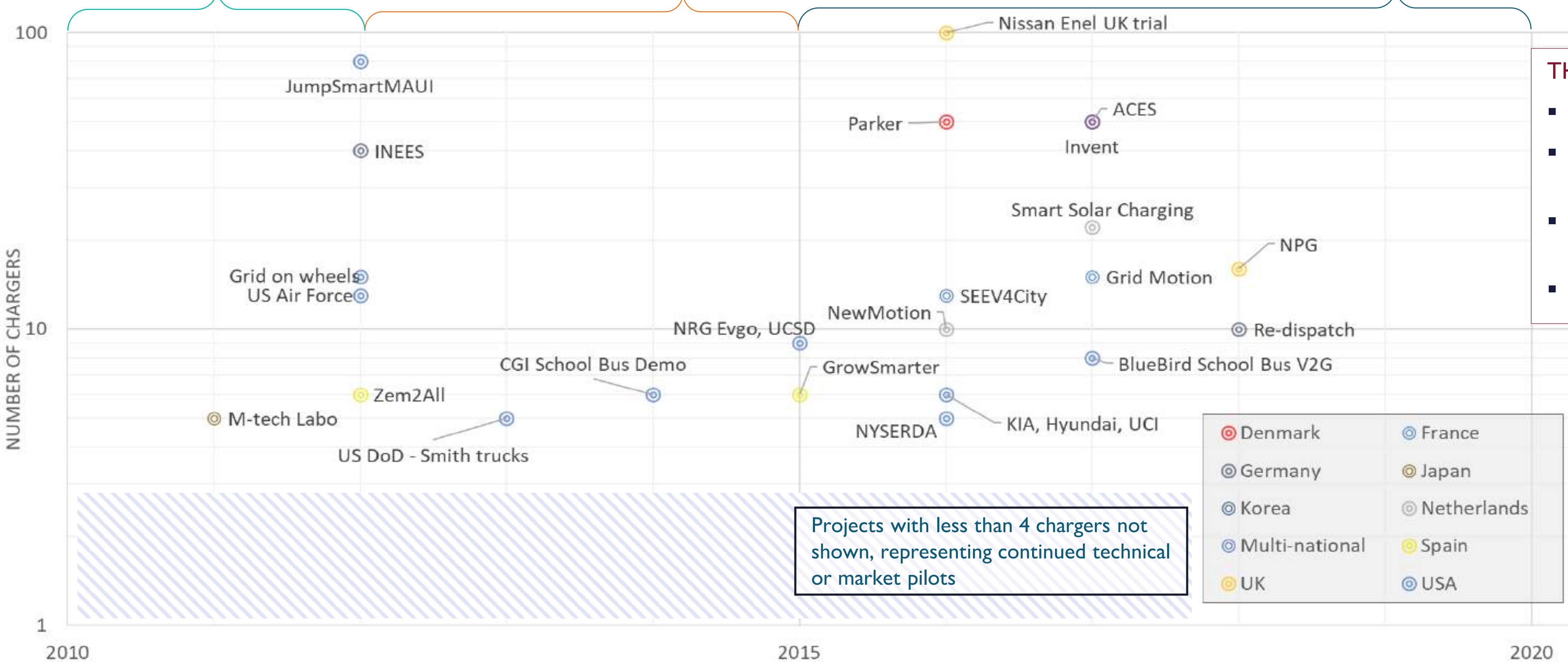
- V2G was pioneered at the Uni of Delaware by Prof. Willett Kempton in 1990s, leading to the first real world test of frequency response with seven vehicles in the PJM* market in 2008.
- In 2011, the Fukushima disaster in Japan spurred Japanese OEMs and market participants to develop bidirectional capability. 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: A number of V2G projects across Europe have scaled back on their ambitions on number of chargers. The reasons are multiple, including:

- Technical: Technical teething 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 **READINESS 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.

TECHNOLOGY READINESS LEVEL								
1	2	3	4	5	6	7	8	9
Basic principles observed	Technology concept formulated	Experimental proof of concept	Technology validated in lab	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)	System prototype demonstrated in operational environment (industrially relevant environment in the case of key enabling technologies)	System complete and qualified	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies)

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.

SERVICE READINESS LEVEL					
1	2	3	4	5	6
FEASIBLE Service theoretically feasible	TESTED/ TESTING Demonstrated that system can technically provide the service (i.e. proof of concept trial)	PROVEN Demonstrated in small-scale commercial trial (most likely with Gov. support and funding)	COMMERCIAL ANYWHERE Service being procured commercially from V2G, in any market not necessarily similar or applicable to the UK	COMMERCIAL (SIMILAR TO UK) Service being procured commercially from V2G in market that is not vertically integrated	COMMERCIAL COMPETITION Service being procured commercially from V2G in market that is not vertically integrated, with some degree of competition from V2G providers

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.

MARKET READINESS LEVEL		
LOW	MEDIUM	HIGH
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.		

CHAPTER 2

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.

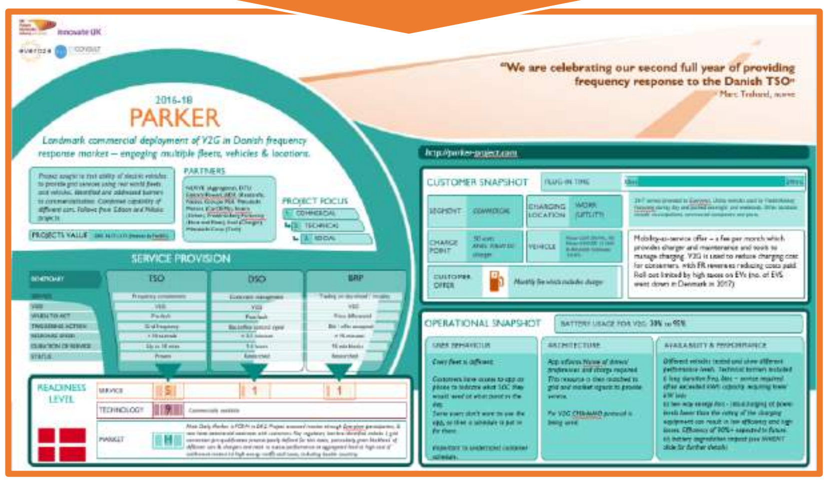
1. PICKING OUR LANDMARK PROJECTS

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

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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.

"SERVICE"	*A defined technical product provided to System Operators, Networks Operators, utilities or consumers, such as frequency response or constraint management.*

CATEGORY	DEFINITION	OPTIONS
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 provide 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 provide 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

“We are celebrating our second full year of providing frequency response to the Danish TSO”
- Marc Trahand, nuvve

2016-18

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.

PROJECTS VALUE *DKK 14,731,471 (financed by ForskEL)*

PARTNERS

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

PROJECT FOCUS

1. COMMERCIAL
2. TECHNICAL
3. SOCIAL

SERVICE PROVISION

BENEFICIARY	TSO	DSO	TPI
SERVICE	Frequency containment	Constraint management	Trading on day-ahead / intraday
V2G?	V2G	V2G	V2G
WHEN TO ACT	Pre-fault	Post-fault	Price differential
TRIGGERING ACTION	Grid frequency	Backoffice control signal	Bid / offer accepted
RESPONSE SPEED	< 10 seconds	< 3-5 minutes	< 15 minutes
DURATION OF SERVICE	Up to 30 mins	1-4 hours	15 min blocks
STATUS	Proven	Researched	Researched

READINESS LEVEL

SERVICE	5 / 1 / 1	
TECHNOLOGY	9	*Commercially available*
MARKET	H	*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) grid connection pre-qualification process poorly defined for this asset, particularly given likelihood of different cars & chargers and need to assess performance at aggregated level ii) high cost of settlement meters iv) high energy tariffs and taxes, including double counting*

PROJECT WEBPAGE

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs – 24hrs

SEGMENT	*COMMERCIAL*	CHARGING LOCATION	*WORK (UTILITY)*
CHARGE POINT	*50 units ENEL 10kW DC charger*	VEHICLE	*Nissan LEAF 30kWh, 10x Nissan E-NV200 24 kWh & Mitsubishi Outlander 12kWh*
CUSTOMER OFFER	*Monthly fee which includes charger*		

24/7 service provided to Energinet. Utility vehicles used by Frederiksberg Forsyning during day and parked overnight and weekends. Other locations include municipalities, commercial companies and ports.

Mobility-as-service offer – a fee per month which provides charger and maintenance and tools to manage charging. V2G is used to reduce charging cost for consumers, with FR revenues reducing costs paid. Roll out limited by high taxes on EVs (no. of EVS went down in Denmark in 2017)

OPERATIONAL SNAPSHOT

BATTERY USAGE FOR V2G: 30% to 95%

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.

AVAILABILITY & PERFORMANCE

Different vehicles tested and show different performance levels. Technical barriers included:
i) long duration freq. bias – service required often exceeded kWh capacity requiring lower kW bids ii) two way energy loss - (dis-charging 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)

UK Power Networks Innovate UK everoze EVCONSULT

"Let's simplify regulations for distributed assets"
- Marcus Fendt, The Mobility House

2018-21

REDISPATCH V2G

Virtual renewable power transport through V2G : reducing transmission constraints & deferring network investment

Demonstration project proving technical ability to use TSO's own field service fleet in addressing transmission constraints in Germany. Highly distributed chargepoint locations. Chargers installed; comms protocol under development

PROJECT VALUE *Corporate funding + TenneT*

PARTNERS

TenneT	*TSO*
The Mobility House	*EMS*
Nissan	*Car OEM*

PROJECT FOCUS

1. TECHNICAL

SERVICE PROVISION

BENEFICIARY	TSO
SERVICE	TSO constraint management
V2G?	V2G (+ V1G at northern sites)
WHEN TO ACT	Pre-fault
TRIGGERING ACTION	TSO control signal
RESPONSE SPEED	From seconds up to 2 minutes
DURATION OF SERVICE	Hours – potentially up to 2-3 days
STATUS	Testing

READINESS LEVEL

SERVICE	2	*Proof of Concept trial in progress. Score will be 3 once project is complete.*
TECHNOLOGY	8	*EVTEC bidirectional charging technology is mature, but not yet in series production.*
MARKET	H	*High. Active demand side response market. Non-vertically integrated market. Regulatory barriers include that storage not yet a regulatory category, creating 'double-charging' problem – levies due as producer AND consumer. Necessity for each vehicle to be individually registered as a power plant.*

PROJECT WEBPAGE

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs – 24hrs

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.*
CHARGE POINT	*EVTEC Charger 10kW DC V2G in South. 7.6kW V1G in north.*
VEHICLE	*Nissan LEAF & ENV200, 40kWh. ~10 vehicles.*
CUSTOMER OFFER	*N/A – project has technical focus at present. There has not been a need to frame customer offer due to TenneT being the fleet owner. However, the project aims to engage other vehicle users in future.*

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.

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.

Constraints are most severe in the north (originating in wind plant), though solar-driven constraints are emerging as a challenge in the south.

OPERATIONAL SNAPSHOT

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

USER BEHAVIOUR

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

However, longer-term the aspiration is to explore other user types with different driving patterns – particularly targeting vehicles that can be plugged-in during work daytime hours, to balance out fleet availability in the EV portfolio.

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 comms 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.

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"Let's revise grid acceptance standards for V2G chargepoints"
- Marisca Zweistra, Alliander

2014-19

CITY-ZEN

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

Dutch project with 4DC V2G chargers – with pioneering focus on DSO services. Adopting a holistic commercial, social and technical approach, with multiple power sector use cases.

PROJECT VALUE *€300k for equip. + subsidised labour.*

PARTNERS

ALLIANDER	*DSO*
NEWMOTION	*CPO*
ENERVALIS	*EMS*
MAGNUM CAP	*Charger*

PROJECT FOCUS

1. TECHNICAL
2. COMMERCIAL
3. SOCIAL

SERVICE PROVISION

BENEFICIARY	DSO	TPI
SERVICE	Constraint management & Power quality	Imbalance and energy trading
V2G?	V2G	V2G
WHEN TO ACT	Pre-fault	When spreads are high
TRIGGERING ACTION	Forecast on USEF platform	During market peaks/troughs
RESPONSE SPEED	Within minutes/hours	Settlement Period – 15 mins
DURATION OF SERVICE	Minutes-hours	Minutes-hours
STATUS	Testing ongoing	Testing ongoing

READINESS LEVEL

SERVICE	2 (DSO)	2 (TPI)
TECHNOLOGY	7	*Slow Starter amendments required initially in chargepoint; now chargepoint is demonstrated in operational environment.*
MARKET	M	*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*

PROJECT WEBPAGE

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs — *variable* — 24hrs

SEGMENT	*HOUSEHOLD & COMMERCIAL*	CHARGING LOCATION	*WORK & PUBLIC*
CHARGE POINT	*4 DC V2G chargers, 10 kW, MagnumCap*	VEHICLE	*2 Mitsubishi Outlander, 2 Nissan EV200 (mini-an), 1 Nissan LEAF*

Variety of customers:
- *2 commercial minivan users*
- *1 individual with irregular driving behaviour*
- *1 individual with routine behaviour (corporate lease)*
- *1 car ordered by app as part of car-sharing solution.*

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

Commercial value still to be quantified. A key challenge is that services such as grid congestion management are not clearly priced in the market.

V2G benefits are expected to be particularly high when customers have onsite solar and consume energy in evenings.

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.

ARCHITECTURE

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.

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EVCONSULT

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

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	Lead
Last Mile Solutions	*CPO*
Stedin	*DSO*
Renault	*OEM*
ElaadNL	*cooperation of DSOs*

PROJECT FOCUS

1. TECHNICAL
2. COMMERCIAL
3. SOCIAL

SERVICE PROVISION

BENEFICIARY	DSO	TSO	TPI (=main focus)
SERVICE	Constraint management	Frequency response	Imbalance and energy trading
V2G?	V2G	V2G	V2G
WHEN TO ACT	Pre-fault	Pre-fault	When spreads are high
TRIGGERING ACTION	Forecast on USEF platform	Forecast on USEF platform	During market peaks/troughs
RESPONSE SPEED	Within minutes/hours	Within minutes/hours	Settlement Period = 15 mins
DURATION OF SERVICE	Minutes-hours	Minutes-hours	Minutes-hours
STATUS	Researched	Researched	Researched

READINESS LEVEL

SERVICE	1 / 1 / 1	
TECHNOLOGY	7	*Chargepoint will be market ready by end of 2018. The vehicles will arrive in same time slot but are still in prototypes.*
MARKET	M	*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.*

PROJECT WEBPAGE

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs — *variable* — 24hrs

SEGMENT	*CITY CAR SHARE SCHEME*
CHARGING LOCATION	*PUBLIC*
CHARGE POINT	AC 22 kW By Seers Group & The People Group (GE in past)
VEHICLE	*22 Renault Zoe (40kWh)*
CUSTOMER OFFER	*Part of car sharing scheme – EUR 99/month. Includes km and insurance*

Car sharing vehicle is standing idle less than private vehicle (only 60-70% vs. >90% for private vehicle). Predictable usage, with idle periods mostly at night

Insights expected at end of 2019

OPERATIONAL SNAPSHOT

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

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

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

Innovate UK

“We need more efficient interconnection standards”
- Paige Mullen, Nuvve

2017-19

GRID MOTION

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

Trial is testing ability to provide grid balancing services through both V1G and V2G. V2G element is fleet of 15 B2B EV Peugeot iOn or Citroën C-ZERO vehicles with Enel bidirectional charging stations. V1G is 50 (Nuvve AC) chargers installed at residential properties.

PROJECT VALUE: PRIVATELY FUNDED

PARTNERS

Groupe PSA	Car OEM
Direct Energie	Market access
Enel	Charger
Nuvve	Aggregator
Proxiserve	Installation
DTU	Research

PROJECT FOCUS

1. TECHNICAL
2. SOCIAL
2. COMMERCIAL

SERVICE PROVISION

BENEFICIARY	TSO	TPI	ENERGY USER
SERVICE	Frequency Response	Trading on day-ahead / intraday	Reduction Time of Use Charges
V2G?	V2G	V2G	V2H/B
WHEN TO ACT	Pre-fault	Price differential - Bid/Offer called	Peak charges
TRIGGERING ACTION	Grid frequency	Bid/Offer called	Scheduled
RESPONSE SPEED	15 sec - 15 min duration	< 15 minutes	Scheduled
DURATION OF SERVICE	1 week bids	15 min blocks	Subject to charges (hours)
STATUS	Researched – plan to test	Researched – plan to test	Researched

READINESS LEVEL

FRANCE

SERVICE	1 / 1 / 1	
TECHNOLOGY	9	*Commercially available chargers.*
MARKET	H	*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*

PROJECT WEBPAGE

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs — *variable* — 24hrs

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

SEGMENT	*Commercial fleet on airport grounds (airport supplier)*
CHARGING LOCATION	*WORK*
CHARGE POINT	*V2G - 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*

Project is developed as the first V2G project established in France. V2G chargers installed with a commercial fleet and V1G at consumer homes. The study is key to demonstrate feasibility commercially to project participants and to break down barriers for market access of DERs in France.

OPERATIONAL SNAPSHOT

BATTERY USAGE FOR V2G (30-95%)

USER BEHAVIOUR

Too early in project to provide learning

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.

UK Power Networks Innovate UK everoze EVCONSULT

> "V2G can help shave summer and winter peaks"
> - Mr Son, Chan, KEPRI

2015-17

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 testbed testing various chargers. Hyundai Mobis were first to have bidirectional charger approved.

PROJECT VALUE *Private funding*

PARTNERS

KEPCO	LEAD
HYUNDAI	EV
MOBIS (Charger), I&C (IT), PNE (Charger), KDN (EMS), Nemo (Business Model)	

PROJECT FOCUS

1. TECHNICAL

SERVICE PROVISION

BENEFICIARY	ENERGY USERS
SERVICE	Time-shifting for energy users
V2G?	V2G
WHEN TO ACT	Peak
TRIGGERING ACTION	Market signals
RESPONSE SPEED	< 10 seconds
DURATION OF SERVICE	1 – 4 hours
STATUS	Tested

READINESS LEVEL

SERVICE	2	
TECHNOLOGY	6	*Prototype testing.*
MARKET	L	*Active demand response market that needs adaption for V2G. Detailed regulations need amendments for V2G*

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs – *discharge* – *charge* – 24hrs

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 (28kWh1xAC,1xDC) 1 ITeng (20kWh AC)*
CUSTOMER OFFER	N/A		

Usually, they have been charged during night time or after-work time and discharged during day time. But it depends on different tested cases.

No real customers - researchers conducting V2G programme

OPERATIONAL SNAPSHOT

BATTERY USAGE FOR V2G (30-100%)

USER BEHAVIOUR

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

Project is now working on finding better range of V2G SOC for battery and users

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.

AVAILABILITY & PERFORMANCE

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

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.

"We proved the technical feasibility of vehicle-to-building five years ago. The next challenge is economics"
- Project representative, Mitsubishi Corp.

Project was set in Mitsubishi Motors' Nagoya plant as a part of Keihanna Smart Community project. The project developed and demonstrated an EMS to deliver peak shaving. Demonstration ran for 1 year.

PROJECT VALUE: *66% Government funded*

PARTNERS

MITSUBISHI CORP	*Lead*
MITSUBISHI MOTORS	*OEM*
MITSUBISHI ELECTRIC	*EMS*
TOKYO INSTITUTE OF TECH	*Advisory*

PROJECT FOCUS

1. TECHNICAL

SERVICE PROVISION

BENEFICIARY	ENERGY USERS
SERVICE	Peak shaving
V2G?	V2B
WHEN TO ACT	Scheduled
TRIGGERING ACTION	Forecast
RESPONSE SPEED	N/A
DURATION OF SERVICE	3 hours (1pm-4pm)
STATUS	Tested

READINESS LEVEL

SERVICE	2	
TECHNOLOGY	6	*Customer charger developed by Mitsubishi Electric (prototype)*
MARKET	L	*EV uptake still low, so difficult market. Market is undergoing liberalisation. V2B achievable, but V2G faces substantial barriers*

PROJECT WEBPAGE

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs – day-time – 24hrs

SEGMENT	*COMMERCIAL*
CHARGING LOCATION	*WORK*
CHARGE POINT	*3 kW DC, Mitsubishi Electric*
VEHICLE	*5 Mitsubishi iMiEV cars, 16kWh each.*
CUSTOMER OFFER	*Mitsubishi Motors' employees selected, to simplify consumer engagement.*

Only weekdays, no weekends. Cars charged during office hours.

Employees at the Administration Building of Mitsubishi Motors Corporation's Nagoya Plant were selected based on their commute to join this project and make use of the vehicles on a day-to-day basis.

OPERATIONAL SNAPSHOT

BATTERY USAGE FOR V2G: *not stated.*

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.

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.

UK Power Networks Innovate UK everoze EVCONSULT

"We delivered V2G at scale…from real world families we had no control over"

- Project representative, Hitachi

2012-16

JUMPSMARTMAUI

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.

PROJECT VALUE *Unknown*

PARTNERS

- HITACHI *Lead*
- NEDO *Funder*
- Mizuho Corporate Bank and Cyber Defense Institute, the State of Hawaii; the County of Maui; Maui Electric Company and Hawaiian Electric Company; Hawaii Natural Energy Institute; Maui Economic Development Board, Inc.; University of Hawaii Maui College

PROJECT FOCUS

1. TECHNICAL
2. SOCIAL
3. COMMERCIAL

SERVICE PROVISION

BENEFICIARY	DSO/TSO (same organisation on Maui)	DSO/TSO (same organisation on Maui)
SERVICE	Peak reduction	Frequency response*
V2G?	Yes through peak reduction at homes	Yes through peak reduction at homes
WHEN TO ACT	Forecast based on system req.	Change in frequency
TRIGGERING ACTION	Backoffice control signal	Control signal from DSO
RESPONSE SPEED	< 4 secs	< 4 secs
DURATION OF SERVICE	3 hours (6-9pm)	2 hours)
STATUS	Proven	Proven

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

READINESS LEVEL

SERVICE	3 (in trial)	3 (in trial)
TECHNOLOGY	9	Commercially available
MARKET	M>H	At time of trial, active demand response market, although limited to I&C. Now revised to allow access by broader range including V2H. Interconnection standards were challenging – now revised to UL certification

PROJECT WEBPAGE

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs … night-time … 24hrs

SEGMENT	INDIVI-DUAL	CHARGING LOCATION	*HOME*
CHARGE POINT	*6kW Hitachi DC*	VEHICLE	*Nissan LEAF 80 cars*
CUSTOMER OFFER	Free charger provided, with no other economic incentive. Participants involved due to environmental or community interest reasons		

Lowest average SoC was at 7pm but even then half of vehicles had 70% or more SoC.

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

OPERATIONAL SNAPSHOT

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

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 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.

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. Hawaiian electric have now revised demand response programme. V2G not directly included but V2H as a form of DR will be eligible. Bidding underway for delivery late 18/19. EVs are very fast and flexible and when combined with other resources can be very valuable to grid.

> **“We are making commercial offers in California”**
> - Marc Trahand, Nuvve

2017-2020

INVENT

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

Trial on UCSD 45 MW micro-grid, with significant amount of solar/storage/generation. Project will test vehicle-to-building (V2B) integration, demand response, freq. regulation and interaction with solar forecasting. AC & DC chargers tested with 6+ types of vehicles.

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

PARTNERS

Nuvve	*Aggregator*
Mitsubishi, BMW & Nissan	OEMs
UCSD	*Research*
Nuvve, Hitachi	*Chargepoint Operators*

PROJECT FOCUS

1. COMMERCIAL
2. TECHNICAL
3. SOCIAL

SERVICE PROVISION

BENEFICIARY	TSO / DSO	TSO	ENERGY USERS
SERVICE	Demand Response / Peak reduction	Frequency regulation	Reduction of demand charges
V2G?	V2G	V2G	V2H/B (although can be stacked)
WHEN TO ACT	Stress event called by TSO/DSO	Continuous response to signal	Peak charge periods (kW)
TRIGGERING ACTION	Stress event called by TSO/DSO	Grid frequency (AGC signal)	Approach of unusual load peak
RESPONSE SPEED	Alerts usually issued day ahead	< 4 seconds	15-min intervals
DURATION OF SERVICE	4 hours	Continuous	Hours
STATUS	Proven	Tested	Tested

READINESS LEVEL

SERVICE	3 / 2 / 2	
TECHNOLOGY	9	*AC chargepoints UL listed and commercially available DC chargepoints have been operated thoroughly in testing environment and commercially available.*
MARKET	H	*Value streams available in DSO and TSO level demand response markets and behind-the-meter applications (V2B). Current barriers to TSO frequency regulation market. Key market barriers include quickly evolving interconnection standards for inverters, market access options for electric vehicles and compensation mechanisms between retail and wholesale.*

PROJECT WEBPAGE

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs — *variable* — 24hrs

SEGMENT	*WORK (University Campus)*	CHARGING LOCATION	*COMMERCIAL (University Campus)*
CHARGE POINT	9 AC Nuvve PowerPorts (18kW) 9 DC Hitachi (6 kW) 30+ TBD (Phase 2/3)	VEHICLE	2 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	*Free charger, parking and electricity*		

Predominantly workplace charging during day, with university fleet charging at night.

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.

OPERATIONAL SNAPSHOT

BATTERY USAGE FOR V2G: OEM and model dependent

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

Nuvve 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.

“Through this project we hope to gain the evidence to streamline the interconnection process in the UK”
- Paige Mullen, Nuvve

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.

PROJECT VALUE *£375k NIA funding to NPG*

PARTNERS

Northern Power Grid	DNO
Nuvve	Aggregator
Newcastle Uni.	Research

PROJECT FOCUS

1. TECHNICAL
2. COMMERCIAL

SERVICE PROVISION

BENEFICIARY	DSO
SERVICE	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)
V2G?	
WHEN TO ACT	
TRIGGERING ACTION	
RESPONSE SPEED	
DURATION OF SERVICE	
STATUS	Testing

READINESS LEVEL

SERVICE	2	
TECHNOLOGY	7	*Chargepoint has been demonstrated in operational environment*
MARKET	H	*High – active demand response market, supportive TSO and DSO environment, strong competition between aggregators. However interconnection process is slow.*

PROJECT WEBPAGE

CUSTOMER SNAPSHOT

PLUG-IN TIME: 0hrs – 24hrs

SEGMENT	COMMERCIAL (NPG fleet)	CHARGING LOCATION	*WORK (NPG offices)*
CHARGE POINT	*19x MagnumCap 10 kW DC*	VEHICLE	*Nissan NV200s and possible Nissan LEAFs*
CUSTOMER OFFER	*Given fleet vehicles of NPG, customer offer has not been major focus.*		

Utilisation is still to be determined – likely that NPG fleet will mainly be plugged in overnight. NPG employees may be able to use during day time as well.

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

OPERATIONAL SNAPSHOT

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

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.

AVAILABILITY & 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.

CHAPTER 3

JOURNAL

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.

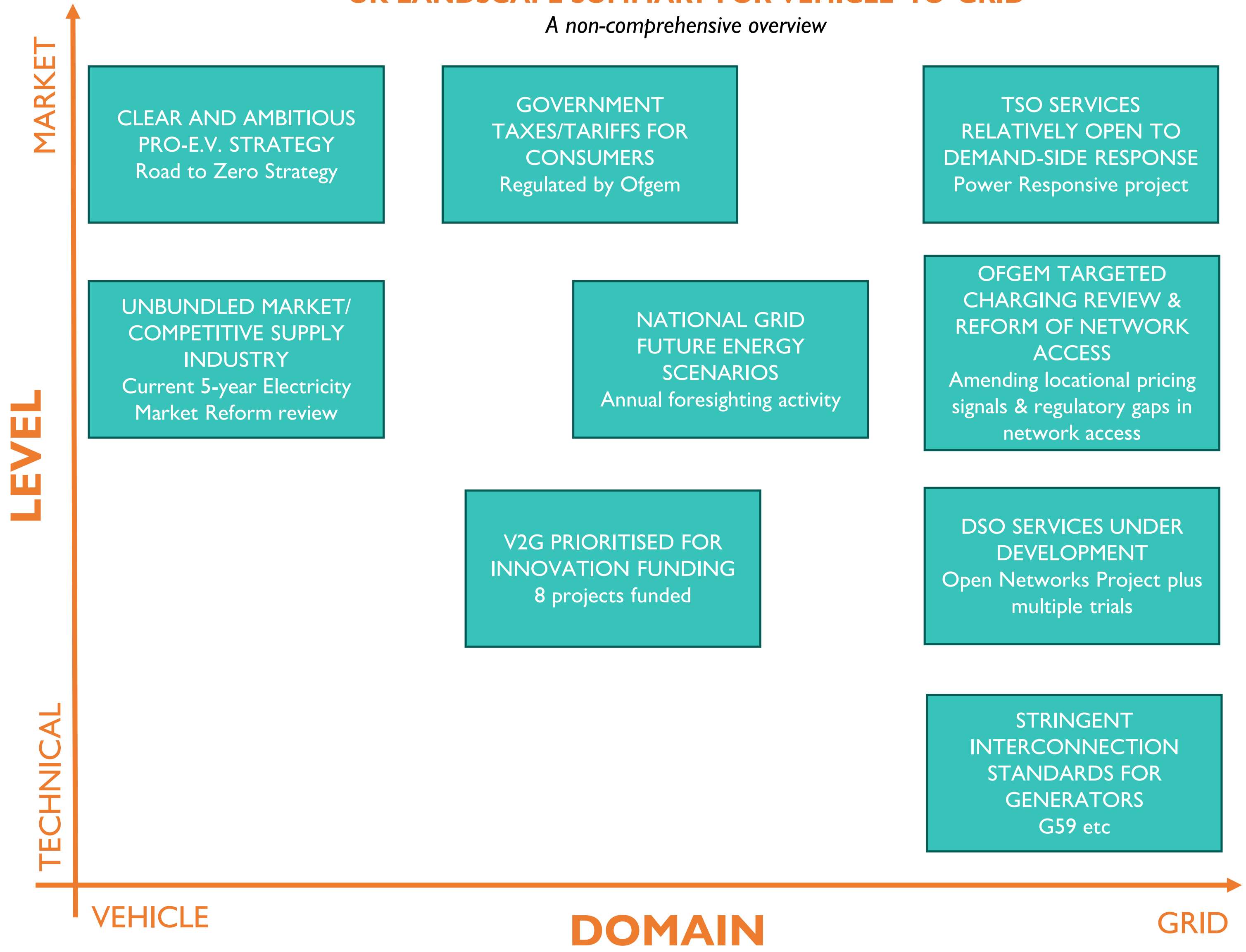
The chart on the right summarises some notable features of the market landscape. Its purpose is not to be comprehensive, since a detailed market review would constitute a report in itself*. Instead, the purpose is to prime our analysis covered on the following pages.

*See 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.

UK LANDSCAPE SUMMARY FOR VEHICLE-TO-GRID

A non-comprehensive overview



EVs CAN PROVIDE FAST AND FLEXIBLE BIDIRECTIONAL ENERGY FLOW, YET THE HARDWARE REMAINS COMMERCIALLY 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.

TECHNICAL CONTINUED.

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

ONLY 10 V2G PROJECTS ARE PROVIDING DISTRIBUTION SERVICES – BUT UK DSOS CAN BENEFIT FROM V2G'S TRACK RECORD IN PROVIDING OTHER SERVICES

COMMERCAL

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.

SERVICE	# OF PROJECTS GLOBALLY*	SERVICE READINESS LEVEL (SRL**)					
		1. RESEARCHED	2. TESTING	3. PROVEN	4. COMMERCIAL ANYWHERE	5. COMMERCIAL (SIMILAR UK)	6. COMMERCIAL COMPEITION
ARBITRAGE	4	FRANCE, DENMARK	NL				
RESERVE	2	FRANCE					
FREQ RESP.	16	FRANCE	NL	USA		DENMARK	Expected in UK shortly
DSO SERVICES	10	DENMARK	UK, NL, (DE)	US	Expected in US 18/19		
TIME SHIFTING***	23		KOREA	USA, UK	JAPAN (Expected in US 18/19)		Expected in UK shortly

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

CUSTOMERS ARE DIVERSE AND A LITTLE UNPREDICTABLE, YET HAVE BEEN A SECONDARY CONSIDERATION TO DATE.

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.

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.

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 it's 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

APPENDIX 1

LIST OF PROJECTS - GLOBAL

#	PROJECT NAME	COUNTRY	START YEAR	NO. CHARGERS	SERVICE	SUMMARY
1	Vehicle-to-Grid (V2G) Pilot Project	Hong Kong	2011	1	-	Small scale proof of concept trial in Hong Kong
2	M-tech Labo	Japan	2010	5	TS	Early V2B trial using 5 iMiEVs, reducing peaks by 12.7% at Mitsubishi Motors' office – together with second life battery
3	Osaka business park	Japan	-	-	-	Small scale trial for V2B, with little information available publicly
4	Toyota Tsuho / Chubu Electric / Nuvve	Japan	2018	-	-	Expected to be first ever V2G (as opposed to V2B) project in Japan. Government-funded trial announced in 2018
5	V2G Aggregator project	Japan	2018	-	-	Government-funded project just announced to build V2G system and test business models in Japan
6	Leaf to home	Japan	2012	4000+	TS	Commercially available vehicle-to-home product in Japan with over 4000 units sold (press release 2017).
7	Korean V2G	Korea	2015	3	TS	KEPCO project laying technical groundwork for EV roll out in Korea
8	Elia V2G	Belgium	2018	2	FR	Leading Belgium project evaluating a mix of V2G and V1G to provide FCR services to TSO Elia.
9	Parker	Denmark	2016	50	FR, DSO, A	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.
10	ACES	Denmark	2017	50	FR, DSO, TS	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
11	Suvilahti pilot	Finland	2017	1	-	Finland first two-way public charger in connection with a solar plant and electrical storage facility.
12	Grid Motion	France	2017	15	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
13	Redispatch V2G	Germany	2018	10	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.
14	Honda, Offenbach	Germany	2017	1	TS	Honda are testing V2B application on a building with on-site solar.
15	INEES	Germany	2012	40	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.
16	Vehicle-to-coffee	Germany	2015	1	TS	The Mobility House's office is powered in part from Nissan LEAF in practical demonstration of vehicle to office concept.
17	Genoa pilot	Italy	2017	2	-	Two car trial testing V1G and awaiting definition of regulatory framework for V2G in Italy

SERVICES: 'FR' – Frequency Response; 'DSO' – Distribution Services; 'A' – Arbitrage, 'TS' – Time Shifting, 'R' – Reserve, '-' Not known

LIST OF PROJECTS - GLOBAL

#	PROJECT NAME	COUNTRY	START YEAR	NO. CHARGERS	SERVICE	SUMMARY
18	SEEV4City	Netherlands, Norway, UK, Belgium	2016	13	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
19	City-Zen Smart City	Netherlands	2014	4	DSO, A	Small-scale commercial trial of DSO service, engaging diverse customers: commercial, individual & car-sharing
20	Smart Solar Charging	Netherlands	2015	22	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.
21	NewMotion V2G	Netherlands	2016	10	FR	First V2G project in NL to provide Frequency Control Reserve (FCR) services to TSO TenneT with chargers at homes, offices and public locations.
22	Amsterdam Vehicle2Grid	Netherlands	2014	2	TS	Small scale domestic trial looking at feasibility of V2H installations in Amsterdam.
23	Solar-powered bidirectional EV charging station	Netherlands	2015	1	TS	Research project developing integrated EV charger and solar PV inverter, designed for solar car port applications.
24	Hitachi, Mitsubishi and Engie	Netherlands	2018	1	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.
25	Porto Santo	Portugal	2018	-	-	Project seeking to make Porto Santo a fossil-free island through the use of EVs to stabilize the grid. At present just V1G.
26	GrowSmarter	Spain	2015	6	TS	6 V2G chargers installed at Endesa facility and used for Time shift, Power balancing and Power quality support.
27	Zem2All	Spain	2012	6	-	At this time largest real world V2G trial in world, forming part of wider e-mobility trial in Malaga.
28	Nissan Enel UK	UK	2016	100	-	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.
29	The Network Impact of Grid-Integrated Vehicles	UK	2018	16	DSO	DNO-run project aiming to understand the negative and positive impacts of V2G-enabled EVs on the distribution network.
30	Hitachi - Isle of Scilly Smart Island	UK	2017	-	-	Wide-ranging smart-grid programme on island network. V2G element appears relatively small at present
31	ITHECA	UK	2015	1	FR	Micro-grid demonstration project at Aston University which installed UK's first ever V2G charger.
32	EFES	UK	2013	4	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.
33	IREQ	Canada	2012	1	DSO, TS	Technology demonstration of back up supply and export to the grid for an assembled electric test vehicle and charging station.
34	Powerstream pilot	Canada	2013	-	-	Small scale, microgrid proof-of-concept trial incorporating V2G in phase 2

SERVICES: 'FR' – Frequency Response; 'DSO' – Distribution Services; 'A' – Arbitrage, 'TS' – Time Shifting, 'R' – Reserve, '-' Not known

LIST OF PROJECTS - GLOBAL

#	PROJECT NAME	COUNTRY	START YEAR	NO. CHARGERS	SERVICE	SUMMARY
35	NYSERDA	USA	2016	5	-	6 Nissan LEAF vehicles used to provide bi-directional grid services on the CUNY Queens College campus
36	JumpSmartMaui	USA	2012	80	DSO, FR	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
37	BlueBird School Bus V2G	USA	2017	8	FR, TS	8 Bluebird electric school buses deployed at the Rialto Unified School District providing ancillary services and energy management services.
38	US Air Force	USA	2012	13	FR, R, TS	Small-scale V2G pilot completed by the US Department of Defence leading to a large-scale testing and evaluation programme on 6 DoD installations.
39	NRG Evgo, UCSD	USA	2015	9	-	EVgo 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).
40	KIA Motors, Hyundai Technical Center Inc., UCI	USA	2016	6	TS	UC Irvine partnered with KIA/Hyundai to demonstrate V2G control software, understand charging behaviour and assess impact on the grid.
41	NREL Integrate / living lab	USA	Not known	3	-	Use cases for V2G assessed for one vehicle and one school bus using grid simulator and on-site solar.
42	US DoD – Fort Carson	USA	2013	5	TS	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.
43	Grid on wheels	USA	2012	15	FR, TS	First, real world field test of V2G technology with 15 vehicles providing frequency response services over two year period and range of driving patterns.
44	Fiat-Chrysler V2G	USA	2009	-	FR, TS	Large scale demonstration with 140 PHEVs, a portion of which were fitted with bi-directional charging capability, to test V2H and V2G capability.
45	Clinton Global Initiative School Bus Demo	USA	2014	6	FR, TS	Project seeking to improve economic viability of electric school buses through V2G and V2B trials in two school districts.
46	Distribution System V2G for Improved Grid Stability for Reliability	USA	2015	2	DSO, TS	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.
47	UCLA WinSmartEV	USA	Not known	1	DSO,. TS	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.
48	Massachusetts Electric School Bus Pilot	USA	2015	-	-	Pilot project to test deployment of three electric school buses in cold weather environments in US.
49	INVENT	USA	2017	50	FR, DSO, TS	Nuvve seeking to deploy V2G technology on 50 UC San Diego electric vehicles, in project part funded by California Energy Commission.
50	Torrance V2G School Bus	USA	2014	2	FR, TS	Department of Energy funded project which retrofitted 2 school buses.

SERVICES: 'FR' – Frequency Response; 'DSO' – Distribution Services; 'A' – Arbitrage, 'TS' – Time Shifting, 'R' – Reserve, '-' Not known

APPENDIX 1

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.

SOURCE: Innovate UK (2017) Results of competition: Innovation in Vehicle-To-Grid (V2) Systems: Real-World Demonstrators, with additional Innovate UK edits to reflect latest project summaries.

PROJECT OVERVIEW		PROJECT PARTNERS							FUNDING		
Project Title	Category	Lead Applicant	Corporations	SME	Research / Consulting	Academia	Local Authorities	Additional Applicants/Partners	Months	Total project cost (£)	Funding sought (£)
V2GO	**Fleets:** fleet-based trial, including customer profiling and suitability for V2G services	EDF	EDF	Arrival Upside Energy The Virtual Forge		University of Oxford	Oxfordshire Conty Council	Vehicles/Automotive: Arrival Infrastructure/Aggregator: Upside Energy, Oxfordshire County Council, Fleet Innovations, EO Charging Energy operators: (EDF) Academia: University of Oxford	36	4,138,313	3,046,784
E-FLEX - Real-world Energy Flexibility through Electric Vehicle Energy Trading	**Car Club**: V2G enabled fleets in urban area	Cisco	Cisco Transport for London	E-Car Club Nuvve	Cenex	Imperial College London	Greater London Authority	Vehicles/Automotive: E-Car Club Infrastructure/Aggregator: Nuvve, Greater London Authority, Transport for London, (Cisco) Academia: Imperial College London Consulting: Cenex	30	5,290,958	3,664,687
Powerloop: Domestic V2G Demonstrator Project	**Domestic:** Implementation of domestic V2G systems interoperable with all providers	Octopus Energy	UK Power Networks ChargePoint	Octopus Energy Octopus Electric Vehicles Open Energi	Energy Saving Trust Navigant Consulting Europe			Vehicles/Automotive: Octopus Electric Vehicles Infrastructure/Aggregator: ChargePoint, (Octopus Energy) Energy operators: Open Energi, UK Power Networks Consulting: Energy Saving Trust, Navigant Consulting Europe	36	6,993,133	3,127,489
SMARTHUBS Demonstrator	**Smart Hub:** Integration of V2G charger, battery and PV controller into a smart hub	Flexisolar		Turbo Power Systems Flexitricity Flexisolar				Infrastructure/Aggregator: Turbo Power Systems, Flexitricity, (Flexisolar), PowerStar	36	2,241,214	1,386,000
Bus2Grid	**Bus:** Evaluation of provision of V2G services from buses while at depot	SSE Services	BYD (UK) SSE Services UK Power Networks			University of Leeds		Vehicles/Automotive: BYD (UK) Infrastructure/Aggregator: (SSE Services) Energy operators: UK Power Networks Academia: University of Leeds	36	2,431,835	774,028
EV-elocity	**Fleets and Airport**: Validation of customer acceptance and business viability	AT Kearney	Honda Motor Europe	E-Car Club SlamJam Toto Energy	AT Kearney Cenex	University of Nottingham Warwick University	Leeds City Council Nottingham City Council	Vehicles/Automotive: Honda Motor Europe, E-Car Club Infrastructure/Aggregator: Leeds City Council, Nottingham City Council, SlamJam Energy operators: Toto Energy Academia: University of Nottingham, Warwick University Consulting: Cenex, (AT Kearney)	36	5,622,154	3,899,284
e4Future	**Mixed:** Validation of stacked V2G services in diverse scenarios	Nissan Motor (GB)	Nissan Motor (GB) National Grid Northern Power Grid UK Power Networks eON			Imperial College London Newcastle University		Vehicles/Automotive: (Nissan) Infrastructure/Aggregator: Nuvve Energy operators: National Grid, Northern PowerGrid, UK Power Networks Academia: Imperial College London, Newcastle University	36	9,864,302	6,000,379
Sciurus	**Domestic:** Implementation of VPP and bundling of energy services with vehicle lease/price	Ovo Energy	Ovo Energy Nissan Motor (GB)	OVO Technology Indra Renewable Technologies	Cenex			Vehicles/Automotive: Nissan Motor (GB) Infrastructure/Aggregator: OVO Technology, Indra Renewable Technologies Energy operators: (OVO Energy) Consulting: Cenex	24	4,775,791	3,138,829

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
- Cenex (2018) V2G Market study: answering the preliminary questions for V2G – What, where and how much
- ENA (2018) Online Smarter Networks Portal
- Elaad.nl (2018) Our Projects
- EPRI (2016) Vehicle-to-Grid: State of the Technology, Markets, and Related Implementation
- NREL (2017) Vehicle-Grid Integration: A global review of opportunities and issues
- Innovate UK (2017) Results of competition: Innovation in Vehicle-To-Grid (V2) Systems: Real-World Demonstrators
- Mobility House (2018) Vehicle-to-Grid (V2) Technology Map
- NREL (2017) Critical Elements of Vehicle-to-Grid (V2G) Economics
- NREL (2015) Multi-Lab EV Smart Grid Integration Requirements Study
- PG&E (2018) Electric Program Investment Charge (EPIC) – EPIC 2.03b – Test Smart Inverter Enhanced Capabilities – Vehicle to Home
- SEEV4-City (2018) Summary of the State-of-the-Art report

Targeted discussions with representatives of

- Cenex
- IEA
- IREC
- NREL
- Mobility House
- Nuvve
- NRCan

Plus, core project team of Everoze, EVConsult, Innovate UK and UK Power Networks.

Other sources consulted during the course of the study

- Sovacool et al (2018) *The Neglected social dimensions to a vehicle-to-grid (V2) transition: a critical and systematic review.* Environ. Res. Lett 13 013001 .
- Energy Networks Association (2018) Open Networks Project: DSO service requirements – definitions
- Kammerlocher et al (2015) Modelling of the vehicle to grid storage potential considering uncertainties in user behaviour based on fleet data. International ETG Congress 2015, Bonn.
- Leitat (2018) Demystifying TRLs for Complex Technologies
- Nemo (2018) Website – e-mobility eu
- Nuvve & DTU (2018) Project report: Integration of new technology in the ancillary service markets
- UK Power Networks (2017) Consultation Report: FutureSmart – a smart grid for all: our transition to Distribution System Operator

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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…

WITH THANKS TO OUR CONTRIBUTORS

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