SCHOOL
OF ENGINEERING

Faculty of Science and Engineering

Electric vehicles and the grid: Intermittent storage balancing intermittent generation.

Graham Town[1,2]
Sohaib Rafiq[1]
Usama Bin Irshad[1]
Chresten Traeholt[2]

1. School of Engineering
   Macquarie University
2. Dept. Electrical Engineering
   Danish Technical University

graham.town@mq.edu.au

EESA 27/11/2018

OVERVIEW

- **Electric vehicles – the future**
  - Drivers and predictions re uptake

- **Electric vehicles – opportunities for the grid**
  - What if all cars electric?
    - \- All charged at once, no management (opposite problem to PV)
    - \+ VPPS and DERMs, coordinated/managed (services to grid)

- **Electric vehicles – three use cases**

1) Parking lots
   - **Suburban shopping centre occupancy analysis**

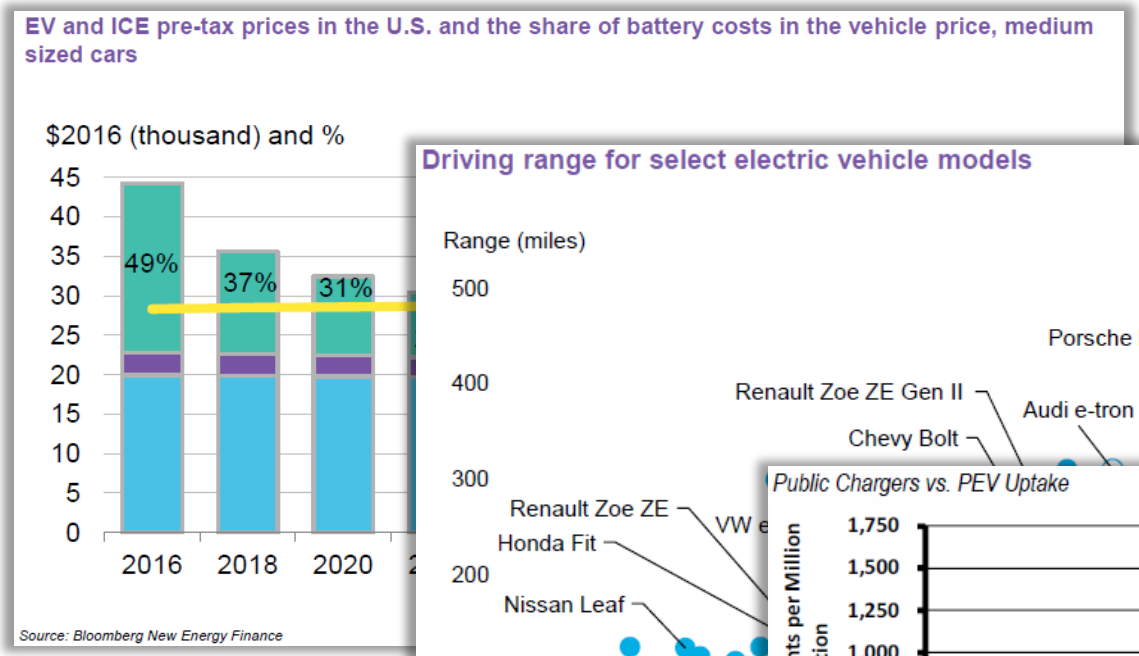
2) Commuter vehicles
   - **Commuter travel survey analysis**

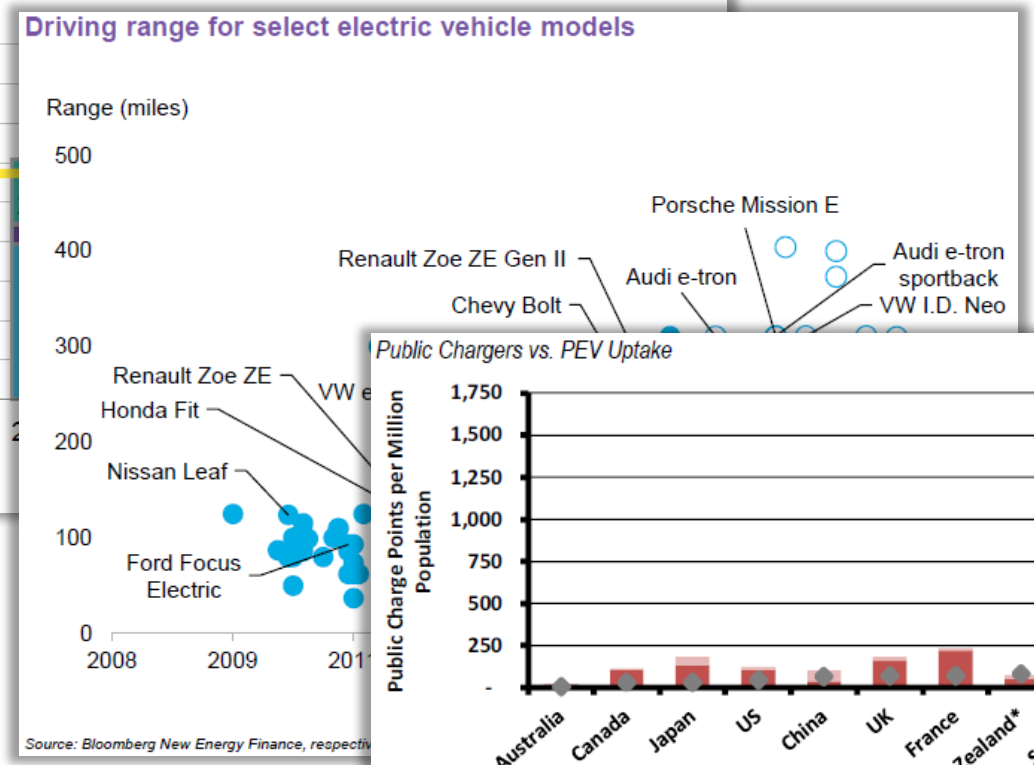
3) Fleet service vehicles
   - **Commercial V2G trial data – Parker Project, Denmark**

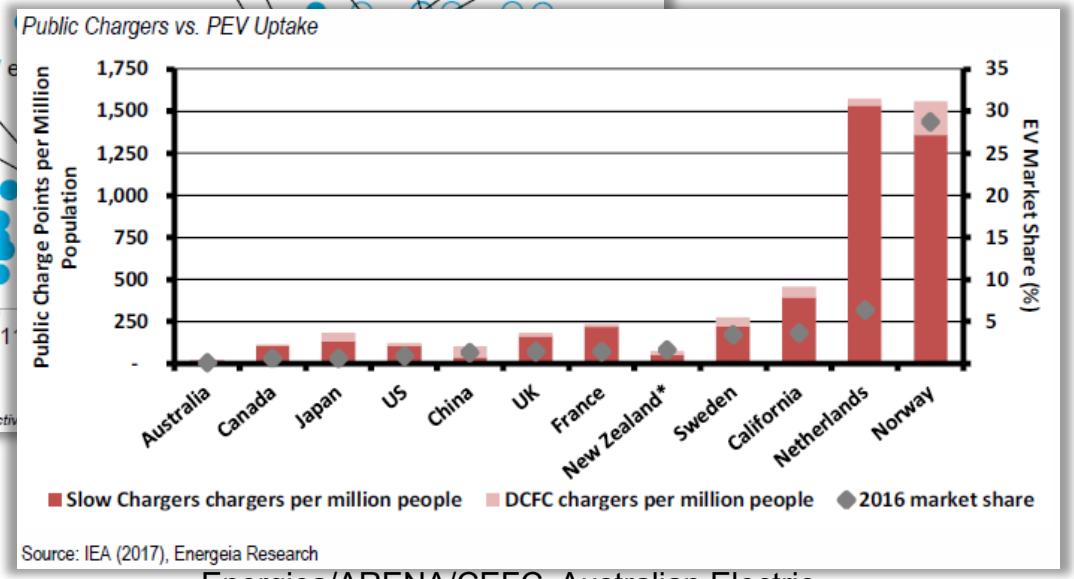
EV TRENDS & FORECASTS
- The Drivers

https://www.youtube.com/channel/UCELrWeVLazR49umE5qSF3VQ

EV Trends & Forecasts - International







Asghar (BNEF), Evidence to Senate Select Committee on Electric Vehicles, Aug. 2018.

Energiea/ARENA/CEFC, Australian Electric Vehicle Market Study, May 2018.

EV Trends & Forecasts - International

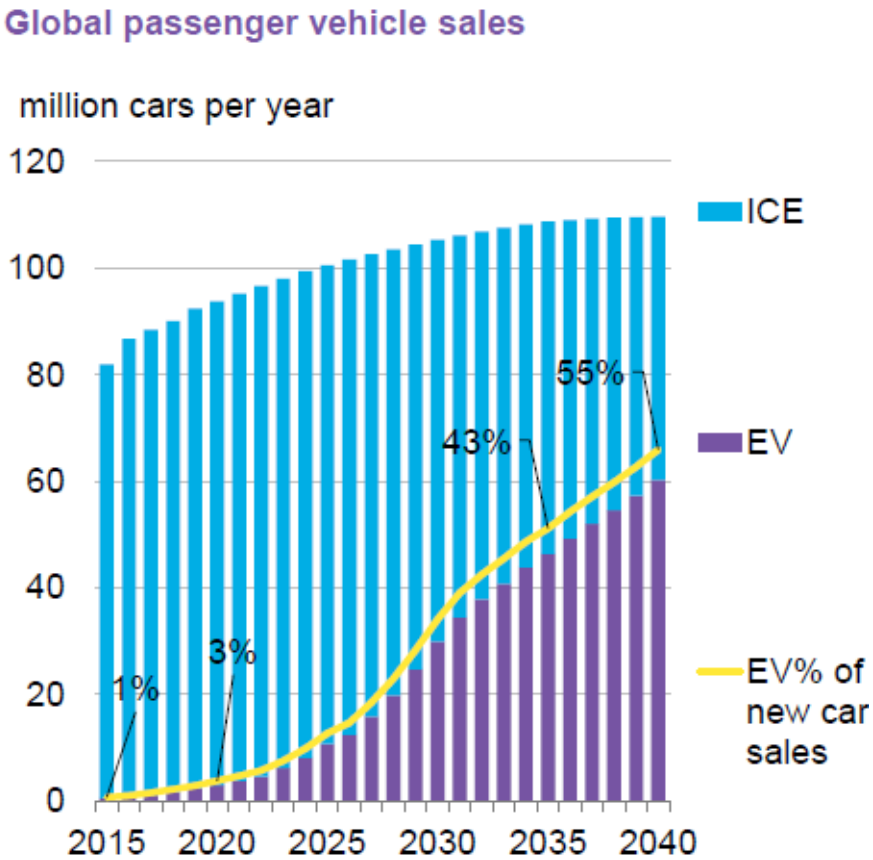
Policies to phase out ICE's, reduce GHG emissions

Country	ICE end	CO2 2030
Norway	2025	-45%
Denmark	2030	-45%
India	2030	?
Germany	2030	-45%
China	2040	75%
Britain	2040	-61%
USA	-	-38%
New Zealand	-	-30%
Australia	-	-27%

https://climateprotection.org/actions-by-countries-phase-out-gas/ **[/2005]**

https://climateactiontracker.org/countries/

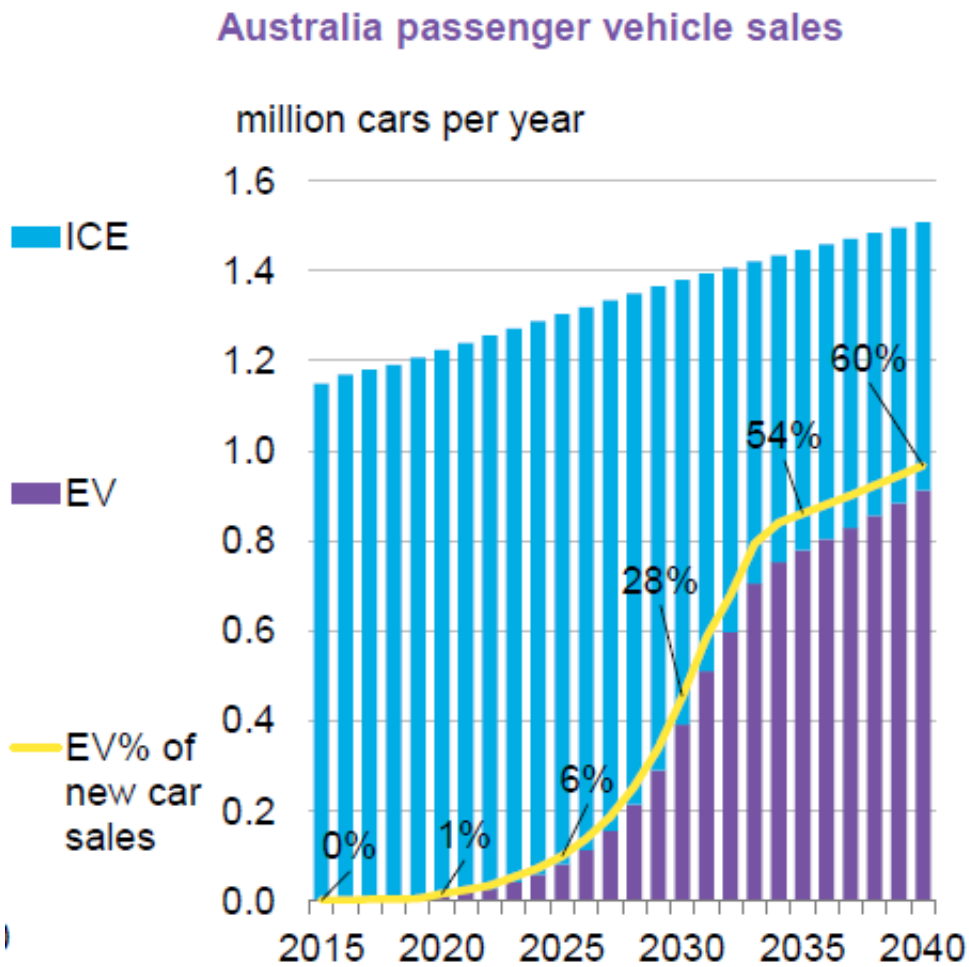
IPCC target: At least 27% share of renewable energy by 2030



Source: Bloomberg New Energy Finance

Asghar (BNEF), Evidence to Senate Select Committee on Electric Vehicles, Aug. 2018.

EV Trends & Forecasts - Domestic



Source: Bloomberg New Energy Finance

Asghar (BNEF), Evidence toSenate Select Committee on Electric Vehicles, Aug. 2018.

10/20/2018 Power bills will soar unless government prepares for electric vehicles, top adviser warns

The Sydney Morning Herald

EXCLUSIVE POLITICS FEDERAL ELECTRICITY

Power bills will soar unless government prepares for electric vehicles, top adviser warns

By Nicole Hasham
18 October 2018 — 6:00pm

A top national infrastructure adviser has warned Australia risks being "caught flat-footed" by the electric vehicle revolution, leaving consumers to pay more for electricity if governments and industry fail to act.

The Future is Electric
- Range of scales, distributions

MACQUARIE University

Proposed solar plant to store power in shippin sized batteries

By Nicola Gage

Updated Sat 23 Jul 2016, 1:25pm

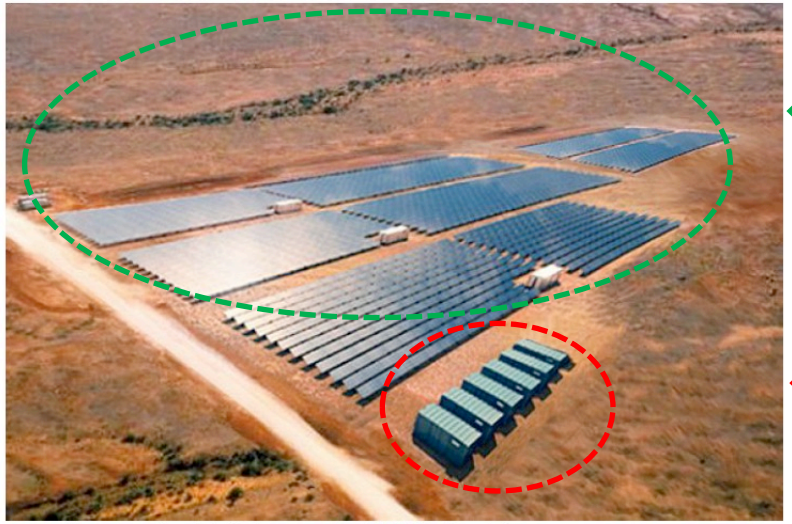
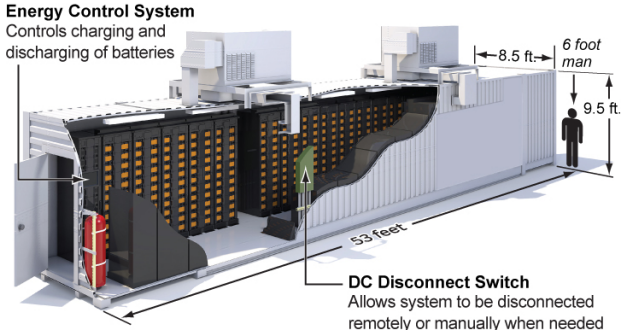


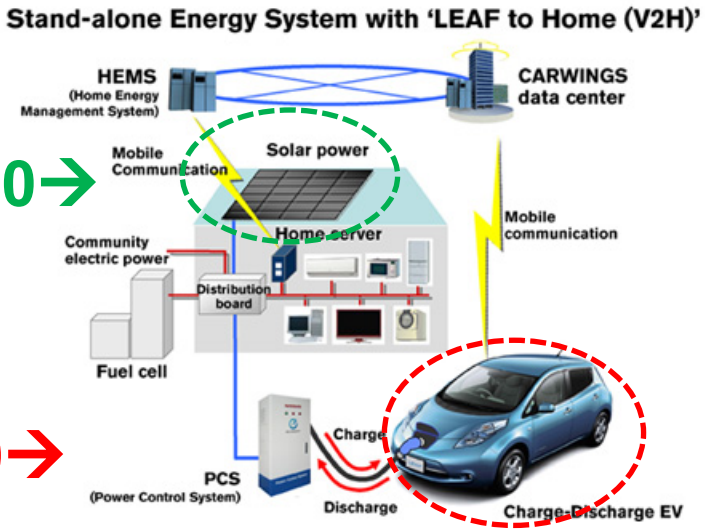
PHOTO: The proposed project will draw power from 800,000 solar panels. (Supplied: Lyon Group)

The first new project is planned for South Australia, with a 100MW solar PV plant to be combined with a battery storage array of up to 40MW, Green says the plant could be in operation near Roxby Downs by early 2018, and there are plans for other similar projects around the country.



←x 20,000→

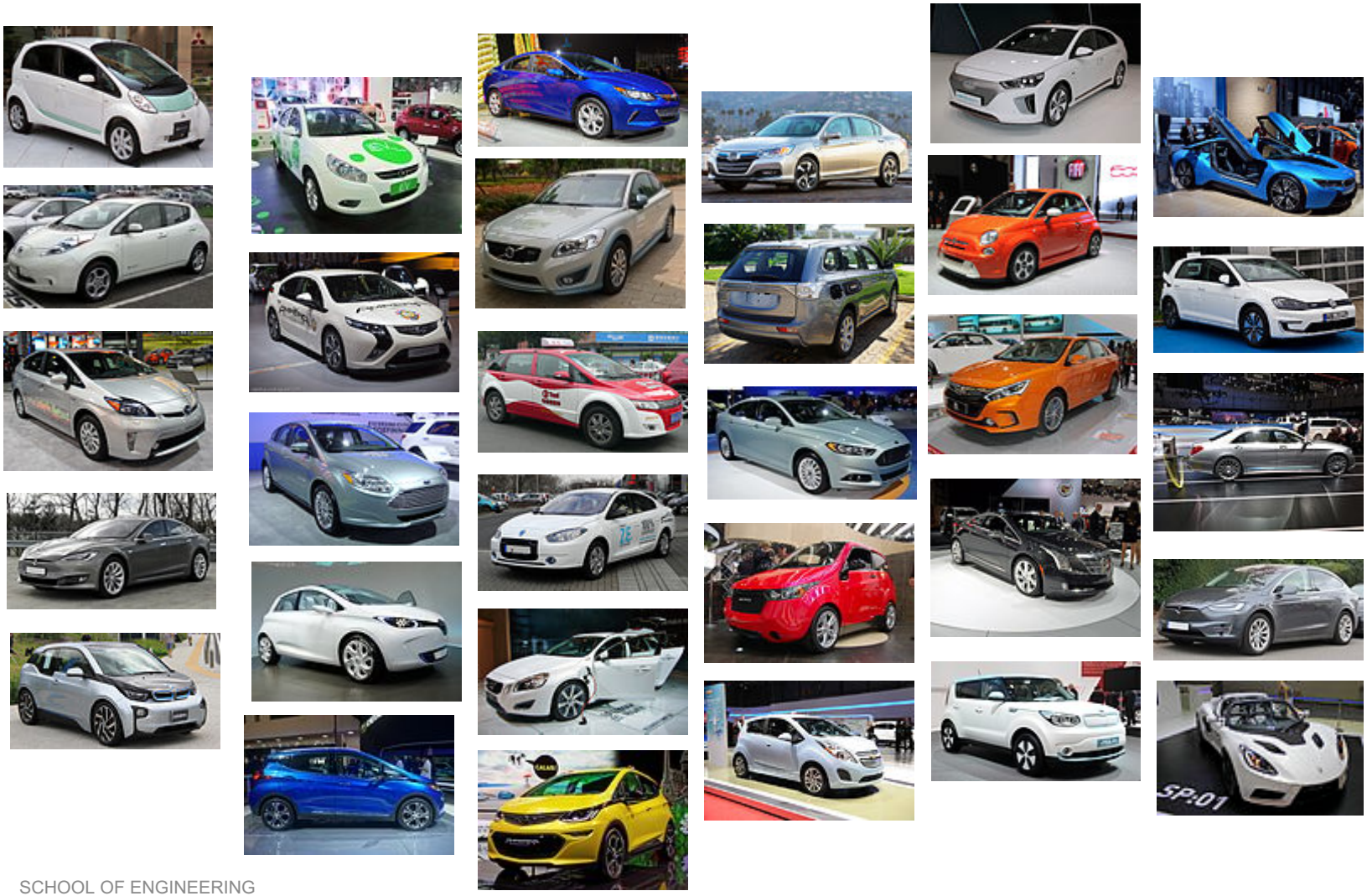
←x 1,000→



http://www.nissan-global.com/EN/NEWS/2011/_STORY/111004-01-e.html

http://electriccarsreport.com/2015/12/nissan-and-enel-team-up-on-v2g-technology/

EVs AND THE GRID
- What If All Cars Were Electric?



Electrification of transport
- Potential impacts of EVs on the grid

MACQUARIE University

- **Transport – can't be ignored**
  - transport consumes ~1/3rd of energy (currently mostly petroleum)
  - electrification inevitable (efficiency, compatibility, cost, etc.)
  - by 2025, 25% of new vehicles sold will be electric [ENERGIEA 2018]

- **Typical EV energy capacity, range**
  - Domestic battery storage (e.g. Tesla Powerwall) 6.4 - 10 [kW.h]
  - Hybrid EV (Toyota Prius) ~ 15 km range 1.3 [kW.h]
  - Full EV (Nissan LEAF) ~ 115/140 km (EPA) 24 - 30 - 40 [kW.h]
  - Full EV (Tesla S) ~ 430km (EPA) 85 - 100 [kW.h]

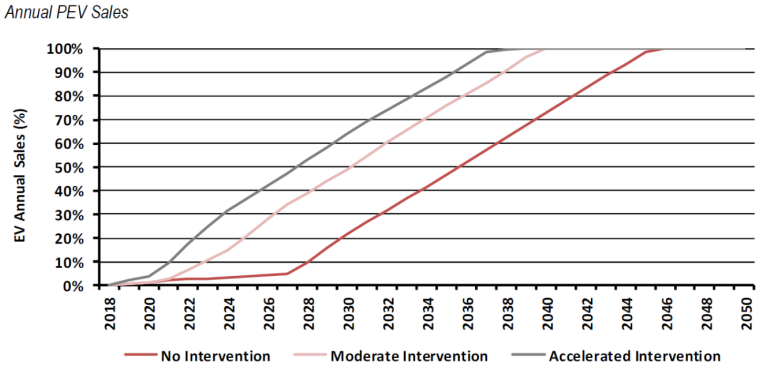
  50 km round trip ~ 10 [kW.h]

  c.f. average domestic household electricity consumption: 17 [kW.h/day]

→ More mobile storage (on wheels) than fixed (in households)

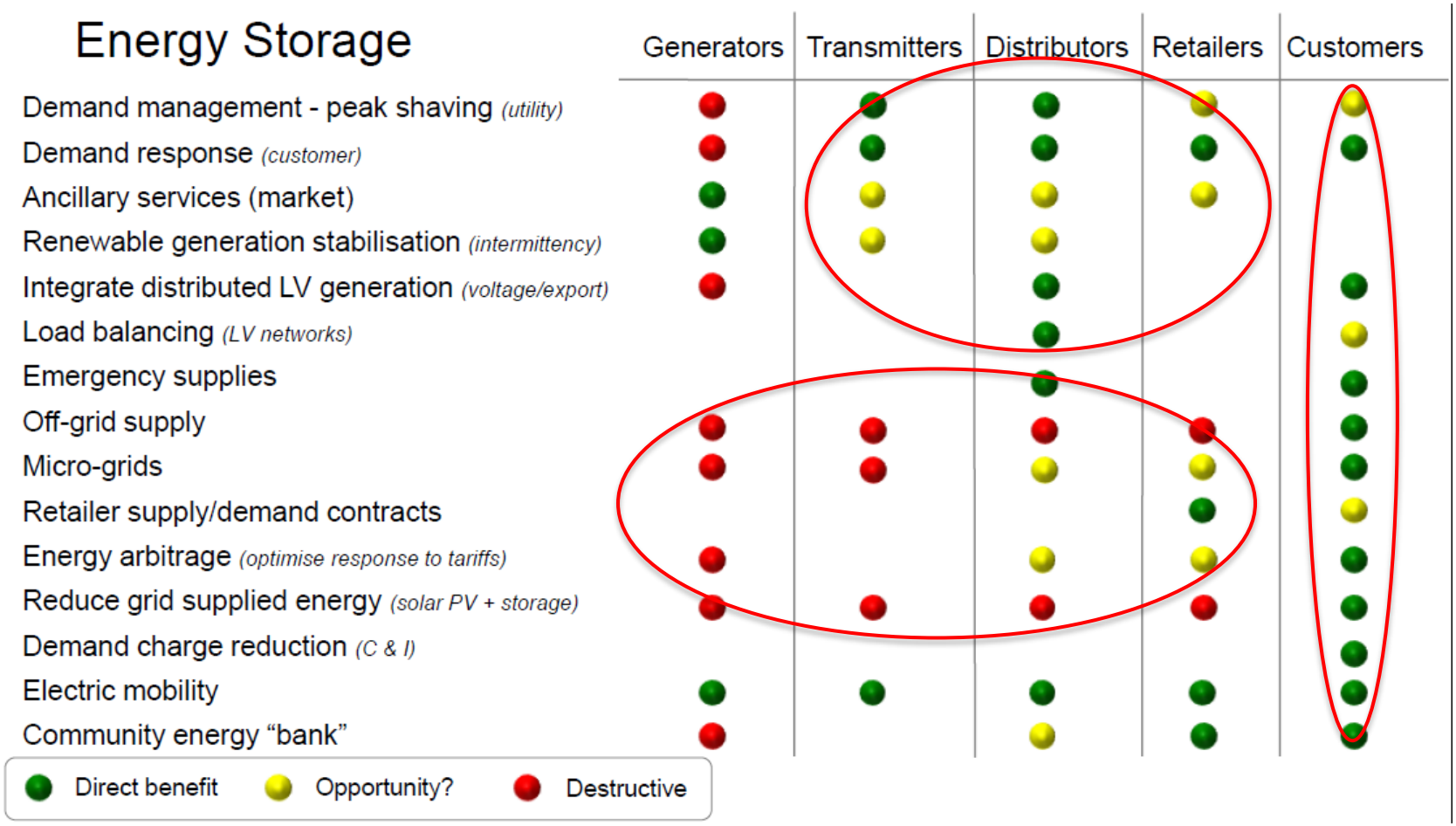
- **EV load/source on grid (overall)**

  e.g. major capital city with 1,000,000 EVs
  - 10 GW.h /day (currently 14.7 GW.h /day)
  - potentially 900 to 1,700 MW peak demand



Source: Energeia Modelling

Battery storage
- Applications, costs, benefits, opportunities



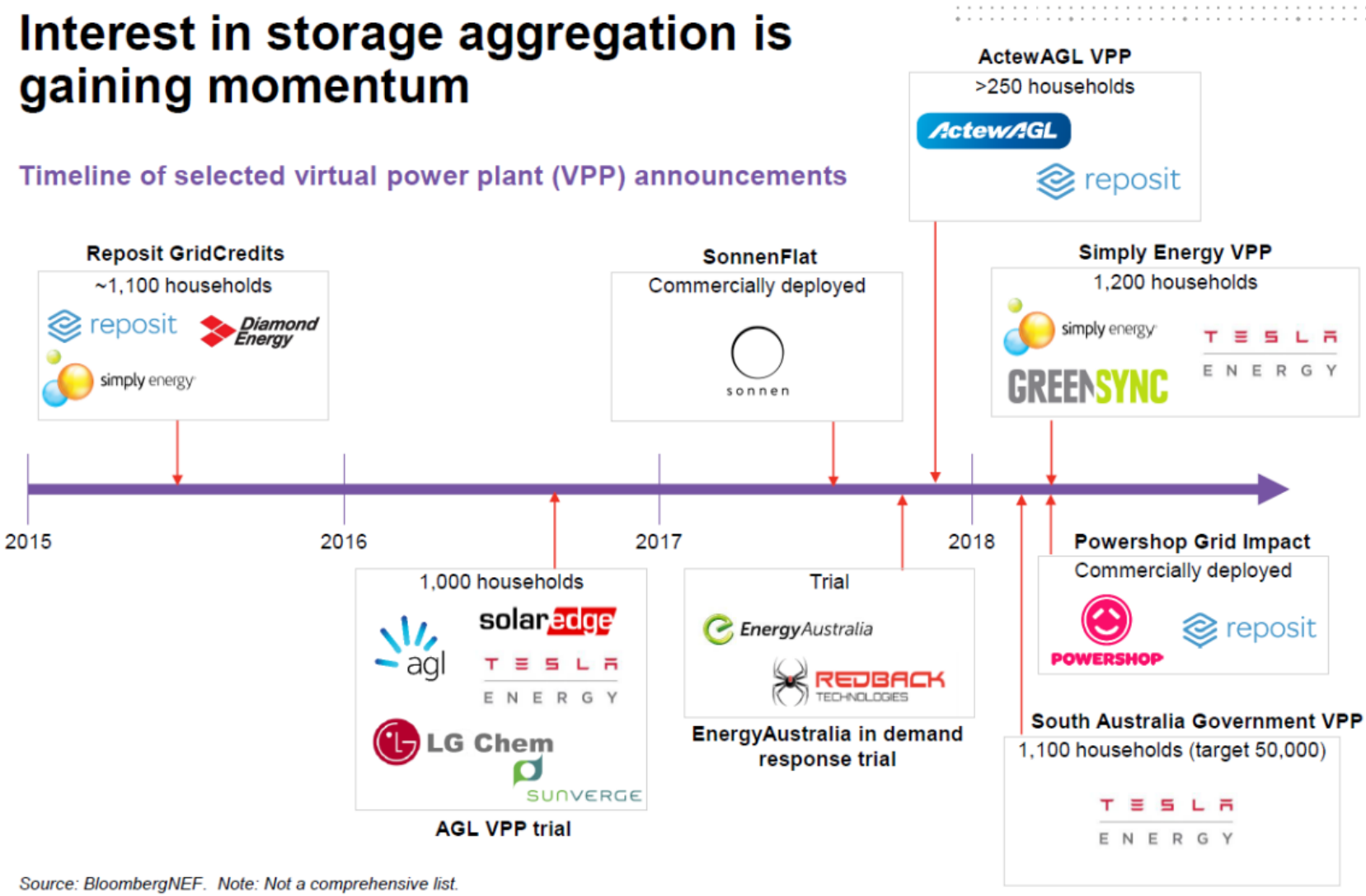
Smart Grid Association, Opportunities for the Electricity Supply Industry, 2014.

The power of aggregation - VPPs and DERM

MACQUARIE University

Interest in storage aggregation is gaining momentum

Timeline of selected virtual power plant (VPP) announcements



Source: BloombergNEF. Note: Not a comprehensive list.

Connected vehicles
- Energy *and* information flows

		Information Flow			
		None	**1-way** **(from vehicle)** e.g. location, ID, SOC, etc	**1-way** **(to vehicle)** e.g. start/stop charge	**2-way** e.g. pricing, time/amount to charge, etc.
Electrical Energy Flow	None	-	e.g. Traffic monitoring	e.g. Traffic Information	e.g. Dynamic routing, etc.
	1-way **(to vehicle)**	-	Smart metering	Demand management	Transactional energy
	1-way **(from vehicle)**	-	-	-	V2H
	2-way	-	-	-	**V2G,X**

EVs in a Smart Grid
- V2G opportunities and challenges

MACQUARIE University

Positive impacts of EVs on grid

- G2V storage for excess renewable energy
- V2G services to grid (frequency, voltage, etc)
- V2H (e.g. peak shaving)
- V2V

Opportunities and challenges with batteries, EVs

- Source or sink of power
- Fast reaction time
- Finite energy – “rebound” effect
- Distributed resources (**storage elements move**)
- **Intermittent / stochastic availability**
  (depends on SOC, **xport** useage, **location**, etc.)

Five Categories of Energy Storage Application

Category 1 — Electric Supply
1. Electric Energy Time-shift
2. Electric Supply Capacity
Category 2 — Ancillary Services
3. Load Following
4. Area Regulation
5. Electric Supply Reserve Capacity
6. Voltage Support
Category 3 — Grid System
7. Transmission Support
8. Transmission Congestion Relief
9. Transmission & Distribution (T&D) Upgrade Deferral
10. Substation On-site Power
Category 4 — End User/Utility Customer
11. Time-of-use (TOU) Energy Cost Management
12. Demand Charge Management
13. Electric Service Reliability
14. Electric Service Power Quality
Category 5 — Renewables Integration
15. Renewables Energy Time-shift
16. Renewables Capacity Firming
17. Wind Generation Grid Integration

Eyer & Corey, Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide. SAND2010-0815

EVs IN A SMART GRID - USE CASES

Parking lots

Commuting

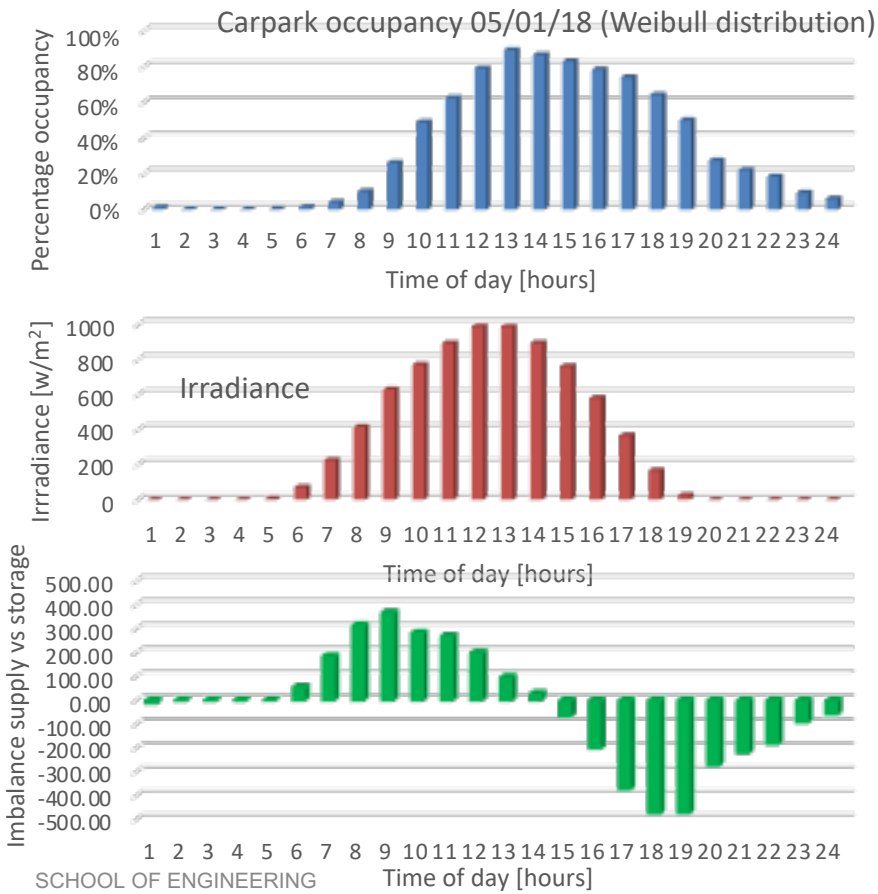
Service fleets

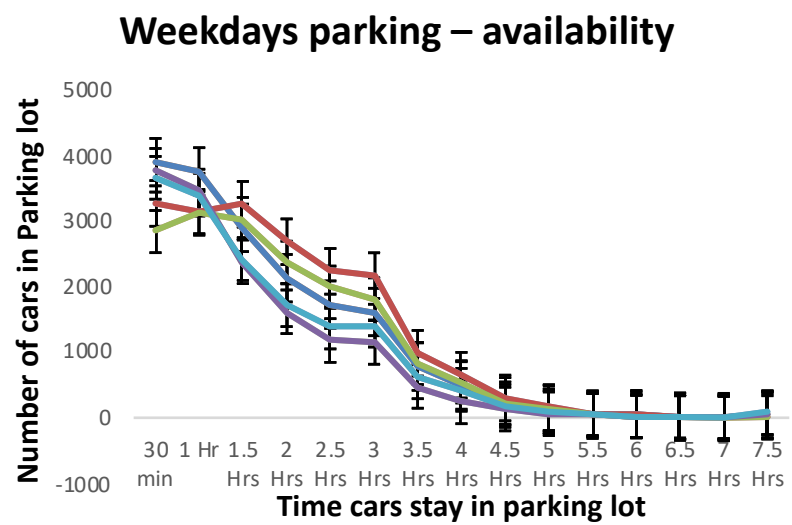
1) If all cars were electric…
- Supermarket parking lot

MACQUARIE University

Parked vehicles, suburban shopping centre in Sydney

→ **4500 parked EVs ~ 180 MWh peak storage** (@ 40 kWh/vehicle)





2) If all cars were electric… - Commuting

MACQUARIE University

Travel survey data analysed

- 2014-15 Household Travel Survey (HTS) Transport Performance and Analytics Transport for NSW
- 50 LGA's (Greater Sydney)
  19 million trips
  1 million weekday commutes
  82% < 35km (70km round trip)
  88% serviceable by EV (LEAF)
- *Results: EV SOC by <u>time</u> and <u>location</u>*
  (Assumption: charged to full o/night)
- Energy available in EV batteries always 3 to 5 times larger (anywhere/time) than Energy required by EVs for transport
  → V2V, V2X
  → V2G (distribution network services)

Time [0 – 24hr] →

← Location [LGA]

Energy Available for V2X

→ ALWAYS 3 to 5 x > THAN →

Energy Required for xport

Spatiotemporal distribution of aggregated ***ENERGY AVAILABLE*** (MWh) for V2X on ***WEEKDAY*** (commute trips ≤ 35 km/trip)

LGA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Blacktown	13	4	0	0	8	12	53	37	124	134	52	12	14	14	24	60	84	160	165	119	41	35	19	24	9	1212
Sydney	0	0	0	7	15	31	62	178	262	137	77	20	14	23	11	26	25	88	76	37	28	19	15	0	1152
Newcastle	4	4	0	3	0	42	73	147	163	34	11	16	25	8	18	67	62	170	65	19	12	11	10	3	967
Parramatta	5	2	0	1	4	8	54	114	136	54	20	1	20	10	11	48	68	116	111	47	20	18	19	13	899
Sutherland Shire	4	0	0	0	2	8	27	76	98	31	21	18	15	31	26	64	108	136	134	44	17	14	9	11	895
Ryde	5	0	0	0	2	3	35	140	128	102	42	16	17	12	19	23	56	77	84	31	10	32	11	2	848
Fairfield	3	0	0	1	5	40	63	87	136	36	4	0	7	9	29	54	80	93	101	45	16	9	16	0	834
Bankstown	7	0	0	0	11	20	55	76	114	39	10	11	4	9	8	75	127	120	62	31	7	20	5	2	814
Warringah	3	0	0	0	0	8	25	70	110	45	9	9	20	5	15	39	57	111	101	24	9	15	11	12	690
Penrith	5	0	0	2	29	14	28	66	71	23	3	17	19	21	16	37	102	99	69	28	10	14	14	0	686
Wollongong	3	0	2	0	9	5	72	61	112	26	0	25	14	9	19	67	62	91	50	10	9	19	11	5	681
Liverpool	6	0	0	0	12	19	70	70	85	14	9	13	20	22	37	33	73	66	57	18	15	6	20	13	679
Randwick	2	0	0	9	0	11	34	45	63	39	17	4	4	21	26	17	103	96	68	47	23	15	22	0	664
Lake Macquarie	5	0	0	0	0	21	34	52	69	21	16	5	11	19	11	44	66	137	52	18	13	10	8	3	614
Auburn	12	0	0	0	20	26	48	95	85	46	13	2	4	28	18	38	27	53	42	30	8	10	0	0	607
Baulkham Hills	0	0	0	0	5	17	65	88	33	24	8	10	17	7	23	57	103	57	41	7	14	9	0	0	586
Hornsby	2	4	0	0	1	6	25	36	84	29	6	13	18	11	7	33	46	100	76	50	17	12	10	0	577
Campbelltown	4	4	0	2	5	11	32	65	76	12	17	6	9	7	38	51	58	55	49	21	6	7	11	13	558
Holroyd	0	0	0	0	14	19	52	51	70	23	0	16	2	4	8	26	48	58	49	24	10	30	8	0	513
Ku-ring-gai	0	2	2	0	0	3	3	56	51	29	15	5	11	16	7	24	25	68	104	52	7	10	7	4	501
Wyong	0	0	0	0	0	14	34	69	55	18	9	13	8	8	33	30	51	54	32	8	3	7	11	9	467
Canada Bay	5	0	0	0	4	9	21	30	59	25	3	3	4	17	11	21	64	56	63	20	10	12	4	4	445
Gosford	3	3	0	0	4	16	18	42	78	18	5	10	3	14	29	22	45	58	34	20	5	10	2	2	442
Hurstville	0	0	4	4	4	0	6	42	56	3	2	11	9	9	5	38	53	77	58	27	15	5	5	5	436
Canterbury	0	0	0	0	0	11	23	42	60	36	0	4	0	8	27	31	56	54	29	24	4	4	10	4	428
Willoughby	3	0	0	0	0	6	14	70	91	55	5	10	11	3	3	7	20	25	45	21	6	12	5	0	422
Camden	0	0	0	3	4	8	27	24	46	20	5	7	2	2	21	25	32	78	48	18	8	9	0	2	389
Rockdale	2	0	0	0	8	8	17	22	49	9	17	2	6	7	9	16	33	82	34	25	7	11	7	16	388
Botany Bay	0	0	0	0	7	38	20	45	72	28	0	4	7	12	10	37	28	33	14	6	11	0	1	9	381
Marrickville	0	9	0	0	1	19	12	32	71	16	5	3	1	9	6	13	29	46	58	12	11	13	8	0	375
North Sydney	0	0	0	0	3	13	46	94	36	5	7	8	12	2	2	17	30	33	13	8	7	5	6	3	348
Kogarah	7	0	0	0	2	6	34	39	7	6	4	3	4	6	25	17	60	15	14	10	3	0	0	0	264
Shellharbour	0	0	0	0	3	4	25	44	8	3	3	4	6	11	41	7	30	31	12	4	7	10	5	24	258
Strathfield	3	0	0	0	2	0	19	34	49	15	7	10	3	6	6	20	7	36	25	3	5	8	0	0	251
Waverley	4	0	0	0	5	4	33	20	13	0	0	16	4	7	13	16	28	40	10	12	0	0	0	0	226
Leichhardt	0	0	0	2	2	9	28	29	21	0	6	6	6	3	3	14	49	22	19	0	0	0	4	0	222
Ashfield	0	0	0	0	3	8	25	26	3	4	4	6	6	8	9	32	19	37	7	3	6	9	2	0	218
Maitland	0	0	2	0	3	3	13	8	38	14	7	1	0	2	8	17	26	22	14	9	4	4	4	2	205
Woollahra	0	0	0	0	0	3	4	22	28	5	8	0	0	0	5	10	16	51	39	7	0	0	0	5	203
Pittwater	0	2	0	0	0	1	10	9	28	8	4	4	4	5	5	12	11	43	28	13	3	5	3	2	199
Lane Cove	2	0	0	0	0	7	2	39	23	21	2	0	2	6	7	3	7	19	41	9	5	4	0	0	194
Manly	0	0	0	3	0	0	10	5	14	7	2	0	4	0	10	11	12	22	41	7	3	5	4	3	185
Port Stephens	2	2	0	0	2	0	14	16	24	6	7	0	6	5	5	18	19	19	9	0	10	0	0	0	164
Burwood	0	0	0	0	0	2	15	32	8	3	3	0	2	3	12	9	11	26	0	7	3	0	7	3	143
Mosman	0	0	0	0	0	10	6	10	11	0	0	6	4	3	10	13	25	22	5	3	2	0	0	0	131
Hunters Hill	0	0	0	0	1	2	5	21	0	0	3	2	0	4	5	6	15	0	1	0	0	6	0	0	67
Kiama	0	0	0	0	1	4	5	12	0	0	0	0	9	0	0	7	3	4	0	0	0	2	3	5	50
Wollondilly	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	8	11	4	0	2	0	0	5	3	35
Cessnock	0	0	0	0	3	1	0	4	2	0	3	2	2	0	3	3	6	2	2	0	0	0	0	3	33
Shoalhaven	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	12

Spatiotemporal distribution of aggregated ***ENERGY REQUIRED*** (MWh) to recharge EVs for ***WEEKDAY*** (commute trips ≤ 35 km/trip)

LGA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Blacktown	3	2	0	0	3	14	11	42	44	14	4	3	3	5	16	21	43	48	31	14	11	6	6	3	345
Wollongong	1	0	1	0	4	2	29	28	48	11	0	10	7	4	9	32	29	42	22	5	4	8	5	2	304
Gosford	2	2	0	0	2	9	10	24	42	11	3	7	2	7	19	13	24	34	21	13	3	7	1	2	259
Lake Macquarie	2	0	0	0	0	8	15	20	29	8	6	2	5	8	5	19	26	55	21	8	6	4	3	2	251
Sutherland Shire	2	0	0	0	1	2	8	19	27	8	5	5	4	9	6	16	30	37	39	14	4	4	3	3	246
Baulkham Hills	0	0	0	0	1	2	9	30	36	14	9	3	3	6	3	9	25	42	23	16	4	7	4	0	243
Penrith	2	0	0	1	9	4	9	21	24	8	1	6	6	7	5	12	33	35	25	9	4	5	5	0	229
Newcastle	1	1	0	1	0	9	18	38	39	7	2	3	5	2	6	16	13	35	12	4	2	2	2	1	218
Wyong	0	0	0	0	0	7	15	33	25	9	5	7	4	4	16	14	22	25	15	4	1	4	5	3	217
Hornsby	1	0	0	0	0	2	8	11	24	8	2	4	5	3	2	9	13	28	22	14	4	4	3	0	169
Liverpool	2	0	0	0	2	4	16	19	22	3	2	4	4	5	8	9	18	16	15	5	4	1	5	3	166
Parramatta	2	0	0	0	2	2	8	23	22	11	4	0	4	1	1	7	12	19	19	9	3	4	5	4	163
Sydney	0	0	0	2	1	8	15	23	36	15	10	3	3	4	2	4	2	7	8	4	3	3	1	0	153
Campbelltown	1	1	0	1	1	2	8	15	18	3	4	1	2	2	11	12	15	16	13	6	1	2	3	3	142
Warringah	0	0	0	0	0	4	15	21	9	2	2	4	1	3	6	10	22	24	6	3	4	2	3	2	141
Ryde	0	0	0	0	0	1	7	27	21	18	8	3	2	3	2	3	6	11	10	4	1	5	1	0	135
Bankstown	1	0	0	0	2	4	12	12	17	7	2	1	0	1	2	10	17	16	11	6	2	3	1	0	127
Fairfield	2	0	0	0	1	7	11	13	18	6	0	0	1	1	3	10	10	14	15	7	2	1	3	0	124
Port Stephens	1	1	0	0	1	8	10	15	14	4	0	4	3	3	11	11	11	11	6	0	6	0	0	0	101
Ku-ring-gai	0	1	1	0	0	0	1	10	7	4	4	1	3	2	3	3	4	11	16	9	2	2	2	1	85
Camden	0	0	0	0	1	2	6	6	9	5	1	2	0	0	5	6	7	15	10	3	2	2	0	0	82
Auburn	1	0	0	0	3	4	6	14	13	5	2	0	0	2	3	3	5	8	5	3	1	1	0	0	80
Randwick	1	0	0	1	0	2	5	6	8	5	1	0	0	3	2	1	7	8	7	5	2	1	2	0	69
Holroyd	0	0	0	0	2	2	7	8	11	2	0	3	1	0	1	2	4	6	5	4	1	4	2	0	67
Maitland	0	0	1	0	1	1	4	3	12	4	2	0	0	1	2	5	8	7	4	3	1	1	1	1	64
Willoughby	0	0	0	0	1	3	14	15	8	0	1	1	3	0	0	0	2	3	6	2	2	2	1	0	64
Botany Bay	0	0	0	0	2	4	4	6	14	4	0	2	0	1	1	5	2	5	2	1	2	0	0	1	60
North Sydney	0	0	0	0	0	1	2	9	13	8	1	1	0	1	0	1	2	3	4	2	1	0	0	1	52
Shellharbour	0	0	0	0	0	1	1	6	8	1	1	1	1	1	2	8	2	6	7	3	1	2	2	1	50
Canterbury	0	0	0	0	1	3	4	7	3	0	1	0	1	4	5	4	6	5	0	5	0	0	1	0	50
Canada Bay	0	0	0	0	2	1	6	7	2	1	0	2	1	1	5	5	7	1	1	1	1	1	0	0	46
Hurstville	0	0	0	0	0	1	4	5	0	1	2	0	1	1	3	5	7	6	6	1	0	1	1	0	44
Rockdale	0	0	0	0	1	1	2	2	4	1	1	0	0	1	1	2	4	9	4	3	1	1	2	2	43
Marrickville	0	1	0	0	2	2	3	7	2	1	0	0	0	1	0	1	4	4	7	2	1	0	0	0	38
Pittwater	0	0	0	0	0	2	2	5	1	1	0	1	1	0	1	4	7	8	3	1	1	0	0	0	38
Strathfield	0	0	0	0	1	0	2	5	8	1	0	1	0	0	1	2	1	5	3	0	1	0	0	0	31
Manly	0	0	0	0	0	0	1	4	3	1	0	0	1	2	2	2	4	8	1	1	0	0	1	0	31
Kogarah	0	0	0	0	0	1	4	5	1	0	0	0	0	0	1	1	6	2	2	1	1	0	0	0	26
Lane Cove	0	0	0	0	1	6	3	5	1	0	0	0	0	0	0	1	2	3	1	1	1	0	0	0	26
Leichhardt	0	0	0	0	1	0	1	3	4	2	0	1	0	0	0	1	3	1	2	0	0	0	0	0	21
Ashfield	0	0	0	0	1	1	2	2	0	1	0	0	0	1	0	2	1	5	1	0	0	2	0	2	21
Waverley	0	0	0	0	0	1	2	1	1	0	0	1	0	1	1	1	2	2	1	1	0	0	0	0	13
Woollahra	0	0	0	0	1	0	2	1	0	0	0	0	0	0	0	1	5	2	0	0	0	0	0	0	13
Wollondilly	1	0	0	0	0	0	6	1	0	0	0	0	0	0	3	4	2	0	1	0	0	0	2	1	13
Cessnock	0	0	0	0	1	0	0	2	1	0	1	1	1	0	1	1	2	1	1	0	0	0	0	0	13
Mosman	0	0	0	0	0	2	1	1	0	0	0	0	1	0	0	1	1	3	1	0	0	0	0	0	12
Kiama	0	0	0	0	1	1	3	0	0	0	0	2	0	0	1	1	2	0	0	0	0	1	1	1	12
Burwood	0	0	0	0	0	1	2	1	1	0	0	0	2	1	0	0	1	2	0	1	0	0	1	1	11
Shoalhaven	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	5
Hunters Hill	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	5

2) Commuting
- UK V2G projects

https://cleantechnica.com/2018/03/23/vehicle-grid-cars/

https://www.autocar.co.uk/car-news/industry/nissan-expand-bi-directional-charging-scheme-uk-project
Oct. 2017

Partnership between Nissan and Ovo Energy to enable EV owners to participate in providing energy supply services to grid - Nissan says the system could generate around £350 (AUD$640) per year for LEAF owners.

https://www.autocar.co.uk/car-news/industry/nissan-and-uk-government-lead-uk%E2%80%99s-biggest-vehicle-grid-project
Jan. 2018

AUD$18m Innovate UK project: installation of 1,000 V2G charge points across UK over next 3 years.

Head of Nissan's energy division, Francisco Carranza, added that plugging EVs into the grid will make the UK grid "more sustainable and more stable".

3) If all cars were electric…
- Fleet service vehicles

THE THREE PILLARS OF PARKER

GRID APPLICATIONS

GRID READINESS CERTIFICATE

REPLICABILITY AND SCALABILITY

Demonstrate that **contemporary** electrical vehicles can participate in **advanced** smart grid services.

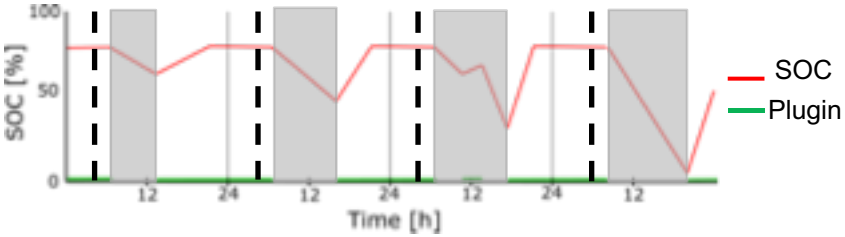
Partners: Nissan, Mitsubishi Corporation, Mitsubishi Motors Corporation, PSA ID, NUVVE, Frederiksberg Forsyning A/S, Insero A/S, Enel and DTU.

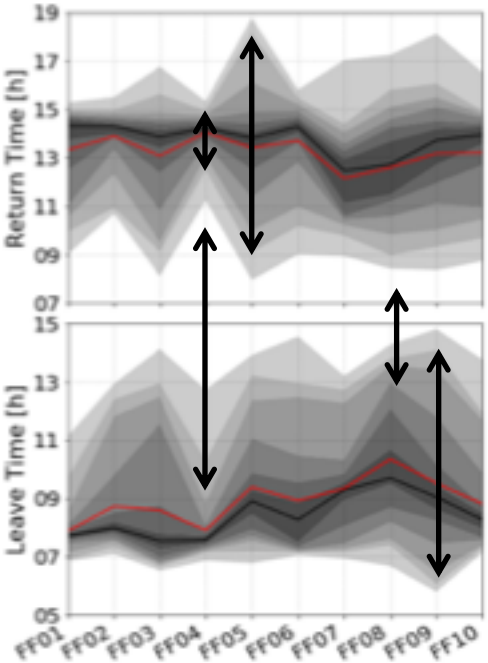
Duration: 8/2016 to 7/2018.

Budget: Two million Euros, funding by ForskEl

http://parker-project.com/

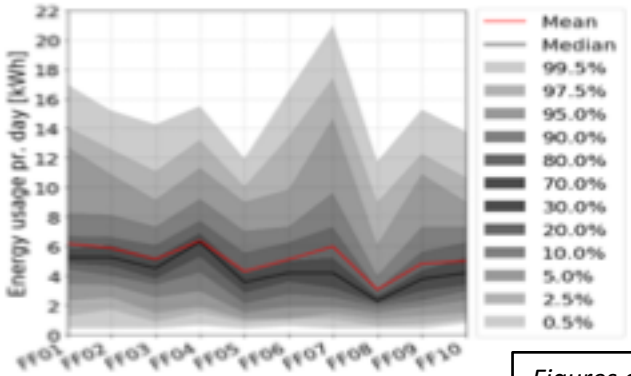
3) Fleet service vehicles
- Parker Project

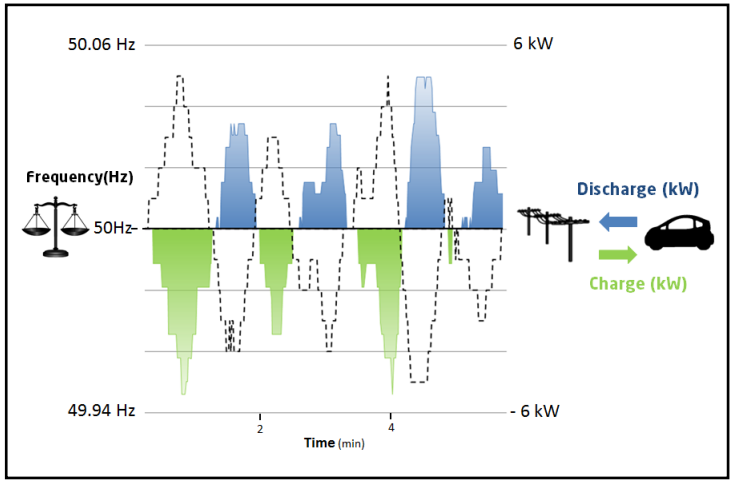




http://parker-project.com/

Parameters:
- Energy Deadline
- Energy Target
- Minimum Energy
- (Return Time)





Calculated FCR-N availability payment with 10kW V2G units (FCR-N, ~14 h/day)
<u>120 Euro / Month / Vehicle</u>

Figures c/o Lea Berthou and Peter Bach Anderson (DTU).

CONCLUSIONS

- **Aggregated EV battery capacity = substantial storage resource**
  - availability during day largely complementary to PV generation
  - from EV side: individual EV use patterns → improved V2G scheduling
  - from grid side: scale of "intermittent storage" outweighs limited availability

- **EVs can/are having valuable positive impacts on the grid**
  - capturing excess renewable energy generation
  - significant existing and future opportunities for provision of services to grid

- **<u>Next steps</u> (looking for partners):**
  - V2G trial in Australia
  - extension of V2G to distribution and other services

→ graham.town@mq.edu.au