DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING

ME519 MENG GROUP PROJECT

1969 DESIGN OF A NEXT-GENERATION ALTERNATIVE FUEL VEHICLE

FINAL REPORT & SUBMISSION

Submission Date – 5.00pm 20/03/17

Project Supervisor – Professor Matthew P. Cartmell

Project Group – R. Anderson, P. Lizzeri & A. Porras

Stakeholder Signature of Agreement; Signatory Date;

Student Website Available@:www.HEVTechStrath.com

En esta primera parte del documento se presentará un resumen en español de la tesis realizada en la universidad de Strathclyde (Glasgow) para luego dar con el archivo original en su correspondiente idioma (inglés).

DESIGN OF A NEXT-GENERATION ALTERNATIVE FUEL VEHICLE

"DISEÑO DE UN VEHÍCULO DE NUEVA GENERACIÓN DE COMBUSTIBLE ALTERNATIVO"

La creciente preocupación social respecto a los vehículos convencionales con motores de combustión interna y su efecto en el crecimiento de agentes contaminantes en la atmósfera (según las estadísticas del gobierno del Reino Unido, más de 28.000 personas mueren al año como resultado directo de la contaminación del aire), ha hecho que tanto los altos cargos de los gobiernos de los grandes estados como las fábricas de automóviles hayan tomado medidas al respecto. De esta manera se han empezado a desarrollar sistemas de propulsión alternativos entre los que destacan los vehículos híbridos (HEV) y eléctricos (EV), dando así con sistemas de transporte más respetuosos con el medio ambiente.
Este Trabajo Fin de Grado pretende mostrar las numerosas oportunidades de innovación en términos de tecnología y desarrollo en procesos de ingeniería que el mercado de HEV y EV puede ofrecer. Además, el éxito en este reporte podría suponer una inversión en esta área por parte de University of Strathclyde, y una base para posibles TFGs de las próximas generaciones en caso de que se dedicasen a investigar temas similares en dicha universidad.
Por otra parte el objetivo principal de este TFG es desarrollar (teniendo en cuenta las limitaciones que se dan por el tiempo ofertado para realizar la tesis) un vehículo de combustible alternativo que sea capaz de liderar el mercado dentro de 2 años. Esto se logrará mediante la realización de dos subconjuntos de objetivos:

- EL PRIMER SUBCONJUNTO "TAREA DE FAMILIARIZACIÓN"

  - **Selección de un mínimo de 15 HEV:** suficientemente variada, comparable en cuanto a la arquitectura del vehículo, aspectos técnicos y diferencias de costos.
  - **Calcular el ratio de costo por mpg de cada vehículo seleccionado:** determinación de una métrica a través de la cual se realizaron comparaciones generales sobre una base que, junto con lo anterior, ayudará a aclarar las diferencias inherentes en las capacidades y el diseño de la arquitectura.
  - **Mejora de selección a 5 vehículos y evaluación detallada:** usando un buen proceso de selección para reducir la anterior lista a los vehículos más deseables, un entendimiento más detallado es alcanzado con respecto a las tecnologías potenciales y las influencias de costos inherentes que influirán en la elección de la arquitectura del grupo.

- **Comparaciones del Prius Liftback y Prius Plug-in:** a través de comparaciones de métricas predefinidas y la evaluación de arquitectura tecnológica, se obtiene información valiosa relacionada con las variaciones en la tecnología (p. Ej., grid-dependent vs grid-independent) y sus inherentes características positivas y negativas que se utilizarán para influir en la selección de la arquitectura final.
- **Investigar el híbrido Nissan Altima y concluir los motivos de su interrupción:** a través de una evaluación estructurada del fracaso de un fabricante importante, reconocible y experimentado como Nissan dentro del sector de HEV, proporcionará al grupo una idea de los posibles defectos que pueden introducirse con respecto al diseño del vehículo, y así que la implementación de estos puedan ser evitados.

- EL SEGUNDO SUBCONJUNTO "INVESTIGACIÓN Y CONCLUSIONES"

- **Análisis de los mercados automovilísticos actuales a nivel mundial, con consideración de los desarrollos futuros:** Esto servirá para guiar los principales requisitos de diseño del vehículo conceptual propuesto; era importante comprender el mercado en relación con la aceptación de la tecnología, las posibles influencias políticas, incluidas las reglamentaciones, y los avances tecnológicos correspondiente con el desarrollo futuro.

- **Identificación de obstáculos sociales y técnicos que impiden el establecimiento masivo de vehículos eléctricos:** la aprobación social es clave para el éxito de un nuevo vehículo alternativo, por lo tanto, es de gran importancia comprender las percepciones del público con respecto a la tecnología del vehículo eléctrico. Además, era importante investigar y analizar las barreras técnicas para su implementación. A través de la identificación de estos problemas, se podrían proponer mitigaciones.

-**Resumen del desarrollo de infraestructura en 4 ciudades principales de Reino Unido, incluido Glasgow:** las arquitecturas de los HEV y EV requieren una infraestructura de apoyo adecuada y bien planificada, equivalente a la red de estaciones de servicio que admiten el uso de vehículos convencionales con motores de combustión interna. Por lo tanto, para obtener una idea del desarrollo y captación de la tecnología EV, es obligatorio comprender los desarrollos de la infraestructura a corto y mediano plazo.

-**Identificación de desarrollos en el almacenamiento de energía:** una consideración crítica del rendimiento de la arquitectura propuesta sería el medio de almacenamiento de energía empleado; con respecto a la capacidad (kWh), el costo (£ / kWh) y las densidades de energía, tanto gravitacional como volumétrica (kg / kWh) y L / kWh). Donde sea relevante, las diferencias en la química de la batería serán consideradas.

- **Consolidación e identificación de la arquitectura más prometedora (marco de tiempo de 2 años):** una compilación de los datos y una decisión grupal sobre la plataforma que se diseñará. Un resumen de vehículos actuales con arquitectura similar también era un requisito.

- **(Si el tiempo lo permitía) desarrollo de un vehículo de combustible alternativo según los datos recogidos previamente:** desempeño del diseño conceptual de una arquitectura de vehículo de alto nivel, si los recursos lo facilitan.

1. SELECCIÓN Y ESTUDIO DE ALGUNOS VEHÍCULOS

La tarea para este apartado era la identificación de un grupo de vehículos HEV que fueran a su vez variados en algunas características para poder ser comparados (hasta 13 distintos fabricantes fueron seleccionados), y así poder entender mejor como funciona esta tecnología. La tecnología de los vehículos seleccionados tenía que ser variada en los aspectos de paralelo o en serie, y en si era grid-dependent o grid-independent.
El siguiente paso fue una comparativa del ratio de mpg de cada coche, teniendo como resultado la tabla mostrada, con la que el equipo pudo organizar un mejor estudio de cada tecnología.

MODELO	COSTE (£)	MPG (MPG)	RATIO (£/MPG)	0-62 MPH (Seg)	KERB MASS (Kg)	CAPACIDAD (kWh)	BATERÍA QUÍMICA	MOTOR PWR (kW)
Outlander	31,749	156	203.52	11	1860	9.8	Li-ion	60
Passat	36,750	166	221.39	7.6	1647	3.5	Li-ion	85
i3 (Rex.)	35,350	470.8	238.46	7	1365	22	Li-ion	125
Ioniq	19,995	83.1	240.61	10.8	1370	1.6	Li-ion	32
V60	38,105	155.2	245.52	6.2	1988	11.2	Li-ion	50
Prius	23,600	94.1	250.80	10.5	1500	1.3	Ni-MH	82
C-max	20,325	51	390.88	7.9	1,374	1.4	Li-ion	85
Q7-etron	64,950	156.9	413.96	6.2	2445	17.3	Ni-MH	94
Accord	24,187	57.6	419.92	6.9	1580	1.3	Li-ion	105
CT200h	21,940	50.4	435.32	10.3	1,370	1.3	Ni-MH	60
Camry	22,194	49	452.95	7.2	1595	1.6	Ni-MH	105
Sonata	24,553	50.4	487.17	8.1	1588	9.8	Li-ion	50
GLE500e	50,570	85.6	590.77	5.3	2465	6.2	Li-ion	85
Silverado	32,068	25	1,282.72	-	2627	0.5	Li-ion	60
P1	866,000	34	25,470.59	2.8	1547	5	Li-ion	131

Por último, de la anterior lista se eligieron 5 vehículos según las preferencias de los integrantes del grupo, teniendo en cuenta el fabricante y las distintas arquitecturas. Estos fueron el BMW i3, debido a su versión rex (Range EXtender) y gran MPG; el Mitsubishi Outlander, fue elegido por su exitosa entrada en el mercado y su gran autonomía de cero emisiones comparado con su tipo de chasis; el Volvo V60 por las mismas razones que el Outlander y tener a su vez tracción trasera; y por último el Lexux CT200h y el Ford C-max debido a su parecido en precio y MPG, pero sus baterías son distintas (una batería de 1.3 kWh Ni-MH y una 1.4 kWh Li-ion respectivamente).

PROPIEDAD	BMW i3 Rex	OUTLANDER	VOLVO V60	LEXUS CT200h	FORD C-MAX
MSRP COSTE (£)	35,530	31,749	38,105	21,940	20,325
MPG (MPG)	149	156	155.2	50.4	52
COSTE POR MPG	bajo	Bajo-medio	Bajo-medio	medio	medio
TIPO DE CHASIS	City Car	Crossover	Wagon	Compact	MPV
TRANSMISIÓN	FWD	FWD	RWD	FWD	FWD
RENDIMIENTO	medio	medio	medio	bajo	bajo
EQUIPAMIENTO	medio	alto	alto	alto	bajo
ARQUITECTURA HÍBRIDA	Serie Grid Dependent	Paralelo Grid Dependent	Paralelo Grid Dependent	Paralelo Grid Independent	Paralelo Grid Independent
ICE TRANS.	pequeña	grande	grande	media	Media-grande
EV TRANS.	grande	grande	media	pequeña	pequeña

2. PRIUS LIFTBACK VS. PRIUS PLUG-IN

En este punto se destaca la gran influencia del uso de una mayor unidad de almacenamiento de energía junto al cambio de Ni-MH por Li-ion para un mayor rango de MPG comparando las dos versiones. La batería de 4.4 kWh empleada en el Plug-in es 238% mayor que la de 1.3 kWh usada en la versión Liftback. Esto facilita una mayor autonomía, pasando de 2 millas a 11-15, reduciendo así tanto el consumo de combustible como las emisiones en el tubo de escape en una jornada corta-media.

3. INTERRUPCIÓN NISSAN ALTIMA

El híbrido Altima fue presentado en 2007 y tuvo una producción continuada hasta su detención en 2012. Era grid-dependent, tenía arquitectura paralela y empleaba la arquitectura de la Hybrid Synergy de Toyota bajo licencia. Se vendió sólo en la versión turismo y sólo en 10 estados. Sus principales competidores eran el Toyota Camry y el Honda Accord.
Desde su comienzo, ya había experimentado ventas limitadas, continuando una media de 7000 coches al año para finalmente acabar disminuyendo. Lo que es más, el uso de una transmisión de un principal rival en el mercado (Toyota) hizo que Nissan redujera sus gastos en investigación y desarrollo en el Altima. Todo ello significaba que estaban financiando a su competidor principal, con lo que se empezaron a proponer usar transmisiones fabricadas por ellos mismos siendo esto causa directa de la interrupción del Altima.

4. OBSTÁCULOS SOCIALES Y TÉCNICOS

Para aliviar estos obstáculos y poder dar con un establecimiento masivo de vehículos eléctricos, estos tienen que mejorar alguna característica, principalmente la autonomía.

Los coches eléctricos no han tenido la recepción que se esperaba en el mercado. Sin embargo, muchos fabricantes siguen desarrollando coches 100% eléctricos, como Renault con Twizy, Fluence y Kangoo, pero como se dijo antes las ventas no han sido exitosas. También nos encontramos países como Noruega, donde EV son considerados un producto interesante, destacando de esta manera las ventas de vehículos como el Nissan Leaf. Por otra parte, también cabe nombrar el mejor posicionamiento en el mercado de versiones HEV y plug-in, ya que pueden tener una autonomía de 40 km (distancia media recorrida por la mayoría de los conductores).

4.1. AUTONOMÍA

Mientras que los vehículos convencionales de combustión interna pueden circular hasta 600km tras 5 minutos de reportaje, las baterías necesitan mucho más tiempo para recorrer muchos menos km. Para solucionarlo, los investigadores están concentrando sus esfuerzos en desarrollar mejores baterías.

4.2. PRECIO

Es un problema a tener en cuenta ya que los HEV y EV se producen en pequeños lotes y la producción en masa es difícil de barajar cuando el producto no es tan querido como se espera. Para intentar activar la demanda por parte de posibles clientes se han tomado acciones como la reducción de impuestos y subvenciones. En España se pueden encontrar ejemplos como el plan MOVEA y MOVELE.

También se tendrían que tener en cuenta otros factores como la fiabilidad de las baterías , la falta de puntos de recarga y el impacto medioambiental que puede tener usar electricidad que tiene de fuente el uso de carbón. Finalmente, para analizar la opinión social, el grupo decidió estudiar distintas encuestas en las que podíamos ver como el 5% de los encuestados estaba pensando en comprar esta tecnología, mientras que el 16% pensaba que era demasiado pronto.

5. ANÁLISIS DE MERCADO

A primera vista y estudiando los distintos gráficos de tendencias entre los años 2010 y 2016, pudimos ver como las ventas de los plug-in y de los híbridos de gasolina crecían exponencialmente a lo largo de los años, mientras que los híbridos de diesel caían. Este último problema se podría explicar por el precio, pérdidas en el torque y un mayor número de emisiones comparado con las que puede producir los motores que usan gasolina.

En el mercado internacional se destaca un aumento del 42% en las ventas de la versión plug-in entre el 2015 y el 2016, alcanzando 773600 unidades. El mes de diciembre de 2016 fue registrado como el mes con más ventas de coches eléctricos en la historia. En particular, China ha demostrado un gran crecimiento, representando así el 45% del mercado de vehículos eléctricos.

También cabe destacar las grandes inversiones (billones de euros) en esta tecnología por parte de fabricantes de gran prestigio como Tesla con su “Gigafactory”, Mercedes, BMW y Nissan.

5.1. ESTUDIO DE LA TECNOLOGÍA HEV

Tal como muestran los estudios, las transmisiones en paralelo de HEV son más eficientes que en serie, ya que las pérdidas de convertir energía mecánica en eléctrica para más tarde volver a convertir en energía mecánica están minimizadas. En términos de coste de producción la transmisión paralela también presenta ventajas, ya que necesita baterías y motores eléctricos más pequeños.

5.2. MOTORES

5.2.1. EN LÍNEA 4

Ventaja: sencillo en montaje, compacto y con menos partes móviles.
Desventaja: alto centro de gravedad.

5.2.2. BOXER

Ventaja: bajo centro de gravedad y menor pérdida de energía que en otros casos.
Desventaja: muy ancho y costes elevados debido a su complejidad.

5.2.3. CONFIGURACIÓN EN V

Ventaja: compacto, rígido y con potencia.
Desventaja: muchos elementos móviles.

5.2.4. TURBINA DE GAS

Ventaja: uso de un ciclo Brayton que le hace ser eficaz. Sencillo y con pocas partes móviles.
Desventaja: mantenimiento costoso, suciedad y escombros, alcanza temperaturas cercanas a los 1000 grados Celsius. Inviable de ser usado en vehículos de uso urbano.

5.3. CHASIS

Los materiales utilizados normalmente en los chasis suelen ser aluminio, acero y fibra de carbono.

Los tipos de chasis que se pueden encontrar son “estructura en cuerpo”, “monobloque”, “monocasco” y “malla espacial”.

6. INFRAESTRUCTURAS

6.1. TECNOLOGÍAS DE RECARGA

Puntos de recarga vs estación de recarga: el primero se refiere a un soporte único o una unidad montada en la pared que ofrece una toma de corriente y/o una conexión adosada para la carga EV. El segundo es un sitio que contiene al menos dos puntos de recarga, adecuado para cargar al menos dos PHEV o EV simultáneamente.

La Unión Europea ha anunciado recientemente que para 2019 todas loa nuevos edificios requerirán de la instalación de puntos o estaciones de recarga. También, se citó la intención de que para 2023 el 10% de los aparcamientos tanto públicos como privados dispondrían de esta tecnología, y así poder aliviar los problemas relacionados con la autonomía.

6.2. TENDENCIAS INTERNACIONALES

Tres de la mayores naciones europeas que destacan en el impulso de esta tecnología son Noruega, por liderar Europa en términos de entrada en el mercado de EV y las infraestructuras; Reino Unido, que está experimentando un considerable crecimiento de EV y HEV; y Alemania que aún invirtiendo más que el anterior país, encuentra más dificultades para lograr su penetración en el mercado.

Tal y como se ha comentado previamente, Alemania es, entre los tres países, el que esta experimentando un crecimiento más débil. En 2015, se registraron 3206000 nuevos vehículos, de los cuales sólo 43000 eran HEV o EV.

En el caso de Noruega, en 2016, las ventas de vehículos HEV y EV experimentaron un crecimiento del 39.6% en el total del año anterior y representaron más del 40% del total de registros de vehículos nuevos dentro de Noruega.

6.3. ESTUDIO DE INFRAESTRUCTURAS EN 4 CIUDADES DE REINO UNIDO

6.3.1. GLASGOW

Esta ciudad escocesa dispone de una densidad de 0.3 estaciones de recarga por cada 1000 vehículos registrados, y a su vez tiene una densidad de 1.8 puntos de recarga por cada 1000 vehículos registrados.

6.3.2. BRISTOL

Posee una densidad de 0.25 puntos de recarga por cada 1000 vehículos registrados.

6.3.3. MILTON KEYNES

Posee una densidad de 0.3 estaciones de recarga y 0.6 puntos de recarga por cada 1000 vehículos registrados.

6.3.4. LONDRES

La densidad de infraestructuras de recarga que presenta la capital de Reino Unido es de 0.63 por cada 1000 vehículos registrados.

El grupo también añadió en este apartado una serie de innovaciones que se han tenido en cuenta ya sea por su reciente implantación o por ser una idea con mucho potencial. Una de ellas trata de un vehículo eléctrico que puede rentarse por horas o días a través de una asociación. Por otra parte, también se tiene en cuenta la idea de estacionamientos dedicados al cambio de baterías. Proceso con el que una recarga pasaría a durar el mismo tiempo que llenar un depósito de gasolina en un coche convencional. También, se tienen en cuenta las “ehighways”. Prácticamente se trata de un sistema eléctrico capaz de suministrar energía de propulsión a un vehículo mientras se circula por la carretera. El sistema es una adaptación de las vías ferroviarias electrificadas. En otro punto, se habla de “energía al gas”, con el que se aprovecha el superávit que generan las renovables para poder sintetizar hidrógeno. Por último, el grupo estudió infraestructuras de recarga inalámbricas. Nos encontramos con carga por inducción estática y dinámica.

7. BATERÍAS ELÉCTRICAS EN VEHÍCULOS

La batería es una de las principales y más utilizadas tecnologías de almacenamiento de energía eléctrica en el día a día y en la industria. El sistema de almacenamiento de energía de la batería está formado por varias celdas electroquímicas que se configuran en serie o en paralelo y producen electricidad gracias a una reacción electroquímica. Una célula es un dispositivo que se compone de dos electrodos (el ánodo y el cátodo) y un electrolito (puede ser sólido, líquido o viscoso). En el momento de la descarga, hay reacciones electroquímicas en el cátodo y el ánodo. Durante esta acción, los electrones van del ánodo al cátodo, de modo que puede haber corriente eléctrica.

7.1. PLOMO-ÁCIDO

Se ha utilizado durante muchos años debido a su precio (50-600 $ / kW h) y la facilidad de fabricación. Lamentablemente, el plomo es un material pesado y puede llegar a alcanzar entre 25 y 50 Wh / Kg.

7.2. NÍQUEL-CADMIO

Es un tipo de tecnología que se usaba principalmente para baterías recargables en los 90's. Se debe reflejar que el cadmio y el níquel son metales pesados y tóxicos que son peligrosos para el medio ambiente. Tiene un gran defecto, ya que tiene un gran efecto de memoria. Esto quiere decir que la batería no puede recargarse hasta que se descargue por completo.

7.3. NÍQUEL-METALHIDRURO

En 2011, la mayoría de los automóviles híbridos que se encontraban en el mercado usaban este tipo de batería debido a su gran cantidad de aplicaciones. Muestra ventajas como una buena energía específica (70-100 W h / kg) y es considerado barato si se compara el precio con sus características. Las baterías de Ni-Mh muestran menos efecto de memoria y son menos tóxicas que Ni-Cd.

7.4. LITIO-ION

Hoy en día es la batería seleccionada por la mayoría de los fabricantes para instalarse en sus vehículos híbridos y eléctricos. Utiliza celdas de gran formato y paquetes con capacidades de 75-200 W h / kg. Tiene una gran cantidad de ciclos de carga (1000-10000) y una autodescarga muy baja. De esta manera, se puede lograr una mayor autonomía con menos peso. La batería Li-ion se considera un buen candidato en los casos en que las dimensiones pequeñas, el tiempo de respuesta y/o el peso del equipo son importantes. Sin embargo, también hay algunas desventajas, como el hecho de que con el paso del tiempo pierde capacidad y es costoso debido a la relativa falta de litio.

Los fabricantes más destacados que se han centrado en el uso y desarrollo de baterías de litio son la asociación de Renault-Nissan, Citroën y Mercedes-Benz. En el caso de Nissan, los investigadores han propuesto un método por el cual se puede suministrar electricidad a una casa con un coche EV o HEV en caso de emergencia.

También se ha realizado un estudio de otro tipo de baterías menos importantes, como el LI-PO y el A123 LIFEPO. Además, se han tenido en cuenta futuras posibilidades: supercondensadores, grafeno, baterías de sales fundidas, combustible líquido para vehículos eléctricos, baterías de aluminio (aluminio-ion y "Light aluminum-air") y "baterías de ciclos infinitos".

Finalmente, el grupo destacó la implicación de Tesla en su proyecto por alcanzar una producción masiva de baterías de li-ion, dando así con una reducción importante en el precio de la batería y de esta manera poder vender vehículos eléctricos a un precio más asequible

8. ARQUITECTURA SELECCIONADA

PROPIEDAD	SELECCIÓN
Chasis	Compact / Small SUV
Arquitectura	Paralelo Híbrido HEV
Precio (£)	£25k-£32k (sin subvención)
Ratio £/MPG	≤ £200
Emisiones CO_2 (g/km)	≤ 75 (g/km)
ICE & EV Transmisión	Tracción delantera (FWD)
ICE Máxima potencia (kW)	75-100 kW
ICE Unidad de potencia	In-line 4-cyl, 1.4-1.6L gasolina ICE
Grid-Dependence / Independence	Grid-Dependent (PHEV)
EV máxima potencia (kW)	60-130 kW
EV química de la batería	Li-ion
EV capacidad de la batería (kWh)	10-15 (kWh)
Autonomía eléctrica (mi)	30-40 (mi)
Máxima velocidad (MPH)	95-115 (MPH)
0-62 (MPH) (Sec)	9-12 (seg)
Peso (kg)	1550-1750 (kg)

9. DESARROLLO DE UNA PÁGINA WEB

El grupo desarrolló una página web como parte del proyecto. Actuando como una parte importante, esta página web se utilizó para reflejar las bases del proyecto, los logros y la estructura de trabajo del grupo a partes externas, incluidos los evaluadores. Además de los objetivos especificados anteriormente, el grupo eligió construir un sitio web que actuaría como una herramienta de cara externa para llegar a las partes con el fin de solicitar patrocinio y/o apoyo; principalmente, se pretendía que se realizara en la conferencia, si la asistencia hubiese sido posible. Por lo tanto, se hicieron objetivos adicionales para maximizar la profesionalidad del sitio web; logrado a través de la compra de una cuenta Premium.

En caso de querer visitar la página web, aquí se les facilita el enlace: www.HEVTechStrath.com

10. TRABAJO EN EQUIPO

Los miembros del equipo nunca habían trabajado juntos, con lo que para ellos era un reto el poder hacerlo de la mejor manera posible, ya que se trataba de preparar un TFG. Para ello se presentaron una serie de tareas a realizar por cada miembro del grupo, para así poder evaluar cual eran las características de cada uno. De esta manera se podía sacar el máximo rendimiento y avanzar en el proyecto de una manera adecuada.

Una de las tareas trataba de realizar una serie de test (“Belbin Self Perception Inventory”), y así saber cuál sería el mejor rol de equipo para cada miembro.
También, se reflejó el conocimiento que tenía cada miembro en las distintas materias y programas informáticos, así como la preferencia que tenía cada uno en algún punto del proyecto.

Finalmente, se concluyó que R. Anderson iba a realizar los roles de gerente de proyecto y administrador de sistema de almacenamiento. Por otra parte, P.Lizzeri, los roles de líder del desarrollo de la página web y director del diseño.
A. Porras realizaría de gerente financiero y de comunicaciones.

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Project Group – R. Anderson, P. Lizzeri & A. Porras

Stakeholder Signature of Agreement; Signatory Date;

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A. REVISION HISTORY

A.1. HISTORIC REVISIONS

Table 1 below outlines the revision history of this document.

***Table 1** the revision history of this document.*

REVISION	DOCUMENT OWNER	MODIFIED BY	DATE	ISSUE
Major	R. Anderson	-	17/03/17	A1
Major	R. Anderson	R.A; A.P.; P.L.	20/03/17	B1

A.2. REVISION NOTES

A summary of the amendments made to this document are as follows;

This is Version B1: decision to utilise this version for marking is at assessor's discretion

Recompilation of the report

Reworking of produced sections to ensure readability - restructuring

Correction of all figure & cross-section references

Additional of all stated appendices

A.3. DOCUMENT REVISION AUTHORISATION

Document Owner Signature of Agreement; Signatory Date;

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Project Manager Signature of Agreement; Signatory Date;

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B. FOREWORD

B.1. GENERAL

The purpose of this document is to act as the principle deliverable between the Group Member(s) and Client, detailing agreed action taken towards completion of project deliverables and reflection upon resource management & structuring, amongst other key information, regarding the scope of the ME519 MEng Group Project, 1969 Design of a next-generation alternative fuel vehicle throughout the 2016/17 academic session within the Department of Mechanical & Aerospace Engineering at the University of Strathclyde.

Declaration of agreement shall be fulfilled through signature on the document front.

B.2. REFERENCED NOMENCLATURE

Within the confines of this document, R. Anderson, P. Lizzeri &/or A. Porras shall assume the roles of “Group Member” &/or “Project Group” whenever specified as a stakeholder.

Similarly, Professor M. P. Cartmell shall assume the roles of Client &/or Project Supervisor whenever such party is denoted as a stakeholder.

C. ACKNOWLEDGEMENTS

Principally the Project Group extend their gratitude to acting Client & Supervisor, Professor M. P. Cartmell of the Universities Mechanical & Aerospace Department, particularly for his accommodating investment of time & effort towards initiating, supporting & encouraging an interesting MEng Mechanical Engineering Thesis.

The group also wishes to extend gratitude to Professor A. McLaren for provision of clarifications when requested by both the project group & Client, in addition to provision of key feedback & advice, alongside Dr C. Maddock, at December’s interim assessment.

The Project Manager also wishes to extend personal gratitude to his colleagues, for their contributions & time invested in supporting the project from its initiation in late September.

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E. ABSTRACT

With growing social concern regarding conventional vehicles powered by internal combustion engines and their intrinsic effects on the growing volume of atmospheric pollutants and greenhouse gasses, a global intervention has been asserted in the attempt to make personal transport more environmentally friendly. This phenomenon has propagated the increasingly greater proliferation & development of alternative fuel powertrains within the automotive industry. The aim of this project is to identify the most pragmatic option pertaining to a commercially viable, alternatively fuelled, personal transport vehicle with the objective of achieving market leading status within a designated two-year period.

To achieve this aim, detailed investigative research has been carried out concerning the availability of alternatively fuelled vehicles currently in the automotive market-place. Pre-defined metrics (e.g. range, cost, MPG) were put in place to guide research towards identification of significantly influential design characteristics, there-in providing information regarding positive attributes to be utilised in the optional, high-level conceptual design of a vehicle, as well as providing key insight into the variety and technical details of alternative vehicle powertrains; including industry terminology. This was also true of an assessment of comparisons of two identical nameplate architectures in the Prius Liftback & Prius Plug-in and in the assessment of the justification for the discontinuation of the Nissan Altima Hybrid.

Furthermore, presented are the outcomes of a significant long-term research investment to identify the HEV or EV architecture which is of most promising value within a forecasted short-medium outlook of a 2-yr period. Tasks undertaken include research pertaining to analysis of the current state of the market & technology, with a focus upon identifying future direction, analysis of proposed barriers to HEV & EV uptake, detailed investigation of supporting infrastructure developments & standards and finally an analysis of current & future energy storage options; principally in the form of battery technology. Subsequently, discussion is presented defining justification for selection of a chosen architecture.

In addition to the above, as this report is the principle deliverable of the M519 course, there is presented a significant discussion pertaining to group organisation, group employed processes and reflection pertaining to the effectiveness & efficiency of both of these aspects.

0. INTRODUCTION

0.1. PROJECT BACKGROUND

After a century of personal transport being dominated by the internal combustion engine rapid growth is now beginning to occur in the application of electric vehicle technology across both current and developing vehicle markets globally. With the growth of this new technology arises a wealth of opportunity for electrically powered vehicles to completely transform the personal transport sector as well as the related infrastructural and technological systems in the upcoming decade.

The electric vehicle revolution has been propagated in part by growing social concern regarding conventional internal combustion engines and their intrinsic contribution to the rising volume of atmospheric pollutants and greenhouse gasses resultant of their use. A global intervention has been asserted by governmental bodies globally to combat these pollutants while instigating vehicle manufacturers to develop innovative alternative fuel powertrains which contribute toward building more environmentally friendly personal transport systems.

According to UK government statistics, over 28,000 people die as a direct result of air pollution per year. The quality of air in major towns and cities is of major concern with almost 90% of Britain's air quality zones breaching imposed EU safety limits for nitrogen dioxide. Figure 1 illustrates the regions of the UK with the most prevalent death rates resultant of poor air quality standards.**Invalid source specified.**

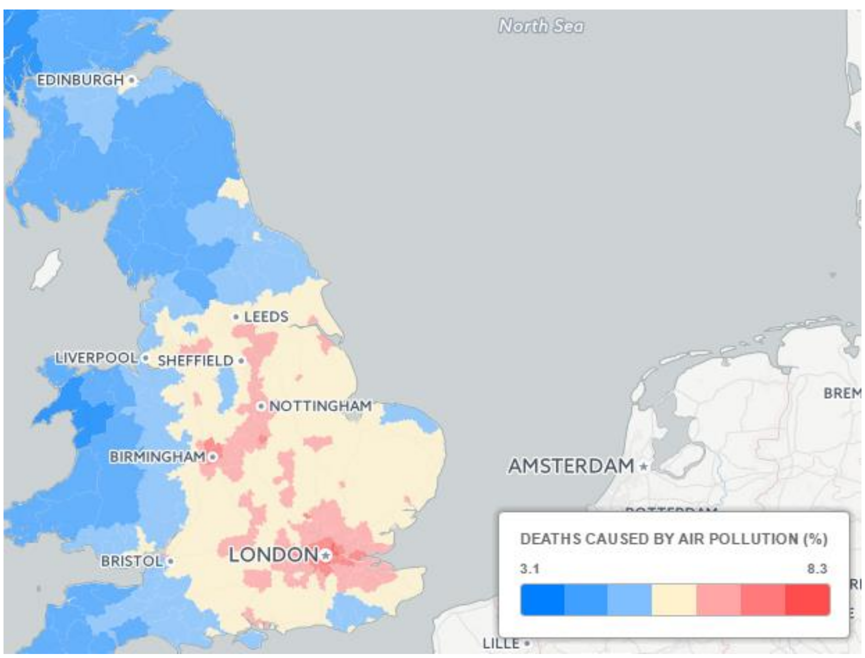


Figure 1** UK deaths caused by air pollution**Invalid source specified.

In reference to Figure 1 it is clear that the area of the UK with the highest volume of air pollutants is London, which comes as no surprise when considering the large population density and therefore necessitated personal and public transport systems associated.

The European Commission issued policy requiring all registered vehicles to produce no more than 95g/Kg of carbon dioxide per kilometre of travel by 2021, backed by legislative penalties of 95 euros per gram of exceedance come 2019. Similar policy has been put in place in China where the local air quality of cities and towns has reached critically poor levels.

The propagation of electric vehicle technology has the potential to serve as a means of energy security when assimilated successfully under schemes such as "power to grid". Plug-in electric and hybrid vehicles can be synergised with the electrical power grid, utilising their on-board storage capacity to aid in electrical supply and demand management whilst simultaneously facilitating greater exploitation of intermittent, uncontrollable, non-dispatchable renewals generation. UK statistics indicate that 1 terawatt hour of power is curtailed on a yearly basis. Electric vehicle technology has the propensity to act as mass storage, alleviating the grid of excessive power generation when necessary whilst maintaining the ability to deliver power back to the grid under desirable circumstances.

Current electrical vehicle technology stands at the precipice of massive technological advancement after a century of stagnation. Public awareness of the technology is at an all-time high, instigated by pioneering vehicle manufacturers such as Tesla, who have kick started the industry by making electric vehicles not only practical but desirable. With large investments made across the majority of large vehicle manufacturers globally, electric motor and battery technologies have improved exponentially.

With the growth of the electric vehicle industry it is of great importance to consider the infrastructure necessary for vehicular support. To this end the UK government has introduced the £40 million "Go Ultra Low" scheme which utilises a combination of grants and infrastructure improvements across the UK to instigate uptake of electric vehicle technology. As part of the scheme more than 96% of UK power stations have electrical charging installations with the capability of recharging a vehicle to 80% capacity within half an hour.

Electric vehicle charging standards are reaching a maturation point where-in universal charging standards have been agreed upon by the European Commission. Type 2 charging points have been installed across Europe with the capability to sustain future growth of EV technology

0.2. PROJECT PURPOSE

Completion of the project will further the continual growth of information available to the University of Strathclyde. The electric vehicle (EV) & Hybrid EV (HEV) market proposes vast opportunity for innovation in terms of technology and development of engineering processes. Success in this project may open further potentialities for investment in the area. This report will also provide a basis for any future work undertaken at the University, consolidating valuable information and guidance.

0.3. PROJECT SPECIFICATION & OBJECTIVES

The specified prime intention of this project is to ultimately identify & where time-permitting develop an innovative concept of an alternative fuel vehicle, capable of attaining class leading status within the industry under a proposed 2-year product life cycle. This will be achieved via the allocation of two objective sub-sets to be completed within schedule. In agreement with the Statement of Purpose, the sub-set objectives are elucidated as follows;

0.3.1. OBJECTIVE SUB-SET ONE – “FAMILIARISATION TASK”

- **Select a minimum of 15 hybrid electric vehicles** – Selection of sufficiently varied, yet comparable, vehicle architecture variations and determine technical disparities and cost differences
- **Calculate ratio of cost to mpg for each of the selected vehicles** – Determination of a metric through which general comparisons were performed on a basis which, in conjunction with the above, will aide in clarification of inherent differences in architecture capabilities and design.
- **Refinement of selection to 5 vehicles & detailed assessment -** By using well defined process to ‘shortlist’ the most desirable vehicles a more detailed understanding is attained with regard to potential technologies & inherent cost influences which will influence group architecture choice.
- **Comparisons of Prius Liftback & Prius Plug-in Models** – Through comparisons of pre-defined metrics and assessment of technology architecture, valuable information is gained pertaining to the variances in technology (e.g. grid-dependent vs. grid-independent) and their inherent positive and negative attributes which will be used to influence the final architecture selection.
- **Investigate hybrid Nissan Altima and conclude reasons for discontinuation** – Through a structured assessment of the failure of a major, recognisable & experienced manufacturer such as Nissan within the HEV market sector would provide the group insight into potential flaws that can be introduced regarding vehicle design and implementation such that these may be avoided.

0.3.2. OBJECTIVE SUB-SET TWO – "RESEARCH & CONCLUSIONS"

- **Analysis of current automotive markets globally, with consideration of future developments** –This will serve to guide the principle design requirements of the proposed conceptual vehicle; It was of importance to understand market regarding uptake of technology, potential political influences, including regulations, & technological advances pertaining to future development.
- **Identification of social & technical obstacles hindering mass adoption of electric vehicles –** Social approval is key in the success of a new alternative vehicle, therefore it is of great importance to have an understanding of the public perceptions with regard to electric vehicle technology. In addition, it was of importance to investigate & analyse technical barriers to adoption. Through identification of these issues, mitigations could be proposed & where relevant, accommodations in selection of the proposed future vehicle architecture with limitations of technology in mind.
- **Summarisation of infrastructural development in 4 major UK cities including Glasgow –** HEV & EV architectures necessitate a well-planned & suitable supportive infrastructure, equivalent to the network of petrol stations supporting use of conventional vehicles with internal combustion engines. Therefore, to gain an insight into EV technology development and uptake it is imperative to understand the infrastructural developments within a short-medium term outlook.
- **Identification of energy storage developments** – A performance critical consideration of the proposed architecture would be the energy storage medium employed; with respect to capacity (kWh), cost (£/kWh) and energy densities, both gravitational & volumetric (kg/kWh) & L/kWh). Where relevant, differences in battery chemistry would be required to be considered.
- **Consolidation & identification of the most promising architecture platform (2-yr timeframe) –** A compilation of resultant findings and a group decision on the platform to be designed. A summary of current, similar architecture vehicles was also a requirement.
- ***(Time permitting)* development of an alt.-fuelled vehicle utilizing pre-performance research –** Performance of conceptual design of a high-level vehicle architecture, if resources facilitate.

0.4. PERSONAL AIMS & ASPIRATIONS

In terms of R. Anderson, personal objectives for the project included a desire for additional development of both time & group management skills. Furthermore, there was a personal interest in developing greater familiarity with modern modelling & simulations techniques. A desire to build skills in basic website development were also identified since it was felt this could be an avenue through which an extended CV of sorts could be made. For A. Porras, there was a strong desire to utilise the group-based nature of the project to improve English-based communications skills; this was noted to be a significant challenge given that both R. Anderson & P. Lizzeri have strong Scottish accents. With respect to P. Lizzeri, there was a strong personal aim of developing deeper in-sight with regards to the technical details of automotive powertrains, namely ICE components & architectures. In addition, there was a desire to develop skills pertaining to rudimentary website construction.

0.5. PROJECT DELIVERABLES

The main deliverable, and their agreed delivery dates for the project's duration are as detailed, overleaf, within Table 2. These are also presented with the contract, on within the group's website.

Table 2 *The main deliverables of the project & their proposed delivery dates.*

DELIVERABLE(S)	DESCRIPTION	DELIVERY DATE
Statement of Purpose	Statement of the aims, resources & budget implications, project management & deliverables.	3.30pm 14-Oct '16
Interim report	To summarise work-to-date, achievement of stated goals and overview of proposed project management structure.	3.30pm 18-Nov '16
Interim Assessment	Details TBC.	9.00am 2-Dec '16
Final report	To summarise of the objectives, outcomes, success & failure(s) and a reflection upon delivery of the Statement of Purpose.	3.30pm 17-Mar '17
Final assessment	Details TBC.	2.15-3.15pm 27-Mar '17
Website	To express the aims, scope and works of the project to external parties.	3.30pm 26-Mar '17
Peer review	A collaborative peer assessment performed by the Group Members.	3.30pm 31-Mar '17

1. PRELIMINARY TASK SET ONE

1.1. COST PER MPG ASSESSMENT OF EXISTING VEHICLES

1.1.1. TASK INTRODUCTION

As defined within Section 0, a large component of the preliminary familiarization task was that of identification of cost (£) per MPG ratio for a range of group-selected HEVs. Following refinement, a selection of five vehicles were identified for deeper analysis where-in justifications for the ratio of cost (£) to achievable MPG were determined; which included technical analysis. Within this section, the purpose of the task, the methodology applied throughout and both results & conclusions drawn shall be presented.

1.1.2. INTENDED TASK PURPOSE

A primary purpose of this task was to facilitate development of familiarity with industry terminology & notation. This was required as although the automotive industry was historically of personal interest to some group members, detailed understanding beyond traditional published specification sheets for performance, high-level technical knowledge of typical component(s) operation & application of transferable terminology from the degree syllabus was very much inadequate at the project's initiation in late September. The secondary proposed purpose of the cost per MPG analysis task was that of developing, or reinforcing pre-existing, analytical & research-oriented skills which would subsequently be utilized extensively by the group throughout the duration of the long-term research assignment and when producing a conclusive decision of the most sustainable package likely to emerge within a 2-yr cycle.

Tertiary purposes were also intended to be served through performance of this task. For example, identification of both personal strengths and weaknesses for individual group members, which would influence future task assignment & the growth of responsibilities with project progression. Furthermore, the task would serve to introduce the differing work styles of group members and would in theory facilitate more rapid development of a group synergy. In addition, the group perceived this task to be an opportunity where-in individual areas of interest could be determined amongst group members; which would be important for an initially proposed future detailed sub-system design assignment.

1.1.3. IDENTIFICATION OF FIFTEEN VEHICLES FOR ASSESSMENT

Of significance to the success of this task in delivering upon the aforementioned purposes, was the identification of vehicles which were suitably non-disparate, yet remained sufficiently varied for insight into cost & MPG influences to be achieved. Therefore, a methodology was derived at task initiation and was subsequently employed successfully by the group to perform the stated task. The first stage of this methodology, which will be defined throughout the following discussion, was initial vehicle identification.

First and foremost, the perceived workload was evenly distributed amongst the three group members; with each assigned a total of five, to-be-determined, vehicles which they held individual responsibility for.

Subsequently, each of the group's members independently undertook an initial period of research where-in foundation-level familiarity with to-date HEV technologies & architectures was developed; serving to facilitate distinctions of parallel & series and grid-dependent & grid-independent vehicle architectures.

Now informed of most significant variations found in modern HEVs, the group met to determine criteria which must be met for each of the to-be-determine vehicles for selection & progression throughout the remaining tasks to be undertaken. The following summarizes the key criteria agreed upon after discussion;

✓ There must be sufficiently, reliably sourced information available (regarding technology & specifications)
✓ There must be variance of HEV architecture (e.g. grid-independent vs. dependent & parallel vs. series)
✓ There must be varied manufacturers, nameplates, chassis-types & performance capabilities

Through application of the above criteria, meaningful insight was expected to be more likely achieved.

Following selection of criteria, the group members cooperatively identified a selection of fifteen vehicles which met the above criteria; details for which are presented within Table 3, overleaf. Regular group communication was maintained throughout identification process, serving to highlight aspects of interest, ensured that the above specified criteria could be satisfactorily achieved & also avoided duplication. The use of a criteria-based approach was found to significantly support the selection of suitable vehicles.

The final aspect of this process was the assignment of five vehicles from the shortlist to each group member. This was performed through informal discussions regarding individual preferences & preexisting familiarities with various selected vehicles & their respective manufacturers and architectures. The allocation will not be presented nor discussed in detail but was agreed as acceptable by group members.

1.1.4. DETAILED RESEARCH & COST PER MPG DETERMINATION

Again, to enable successful achievement of the required outcomes, a methodology was derived by the group prior to commencing this component of the familiarization task set. The method is as follows;

✓ Independently reconfirm the suitability of the shortlisted vehicles assigned to member (5x)
✓ Determine preliminary a purchase cost (£) to achievable MPG ratio for the assigned vehicles (5x)
✓ Compile all relevant statistics and compile notable anecdotal or technical information for vehicle (5x)
✓ Compile & circulate findings to all other group members; providing clarifications where necessary
✓ Group peer-review of research data & statistics, ensuring compliance with criteria & adequacy
✓ Generate relevant plots & tables using data and assess general conclusions of preliminary estimations

Through the application of the above process, the group successfully developed significant preliminary insight into the fifteen identified vehicles; Table 3, overleaf, summarizes the key specifications and data. Supported by Table 4, also overleaf, the group were clearly successful in their bid to obtain data for various manufacturers, name plates, chassis types & performance levels reflecting the adequacy of the process. For example, although not visible in tabulated summaries, of the fifteen vehicles selected for assessment there were 15 unique nameplates with a corresponding 13 unique manufacturers; including leading mass market producers such as Volkswagen & Ford, leading luxury producers including BMW & Audi and leading performance manufacturers were represented by McLaren and their P1 hybrid vehicle. Furthermore, with respect to the criteria for various performance capabilities and chassis classifications, as is depicted, this was firmly accomplished; e.g. the Audi Q7 e-tron is a luxury crossover SUV with a 0-62MPH of 6.2s which compares to the Lexus CT200h compact sports hatch which has a respective 0-62MPH of 10.3s (Table 3).

Table 3 *Summary of the findings from the preliminary Cost to MPG ratio study (Ascending Ratio order).*

MODEL	COST (£)	MPG (MPG)	RATIO (£/MPG)	0-62 MPH (Sec)	KERB MASS (Kg)	CAPACITY (kWh)	BATTERY CHEMISTRY	MOTOR PWR (kW)
Outlander	31,749	156	203.52	11	1860	9.8	Li-ion	60
Passat	36,750	166	221.39	7.6	1647	3.5	Li-ion	85
i3 (Rex.)	35,350	470.8	238.46	7	1365	22	Li-ion	125
Ioniq	19,995	83.1	240.61	10.8	1370	1.6	Li-ion	32
V60	38,105	155.2	245.52	6.2	1988	11.2	Li-ion	50
Prius	23,600	94.1	250.80	10.5	1500	1.3	Ni-MH	82
C-max	20,325	51	390.88	7.9	1,374	1.4	Li-ion	85
Q7-etron	64,950	156.9	413.96	6.2	2445	17.3	Ni-MH	94
Accord	24,187	57.6	419.92	6.9	1580	1.3	Li-ion	105
CT200h	21,940	50.4	435.32	10.3	1,370	1.3	Ni-MH	60
Camry	22,194	49	452.95	7.2	1595	1.6	Ni-MH	105
Sonata	24,553	50.4	487.17	8.1	1588	9.8	Li-ion	50
GLE500e	50,570	85.6	590.77	5.3	2465	6.2	Li-ion	85
Silverado	32,068	25	1,282.72	-	2627	0.5	Li-ion	60
P1	866,000	34	25,470.59	2.8	1547	5	Li-ion	131

Table 4 *Summary of the vehicle classification of chassis types from the assessed pool of vehicles.*

CLASS	CITY	COMPACT	HATCH	MPV	CROSSOVER	SEDAN	PICK-UP	SPORTS	WAGON
COUNT	1	2	2	1	3	4	1	1	1

Particularly noteworthy too is that although a large range of price points were represented, a significant portion of the assessed vehicles were within the bounds of the mass market sub-£40k purchase MSRP. This was a deliberate attempt by the group to enable familiarization with the performance capabilities & technology readiness levels of architectures within the price range that would be considered in future tasks regarding the assessment of sustainable HEV or EV packages & development of a leading concept. This decision was founded upon research findings which indicated that industry experts estimate that as much as 50% of Europe's current *luxury* car market, in terms of sales volume, exists below a £32k MSRP [1]. Also of note is that the group elected to utilize a cost to MPG metric in terms of £GBP and not $US; this decision was made as the group held significantly greater appreciation for the value of the £GBP. The group notified the Client of this minor adjustment early & contract was updated to reflect this decision.

Also of importance was that to facilitate comparisons across models assessed, the group elected to utilize a consistent test cycle for MPG estimation when deriving figures for the vehicles. Although superseded by the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) test cycle which claims to better reflect real world driving conditions through distinguishing between classifications of vehicle, the New European

Driving Cycle (NEDC) was employed throughout performance of this task. Though the NEDC has historically been shown to not fully represent the real-world MPG that can be attained by a vehicle, it remains that which is most prominently available & most commonly specified by manufacturers, hence the group's decision to use it [2]. Figure 2 depicts the differences in the cycles for reference purposes. In addition, notable is that only base models were considered, to minimize fitted equipment influences.

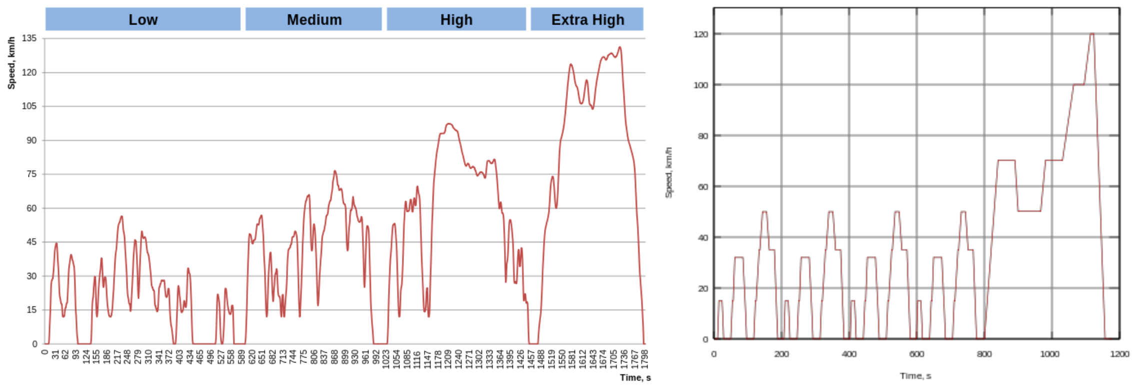


***Figure 2 LHS** WLTP showing time(s) vs. speed (kms^{-1}). **RHS** NEDC with time(s) vs. speed (kms^{-1})* [3].

In terms of the presentation of data, the group initially experimented with generating plots of specifications such as On the Road (OTR) price vs. achievable MPG, however as is demonstrated with the example provided in Figure 3, the presentation of data through such methods proved misleading. In the case presented, the cost per MPG for four vehicles is overlaid to demonstrate that the four-quadrant methodology for data presentation was misleading. For example, though the Mercedes GLE500e is shown within red "High cost- Low MPG" quadrant, its cost per MPG is around one-third of that of the Chevrolet Silverado which is shown in the yellow "Low cost – Low MPG" quadrant (£590.77 & 1282.72 respectively). A simpler approach to data presentation was therefore employed, visible within Figures 4 & 5, overleaf.

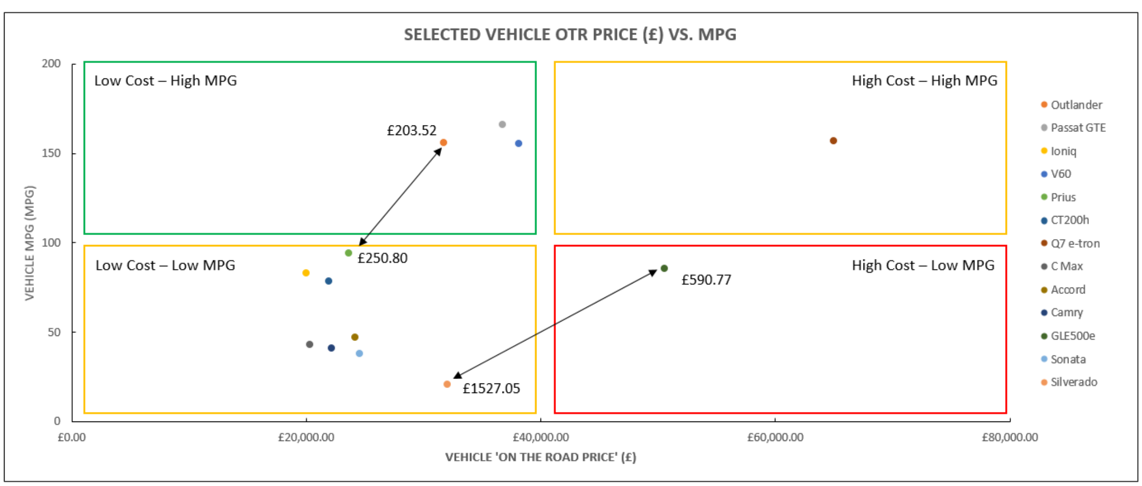


***Figure 3** The failed approach of presenting data arising from the cost to MPG assessment of 15 vehicles.*

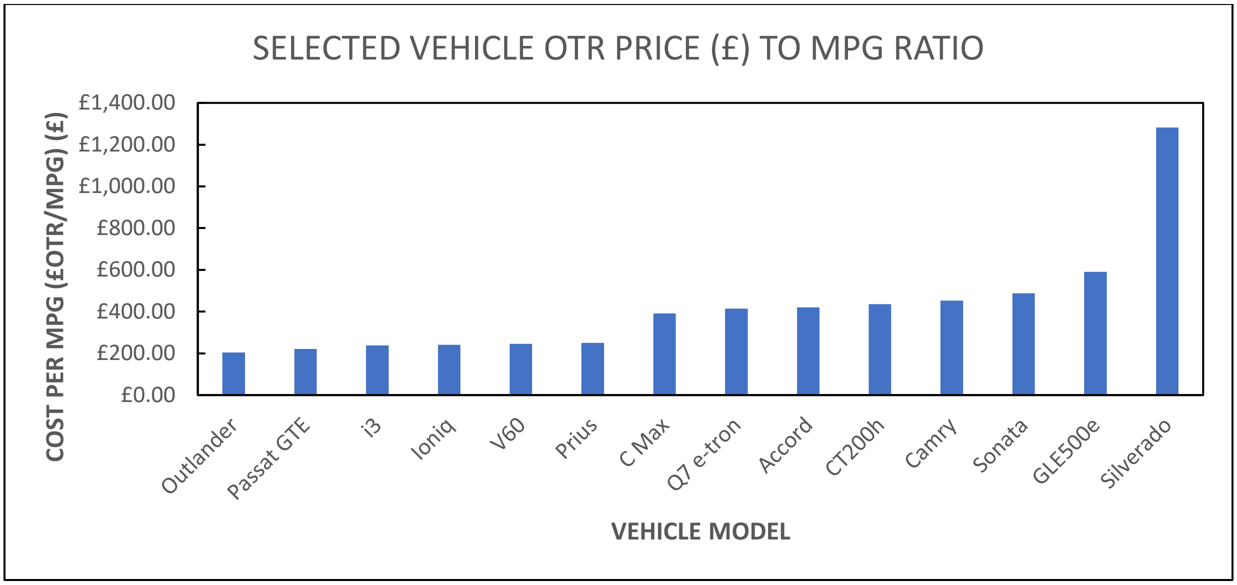


Figure 4 *Vehicle model vs. Cost per MPG (£) for the vehicles assessed.* ***N.B.*** *McLaren outlier not shown.*

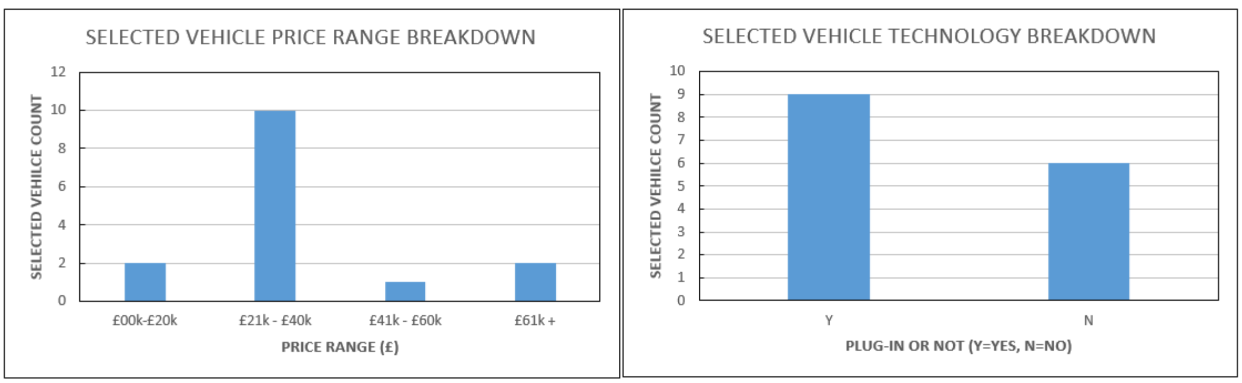


Figure 5 LHS *Breakdown of vehicle on the road price (£).* ***RHS*** *Breakdown of grid-dependence of vehicles.*

1.1.5. DETAILED ASSESSMENT OF COST PER MPG FOR SELECT VEHICLES

Following the general assessment at medium-high level for all fifteen vehicles, as per the agreed contract the group were required to identify five vehicles for further assessment, where-in a more thorough analysis would be performed to explain the cost to mpg ratio which was observed. Again, the group derived and employed a methodology which enabled sufficient achievement of the task objectives. This methodology is as defined overleaf & was its success influenced by vehicles selected for detailed study.

- ✓ Group revisited & discussed anecdotal supporting information for all fifteen vehicles
- ✓ Group cooperatively identified five vehicles of interest; data & information availability was considered
- ✓ Group decision for distribution and assignment of vehicles to individual group members for assessment
- ✓ Independent assessment of identified vehicles and compilation of research; regular communications
- ✓ Group compilation of information to a centralized document;
- ✓ A one-off review of the presented data was performed to assess quality & source reliability

The group identified interest in five vehicles in-line with the stated work scope. These were the BMW i3, primarily due to its unique series rex. architecture & large MPG capabilities; the Mitsubishi Outlander which was of interest due to its relatively successful market penetration and its large zero-emissions range relative to its bulk & chassis type; the Volvo V60 which was selected again for its large zero-emissions range relative to its bulk & chassis type, along with its utilization of rear-wheel drive and lastly the Lexus CT200h and Ford C-max were chosen as, they had both a comparable on the road price & comparable MPG capability, yet the Lexus CT200h utilized a 1.3 kWh Ni-MH battery and the Ford C-max employed a, larger, 1.4 kWh Li-ion based powertrain (£435.32 and £390.88 respectively). For the five vehicles, the group determined cooperatively that all of the above criteria were adequately met. Although all five vehicles were investigated in detail, only the Lexus CT200h will be presented within this report for purposes of maintaining a concise report; the group can provide details for others upon request. Noteworthy is that a milestone review performed late October confirmed adequacy of the group's efforts.

With regards to the Lexus CT200h, the vehicle is a compact sports hatch priced at the mid-range point of the market for such vehicles; the on the road price (£) for the 5-dr entry level "S" model, with no options, was £21k reflecting that the CT200h was priced above low-end competitors such as the base VW Golf & Ford Focus models, instead being priced to compete with low-specification Audi A3 and Mercedes A-class. For the CT200h, Lexus utilized a mid-sized four-cylinder, 16-valve, 1.8L VVT-i petrol engine which was maintained as standard across all models available for purchase; a decision determined to aide in reducing costs through standardization & reduction of manufacturing variance. Capable of 98HP & 142Nm output, the engine employed utilized the Atkinson Cycle, which in this case utilizes unconventional valve timing to replicate the effects of a shorter compression stroke and a longer power stroke. The use of the Atkinson Cycle in place of a conventional Otto Cycle enables achievement of greater efficiency of fuel burn at the expense of reduced power density (Refer to Figure 6 for comparison to the auto cycle); however, in the case of the parallel hybrid CT200h where-in supporting electric drivetrain is available, a reduction in power output can be negated facilitating improved MPG achievable without significant loss of performance.

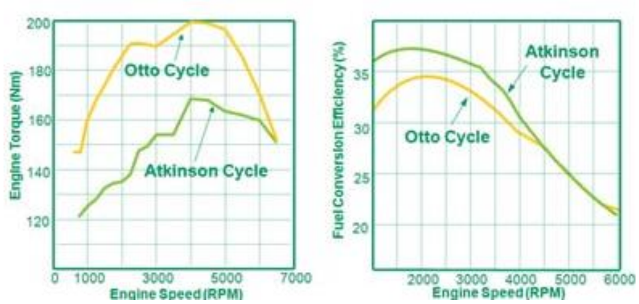


Figure 6 *Exemplarily comparisons of the Otto & Atkinson Cycle capabilities for comparably sized engines.*

In regards to the electric drivetrain which is employed within all models of the CT200h, the sizing is that which defines a powertrain designed to support a conventional ICE rather than operate independently for significant durations nor ranges (known as a parallel hybrid); this holds significant influence to the cost per MPG ratio as it facilitates the use of a reasonably light, relatively low-cost electric powertrain. A 60kW (80HP), AC-derived permanent magnet synchronous motor-generator is employed in conjunction with a 1.3kWh nickel-metal hydride (Ni-MH) battery pack. For comparison, the BMW i3 Rex utilizes a 125kWh (168HP) motor-generator & 22kWh Li-based on-board storage and the base Tesla Model S employs a 270kW AC induction motor-generator & 60kWh on-board Li-based storage; demonstrating that the

CT200h's parallel drivetrain facilitates use of a significantly less bulky, less expensive & less powerful electric drivetrain. Industry estimates are that a battery can account for up to one-third of a vehicles on the road price hence the CT200h small on-board storage facilitating significant cost reductions [4]. Of further significance to the cost per MPG ratio observed was that Lexus employed Toyota's Hybrid Synergy drivetrain, which though employed under license, enabled minimization of research & development costs. The implementation of regenerative braking further improves the cost to MPG through enabling achievement of significantly larger range before refueling but is restricted due to lack of plug-in model. Additionally, the implementation of continuously variable transmission (CVT) improves achievable MPG through capability to maintain ICE operation at peak efficiency, though with additional complexity & cost.

The group performed assessments of other influencing factors, from a non-technical perspective also. Again, reference to the Lexus CT200h these would include that the vehicle was a low-volume production which through implication of economies of scale increases per unit cost for manufacture; that the vehicle scores very highly on both reliability & safety metrics which would indicate a degree of over-engineering &/or increased safety margins for component lifecycle purposes which would increase cost of manufacture and also the range of standard equipment found on the CT200h across the range is large. Whilst all of the above would push both the manufacturing costs & respective initial purchase price up, the group found that, in contrast as, Lexus were targeting market share growth which majorly limited the extent to which such incurred costs were permitted to grow to enable competitive market pricing.

Throughout all other assessments of vehicles, it was found that the most significant influence upon the cost per MPG ratio calculated was the scale, complexity and storage technology of the electric drivetrain in conjunction with production volumes. In addition, increased performance capability (i.e. acceleration) was generally found to directly correlate to both increased drivetrain scale & on the road price (£). With regards to the cost per MPG similarity of the comparably priced Ford C-Max & Lexus CT200h, although the Ford employed a larger & more powerful ICE & electric drivetrain which enabled greater performance at the cost of increased drivetrain mass, as is visible within Table 3 the curb weight remained comparable due to the weight-saving achieved with use of a Li-ion chemistry. Additionally, the Ford's targeted class is lower than that of the CT200h, evident in standard equipment (Table 5), hence the group determined that savings associated with both reduced refinement & equipment facilitated Ford's lower On the Road Price. Table 5, below, presents a summary of comparisons drawn across the five vehicles assessed in detail.

Table 5 *Table providing a summary of the detailed data for the five vehicles assessed.*

PROPERTY	BMW i3 Rex	OUTLANDER	VOLVO V60	LEXUS CT200h	FORD C-MAX
MSRP COST (£)	35,530	31,749	38,105	21,940	20,325
MPG (MPG)	149	156	155.2	50.4	52
COST PER MPG	Low	Low-Medium	Low-Medium	Medium	Medium
CHASSIS TYPE	City Car	Crossover	Wagon	Compact	MPV
DRIVETRAIN	FWD	FWD	RWD	FWD	FWD
PERFORMANCE	Medium	Medium	Medium	Low	Low
EQUIPMENT	Medium	High	High	High	Low
HYBRID ARCHITECTURE	Series Grid Dependent	Parallel Grid Dependent	Parallel Grid Dependent	Parallel Grid Independent	Parallel Grid Independent
ICE DRIVETRAIN	Small	Large	Large	Medium	Medium-Large
EV DRIVETRAIN	Large	Large	Medium	Small	Small

1.2. PRIUS LIFTBACK VS. PRIUS PLUG-IN COMPARISONS

1.2.1. TASK INTRODUCTION

As stated within the contract, the group were required to assess the differences in the cost per MPG achievable for both the '12 Prius Liftback (Read: Hatchback) and the '12 Prius Plug-in. Within this brief section, an overview of the purpose intended to be fulfilled by performance of this task, the methodology derived & applied by the group and the conclusions reached cooperatively will be presented.

1.2.2. INTENDED TASK PURPOSE

As with the previous cost per MPG assessment task a primary purpose of the Prius Liftback & Plug-in variant comparison was to facilitate development of familiarity with industry terminology & notation. Successful achievement of such an outcome would streamline forthcoming long-term research investigations, whilst simultaneously would act to broaden the group's fundamental knowledge of the existing HEV & EV technologies. In addition to this principle objective, there were several other primary motivations for performance of this intra-nameplate comparison task set. Most notable would be that of the further development of critical analysis skills, which would be of primary use when cooperatively developing a decision upon the most promising, sustainable package likely to emerge within a 2-yr cycle. In addition, as in this case the subject matter was fixed and relating to a nameplate which was significantly older than those previously assessed, the task would facilitate further development of research skills, principally those which pertain to identification of reliable data & statistics. Again, such would be of great significance to the outcomes of the future research assessment & eventual cooperative decision.

As was the case of both previous tasks, numerous tertiary objectives pertaining to development of a group synergy and inter-compatible work style were applicable to the intra-nameplate comparison assessment.

1.2.3. INTRA-NAMEPLATE PRIUS COMPARISONS

To facilitate meaningful assessment of both nameplates and to better ensure satisfaction of the task intended purposes, the group derived and implemented a structured methodology for task completion;

- ✓ Group members independently research vehicle variants & define metrics for comparison
- ✓ Group members cooperatively decide on critical metrics which reflect inter-nameplate variance
- ✓ Group independently researches the identified metrics, remaining in near-constant communication
- ✓ Group discusses the outcomes of independent research and reaches unambiguous conclusions
- ✓ Group members assigned to compile all relevant information, including sources where relevant

Through the application of the above, the group successfully accomplished the intended purposes of the task. Table 6, overleaf, summarizes notable differences across both nameplate which affect cost to MPG, as does the following brief discussion & analysis passage (refer overleaf).

The most significant influence to cost per MPG ratio of the '12 Prius Plug-in variant in comparison to the Liftback was the utilization of a significantly larger on-board energy storage unit, in conjunction with replacement of the nickel-metal hydride (Ni-MH) chemistry by an, undisclosed, lithium-ion chemistry. As depicted within Table X, the 4.4kWh battery employed in the Plug-in variant is 238% larger than the 1.3kWh unit which is installed within all Liftback variants. This facilitates a significantly large increase to the vehicles all-electric range, with an increase from 2mi capability to, around 11-15mi; this influences the MPG achievable as the extension of the electric range reduces reliance upon the on-board ICE, thus significantly reducing both fuel consumption & localized tailpipe emissions over short-medium journeys. In addition, the transition from a Ni-MH chemistry to a Li-ion based chemistry facilitates more rapid delivery of stored power, which manifests in the ability to maintain fully-electric propulsion at a speed of up 62MPH in comparison to the Liftback's limit of 25MPH. In addition, the body work & major drivetrain components including ICE, transmission & motor-generator remain unchanged across both Prius variants and thus capacity of the battery has been dramatically increased without significant weight penalty; a paltry 50kg curb weight growth has been accomplished thanks to the Li-based battery's significantly greater gravimetric energy density (kWh/kg), a benefit inherent to the chemistry employed.

Table 6 *Summary of the key performance & specification data for both the Prius Liftback & Prius Plug-in.*

PROPERTY	'12 PRIUS LIFTBACK	'12 PRIUS PLUG-IN
Chassis Classification	5-dr Sedan	5-dr Sedan
On the Road Price (£)	24,000	32,000 (+33%)
Achievable MPG (MPG)	50MPG Combined	95MPGe Combined (+90%)
Cost per MPG Ratio (£/MPG)	480.00	336.84 (-29.8%)
CO_2 Emissions (g/km)	92	82.6 (-6.5%)
2011-2012 Yearly Sales (thous.)	147.5	12.8
Drivetrain (FWD / RWD / 4WD)	FWD	FWD
Hybrid Architecture	Parallel Grid-Independent	Parallel Grid-Dependent
ICE Displacement & Config.	1.8L Four-Cyl Atkinson	1.8L Four-Cyl Atkinson
ICE Peak Power (kW)	73	73
ICE Peak Torque (Nm)	142.4	142.4
Electrical Motor Power (kW)	60	60
Electric Motor Torque (Nm)	207.4	207.4
Battery Chemistry Employed	Ni-MH	Li-based Ion
On-board Battery Storage (kWh)	1.3	4.4 (+238%)
Achievable all electric range (mi)	2mi @25MPH	11-15mi @62MPH (+450%)
Maximum Top Speed (MPH)	114 (25 All-Electric)	112 (62 All-Electric)
Achievable 0-62 MPH (sec)	9.8	10.7 (+9.1%)
Curb Mass Estimation (kg)	1,370	1,420 (+3.6%)

However, whilst the installation of a larger capacity battery unit of differing chemistry is beneficial to the achievable MPG & all-electric performance of the Prius Plug-in variant, a significant compromise with regards to manufacture, materials and total cost of ownership is incurred. As depicted within Table 6, the on the road MSRP of the Plug-in variant is £8,000 larger than its grid-independent counterpart; & whilst installation costs of the plug-in components & control systems are not entirely insignificant, most of the required price increase comes as a result of the battery chemistry switch (Ni-MH to Li). Due to inherent influences of manufacture complexity, materials availability and inter-market demand, Li-based batteries are significantly more expensive per kilowatt hour energy storage capacity (£/kWh) than Ni-MH equivalents. The implications for this are largely that the cost per MPG gains are limited in that the purchase price to the consumer is significantly larger. Additionally, since all other aspects of the drivetrain remain identical across the variants, the MPG achievable in the Plug-in following initial depletion of the on-board storage is identical to that of the non-plug-in; Thus, if a consumer does not utilize the plug-in functionality, or if the consumer regularly drives significant distances, there-in using the ICE to a greater extent, proposed reduced running costs of the plug-in are not realized increasing total cost of ownership.

It should be noted that whilst a comparable capacity Ni-MH unit which is inherently cheaper per kWh could have been installed to increase all-electric range with reduced impact upon purchase cost, the weight of the equivalent Ni-MH battery would have been significantly larger, there-in negatively impacting important metrics such as performance & fuel efficiency. Furthermore, either the interior or boot capacity would be required to be significantly reduced, or the body enlarged, if a Ni-MH battery of equivalent capacity to the Li-ion based unit installed were to be used given that the volumetric density of Ni-MH units is significantly smaller than that of Li-based units. In addition, the use of Li-based chemistry enables both a reduced self-discharge rate and, theoretically, an improved system cycle life, meaning that the Li unit can hold its charge better and is also less likely to require replacing (For further reading, refer to Section 5. of this report where-in detailed examination of battery chemistry is performed).

Frustratingly, although extensive study has been performed, at present the group is unable to ascertain the reason for the slight increase to the 0-62MPH achievable by the Prius Plug-in variant. Current belief is that a combination of the additional curb weight, although minor at just 50kg, and artificial limitations to performance through on-board drivetrain management systems are the route cause; i.e. under harsh acceleration, since there is a larger reservoir of electrical energy to be drawn from, the use of the ICE is possibly delayed in favor of utilizing the, less powerful, on-board electric powertrain for fuel economy.

1.3. NISSAN ALTIMA DISCONTINUATION

1.3.1. TASK INTRODUCTION

As stated within the agreed contract, the group were required to determine a justification for the discontinuation of the Nissan Altima Hybrid, which occurred during the 2012 calendar year. Within this section, a brief overview of the purpose of this task, the methodology derived and utilized by the group and a summary of the resultant conclusions drawn shall be briefly presented.

1.3.2. INTENDED TASK PURPOSE

The previous two task’s primary objectives had been pertaining to development of familiarity with industry terminology & notation, the development of a group compatible work style and the development, or refinement where applicable, of analytical & research oriented skills. However, for this task the group felt a distinct shift where-in the primary purpose was observed to be more in-line with that pertaining to a practical application of the expertise and capabilities developed thus far within the project. Also, identification of the route cause(s) for market failings & subsequent discontinuation, whether technical &/or commercial, of a modern hybrid vehicle would serve to prepare the group for determining a suitable HEV or EV package, believed to hold potential for market leading status within a 2-yr development cycle, following a forthcoming, significantly large research and data processing undertaking.

1.3.3. NISSAN ALTIMA HYBRID DISCONTINUATION ASSESSMENT

Again, the group spent time developing a structured approach which would facilitate meaningful achievement of the Nissan Altima discontinuation assessment's stated purpose. It was as follows;

- ✓ Group members independently research nameplate & hybrid history and specifications
- ✓ Group members cooperatively identify principle failings, both commercial & technical
- ✓ Group independently perform detailed research upon identified failings; holding near-constant comm.
- ✓ Group discusses the outcomes of the independent research & draws unambiguous conclusions
- ✓ Group member assigned to compile all relevant information, including sources where relevant

The application of the above structured methodology facilitated satisfactory achievement of the stated intended purposes for the Nissan Altima discontinuation assessment task and enabled application of key skills which will be relied upon in forthcoming, long-term research and critical analysis.

Initial research performed by the group pertaining to the history of the vehicle indicated that the Nissan Altima had been a successful nameplate for the manufacturer since debuting in its first incarnation in '92; achieving sales of more than 330,000 units in the 2014/15 sales year, placing it 9th in the list of total selling nameplates within the U.S. region. To provide context, the UK's top selling nameplate, the Ford Fiesta, sold a comparatively paltry 133,000 units throughout the same 2014/15 sales period. The Altima Hybrid was introduced in 2007 and saw continued production until it production was halted in the year 2012. The hybrid, which was a grid-independent (read: no plug-in), parallel variant & which employed Toyota's Hybrid Synergy architecture under license, was sold only in the sedan form and only in a limited ten states. Principle competitors of the Nissan Altima throughout the period of the hybrids production included Toyota's Camry & Honda's Accord; the 4th & 5th top selling U.S.-based nameplates respectively in '14/'15). Details for the comparable Camry hybrid are presented within Table 7, overleaf, for comparison purposes.

The architecture of the Altima Hybrid sedan is comparable to that employed by the Prius Liftback defined previously, though with differences in ICE & component sizing. Again, Toyota's Parallel Hybrid Synergy drivetrain was employed under license though in this case the supporting ICE is a comparatively much larger 2.5L four-cylinder Atkinson cycle gasoline (read: petrol) engine. In addition, both the ICE & on-board AC synchronous permanent magnet motor-generators are significantly more powerful; with peak outputs of 148kW and 105kW respectively for the ICE & AC motor-generators. The utilization of the Atkinson cycle, which features extended intake valve opening times, acts to 'lengthen' the power stroke at the expense of an increased duration of intake valve opening, which manifests as a reduced compression ratio. The resultant performance is a reduced power density in comparison to a comparable Otto Cycle engine but with benefits of significantly greater fuel burn efficiency & more power generated per unit volume of air. Specifications located online indicate that a 1.4kW Ni-MH on-board storage unit is employed within the Altima, though unfortunately estimations for the maximum achievable all-electric range are not available;

the group estimates however that a 1-2mi all-electric range, comparable to the Prius Liftback, is achievable. Notable is that the drivetrain is front-wheel drive (FWD) & is grid-independent (no plug-in variant). Regenerative braking functionality is employed & a high-efficiency planetary gearbox is deployed to facilitate power-splitting to the drive-wheels from the motor-generators & conventional ICE.

Table 7 *Comparison of the Nissan Altima & Toyota Camry Hybrids (2011 variants).*

PROPERTY	’12 NISSAN ALTIMA	’12 TOYOTA CAMRY
Chassis Classification	5-dr Sedan	5-dr Sedan
On the Road Price (£)	21,618	21,756
Achievable MPG (MPG)	41	41
Cost per MPG Ratio (£/MPG)	527.31	530.63
CO_2 Emissions (g/km)	167.1	137.9
2011-2012 Yearly Sales (thous.)	3,300	9,241
Drivetrain (FWD / RWD / 4WD)	FWD	FWD
Hybrid Architecture	Parallel HEV Grid Independent	Parallel HEV Grid Independent
ICE Displacement & Config.	2.5L 4-cyl Atkinson Cycle	2.5L 4-cyl Atkinson Cycle
ICE Peak Power (kW)	117.8	116.3
ICE Peak Torque (Nm)	219.6	211.5
ICE Drivetrain Sizing	Large	Large
Electrical Motor Power (kW)	105	105
Electric Motor Torque (Nm)	269.8	269.8
Electric Drivetrain Sizing	Medium	Medium
Battery Chemistry Employed	Ni-MH	Ni-MH
On-board Battery Storage (kWh)	1.4	1.6
All Electric Range (mi)	1-2mi (Est.)	1.6 @25MPH
Maximum Top Speed (MPH)	121	117
Achievable 0-62 MPH (sec)	8.2	7.3
Curb Mass Estimation (kg)	1442-1447	1549

With regards to the primary task at hand; the group cooperatively identified several technical & commercial justifications for the discontinuation of the Nissan Altima nameplate hybrid variant in 2012. Principally the hybrid sedan variant had experienced limited initial sales which, since variant production began in 2007, had further significantly declined. This is visible in Figure 7, overleaf, which indicates that lifetime sales of just 35,000 est. were achieved, averaging 7,000 model sales per annum; for context lifetime sales across a 5-year span accounted for close to 10% of the total nameplate sales in just the ‘14/’15 sales period. In addition to significantly declining sales, through use of a direct competitor’s technology in Toyota’s Hybrid Synergy drivetrain under license, Nissan had initially reduced their research & development costs for the Altima hybrid. However, extended use of the system in combination with declining sales meant that Nissan were, in part, funding their direct competitor’s research & development costs; indeed, reports indicated that Nissan had acknowledged this and had begun to implement proposals to enable development their subsequent hybrid powertrain “in-house”, giving credibility to the group's conclusion for this being a direct influence upon the Altima's discontinuation. Furthermore, the use of a proprietary 3rd party drivetrain would have negative implications for servicing & eventual replacement due to reliance on said 3rd party for extended manufacture & procurement. In addition, the technology within the Altima was beginning to become dated & undesirable; the cost per kWh of differing, emerging, battery chemistries, such as Li-ion, was becoming commercially viable in conjunction with improvements to general battery gravimetric density (kWh/kg) and volumetric density (kWh/L). Modernized competitors, particularly those of plug-in grid dependence, were capable of significantly greater all-electric range & performance, which was significant to consumer operating costs. Both significant redesign of the Altima and retooling of its manufacturing would be required to facilitate incorporation of more recent technical capabilities; however, significant expenses predicted to be incurred through retooling could potentially not be recouped due to the variants low, declining sales performance. This risk, in conjunction with the outlined issues resulted in Altima Hybrid discontinuation.

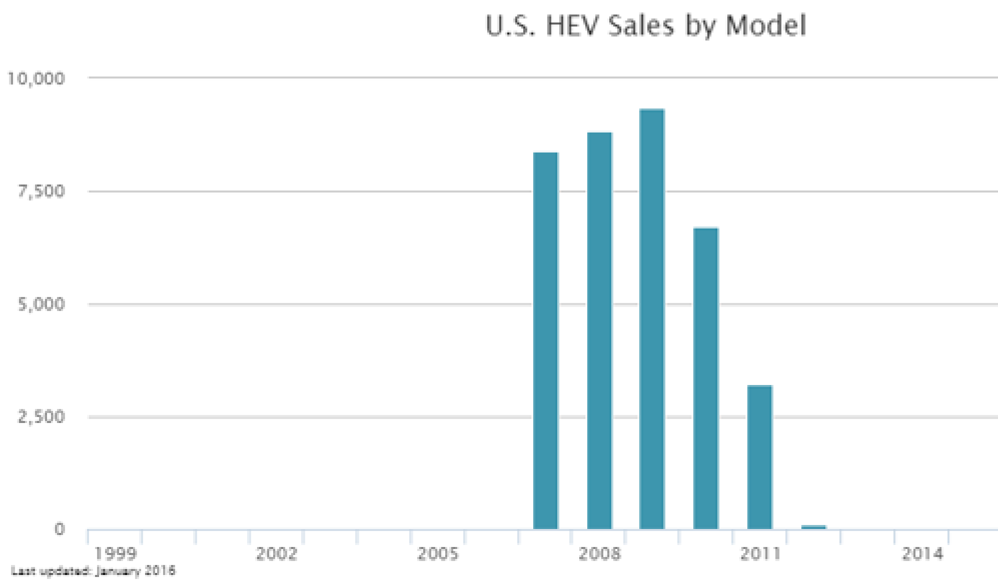


***Figure 7** Historic per annum sales of the Nissan Altima hybrid throughout production ('07-'11)* [5].

2. BARRIERS TO MASS TAKE UP & MITIGATIONS

2.1. SECTION INTRODUCTION & OVERVIEW

In order to succed and alliviate the obstacles to mass take-up, electric cars need to improve some determined features, the most important one: autonomy.

Electric cars have not had the expected market reception. However, most of the manufacturers keep on developing this kind of cars, some of them own 100% electric models in their inventory like Renault with Twizy, Fluence and Kangoo, but as it has been said before sales have not succeed. In some countries like Norway, electric cars are considered as an interesting product, in particular there is a successful rate of sales in the case of Nissan Leaf [6]. On the other hand, hybrids and the plug-in version have a better place in the market as they can reach autonomies around 40 km (it is a distance that is done by most of the drivers) [7] [8] just using the electric motor, but it is still not enough. This is why the reasons that make these vehicles not be in a good position in the market should be studied point by point:

2.2. AUTONOMY AND CHARGING

The autonomy is the main disadvantage of the electric vehicles against IC cars. In addition, these kind of vehicles have not just less available kilometres, but their “refuelling” is slow: filling an IC tank allows you to drive 600 km and it lasts 5 min, while obtaining for the battery energy that can reach 200 km needs several hours of charge. In order to solve this problem, manufacturers are investing millions of pounds on the development of new batteries that can stand in a better way quick charges and store more energy in less space (this would reduce the weight of the battery). In particular, Tesla models stick out since similar autonomies to IC cars and features that can be better. Most of the branches are focusing on quick charge systems which are able to store 80% of the total charge in 15 minutes. This is possible as the charge is not a lineal process: at the moment the battery is “empty”, the voltage between it and the charger is maximum, so the charge is fast. As it is loading, the voltage difference decreases and this makes the charge going slower than before. Theoretically, charging a battery to its full capacity (100%) would take an infinite time [6]. Another option is the idea of exchangeable batteries: replacing a discharge battery by a full charge one.

Studies show that most of the drivers do around 40-60 km per day, so current electric cars can satisfy customers demand in autonomy terms (Section 4.2.), the problem comes when customers want to do long trips. People still think that they need a car with a huge autonomy although they made “short distances” most of the days. What is more, families use to have two cars: one for short distances and other that can be used for long trips. The short distance car can be substituted by an electric one. Nevertheless, this fact is not done because of other issues that must be taken into account.

2.3. THE COST OF OWNERSHIP

The second problem is its price. It makes customers look to other options and avoid electric cars. This is a big problem as they are expensive because they are produced in small amounts and the idea of mass production is difficult to have if the product is not as wanted as it should be. In other to solve this, they are benefited with tax deductions, but this is still not enough. In the case of Spain, the Government tried to push the market of electric and hybrid cars with Plan MOVELE and MOVEA. Plan MOVELE, whose aim was to help customers in an economic way in other to motivate them to buy an electric vehicle, was a grant that finished in 2015. This grant participated with 7 million of euros. The support depended in the electric autonomy of each vehicle. 2700 euros were assigned to vehicles with 15-40 km of autonomy, 3700 euros to the ones with 41-90 km and 5500 euros to cars that overcome 90 km. In addition, 1000 euros were given for each sold car, so that customers could install recharge points. On the other hand, cars that exceeded 40000 euros were not helped [9]. In the case of the recent Plan MOVEA, the amount of money that is delivered depending on the autonomy is the same as for the MOVELE. However, the total money that is going to take part in the project is 16.6 million of euros, but another important fact is that to let a car have this grant its maximum price has to be 32000 euros. In addition, public charge stations are supported with 2000 euros for the semi quick ones (they supply between 15-40 kw) and 15000 for the quickest ones (40 kw or more) [10]. In the case of UK, the Government Plug-in Car grant for electric and plug-in hybrids help customers with a maximum amount of 4500 pounds depending on the category they are. Category one is assigned to cars that emit less than 50 g/km of CO_2, 70 miles of autonomy between charges and their batteries need to have a warranty for their batteries of 60000 miles or three years. Here the grant is up to 4500 pounds. In this category, some of the cars can be listed:

- BMW i3
- Citroen CZero
- Ford Focus Electric
- Hyundai Ioniq
- Kia Soul EV
- Mercedes B-Class Electric Drive
- Mitsubishi iMiEV
- Nissan Leaf
- Peugeot iON
- Renault Zoe
- Smart ForTwo Electric Drive
- Tesla Model S
- Tesla Model X
- Toyota Mirai
- Volkswagen e-Up
- Volkswagen e-Golf

Category two corresponds to cars that emit no more than 50 g/km of CO_2 with an electric autonomy between 10 and 69 miles. Here the grant is up to 2500 pounds. Some benefited cars are:

- Audi A3 e-tron
- BMW 225xe Active Tourer
- BMW 330e
- Kia Optima PHEV
- Mercedes C350e
- Mercedes E350e SE (with 17-inch alloy wheels only)
- Mitsubishi Outlander PHEV
- Toyota Prius Plug-in
- Volkswagen Golf GTE
- Volkswagen Passat GTE
- Volvo V60 D5 and D6 Twin Engine
- Volvo XC90 T8 Twin Engine

Category three is for cars that emit between 50 and 70 g/km of CO_2 and can travel 20 miles in pure-electric mode. These has got a grant up to 2500 pound like in the previous case. The only car that has been settled in this category is the Mercedes E350e. Unfortunately, all these UK grants cannot be applied to cars with a value that exceeds 60000 pounds [11].

Another important fact is that the success or failure of these cars depends on the battery. It has to be durable, reliable, quick to charge and economic. The industry of batteries can participate in one of the most important battles of the automotive sector, since the company or group of researchers that can find the best way to make more efficient the mass production of batteries can get cheaper electric cars and this can be a terrific impact for the business. That is why the government and companies have the priority of investing for the development and the innovation of the electric batteries [12].

In the particular case of Tesla, the prices were too high with its 109000 US dollars Roadster model. However, it was a high-end sport car that helped people to change their minds about the performances that electric cars could achieve as it was able to accelerate from 0 to 60 mph in less tan four seconds, which was faster than a Ferrari Testarossa and in the same range as more recent Ferrari models. In addition, it had a range of 250 miles. Nowadays, Tesla is about to launch its last version called Model 3. It is going to be mass produced in order to have lower prices that can be more affordable, 35000 dollars each car with an autonomy of 340 kilometres. This can be done thanks to the Tesla's Gigafactory that is being developed in USA [13].

Another branch that wants to have more presence and reduce its prices with a mass production is Toyota. It seems that the company is developing electric cars with autonomies that can easily reach 300 km for 2020. Their main markets would be placed in Japan, China and California, since there the use of electric cars has been encouraged. What is more, from 2018, California and other States of North America will demand manufacturers for more percentage of electric and hybrid cars and Toyota does not want to miss the chance in this markets. The aim of Toyota is having just "Zero Emissions" cars by 2050 [14].

2.4. THE DESIGN OF HEV & EVS

Electric batteries weighs too much. This means that there has to be an important effort to counter this weight and reduce the rolling resistance. To this end, the car is going to be incorporated with light materials, but in some cases there are a lot of plastics in the inner part of the car that removes the appealing of the vehicle in terms of aesthetic. What is more, their tyres are narrow as in this way they work perfectly having a great efficiency, but these tyres does not make the car well looking [6].

2.5. INFRASTRUCTURE DEVELOPMENTS

Another factor that is an obstacle for the mass take up is the shortage of charging stations. It would be easier to have more presence of electric cars in the roads if houses and companies with facilities to charge electric vehicles and charging battery stations placed along the road (like petrol stations) increased. The latter issues were being resolved, as many companies and public entities started offering both private and public charging stations. However, this is again difficult to achieve as the low amount of electric cars makes this project advance slowly. Solving this is not so crucial as customers used to leave their houses with fully charged batteries and as it has been said before the autonomy is enough, so the spread of public charging points is not so vital. In addition, as previously reported, in the case of house charging stations, grants help customers to set up their own facility [6].

2.6. ESTIMATED ENVIRONEMNTAL IMPACT

It is thought that electric cars are going to be a good substitute of IC cars because they are clean and environmental friendly. It is truth that during the period of drive the vehicle does not produce toxic gases, but the electricity is obtained in plants that work with coal which is most dangerous than petrol. In other words if the electricity is not produced by clean procedures as in a hydraulic plant, electric cars will not solve the problem of global warming, they will just relieve toxic gases from big cities [6].

However, if there were a massive deployment of electric cars, the growth of electricity would just be 2% of the total as maximum in a period of at least 10 years. This increase in the demand can be delivered without raising the production: most of the charges are going to be hold during night and this means the optimization of the renewable energy because off-peak hours are going to be exploited. What is more, as it has been said in electric cars are going to be used as energy stores and this can also help to satisfy demand peaks without increasing the production [15].

2.7. OVERVIEW OF THE AVAILABILITY OF OIL & FOSSIL FUELS

Another important fact that could be decisive for the mass take up of electric cars and should be taken into account is that cheap petrol (less than 100p/litre) will not appear again for sure [16].

The electricity required to travel 100 km costs 1.5 euros, while for the case of IC cars it is going to take 5-6 euros. Nobody will bet the reduction of the price as the statistics expect an increase in the demand of petrol in emerging countries that are developing quickly. What is more, nowadays there are approximately 800 million cars around the world and in 2050 there will be 2000 million. In 2010, just in China, the automotive market grew up almost 4 million of cars (that was the amount of sold cars in Germany in the same year) overcoming the sales in USA. More countries like Russia, Brazil and Mexico are going to face this situation. Another problem is that there will not be enough petrol for everybody as the demand is increasing constantly (in more rate than expected because of emerging countries) and sources of oil are becoming depleted. What is more, the use of oil for cars has to be stopped as soon as possible since it is needed to make plastics and medicines. In addition, the air transport´s technology change is going to be slower than the road one, so petrol has to be reserved for aeroplanes.

The growth of the emerging countries means more emissions that the planet will not be able to stand. The development of current technologies based on petrol will allow an improvement in other to reduce 50% the consumption and emissions in the next 10-15 years. After that investment will not have sense because they would just contribute to minimum improvements [15].

It is important to know what people think about electric vehicles in other to get a knowledge of what the main problems customers can probably find to avoid buying them are and thus making difficult to achieve a mass take up of HEV and EV. To this end, a statistical release of the Department for Transport has been taken into account as it looks for people's attitudes towards these kind of technology [17]. As it can be seen from the really beginning of this report (figure 8) just a 5% of respondents was thinking about buying an electric vehicle (red box) while the 16% thinks that it is too soon to get this technology (blue box).

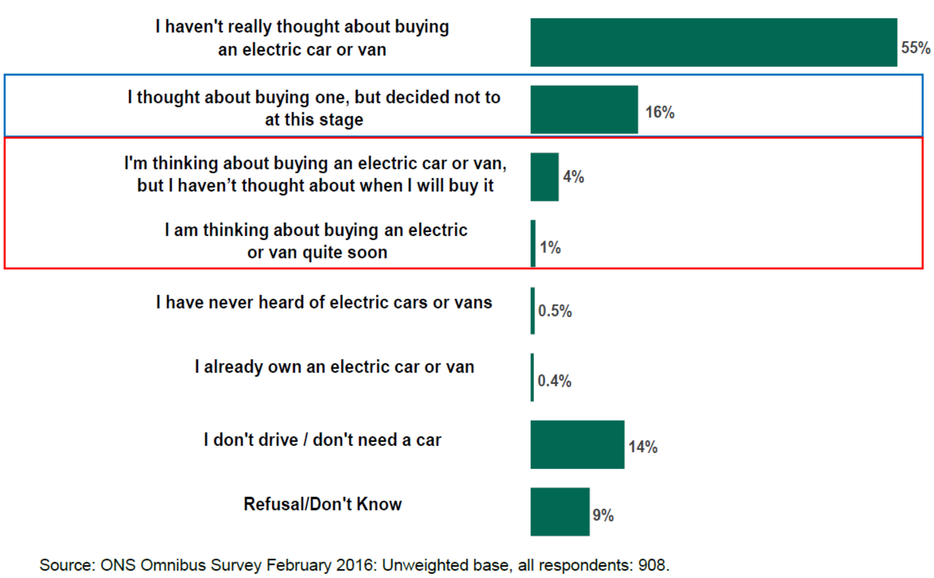


Figure 8. Attitudes to electric cars and vans, all respondents.

Another important fact that has been studied is the importance of the introduction of grants by the government to push these king of vehicles in the market. As it can be seen in figure 9 31% of licence holders think that grants are important (orange box), while a surprising 33% was not aware of their existence (blue-grey box).

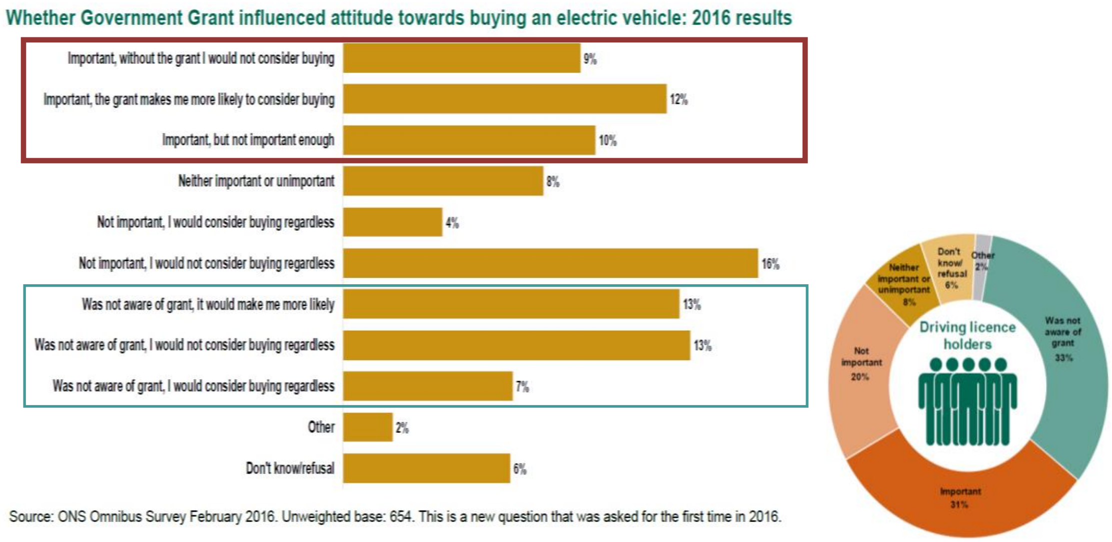


Figure 9. Government Grant influenced attitude of licence holders.

As it has been said at the really beginning of this task, the main factors that influence customers to put them off buying these cars are the time that is needed in the recharge which seems to be quite annoying with a 45% of rate in the survey, the autonomy with a 39% and the cost with a 28%. Again the lack of knowledge affects their position in the market as it is rated with a 13% in the left graph of the image x. On the right graph of the same image, it is shown that it is vital to solve the first problems because cost, autonomy and a good recharge are rated with 32%, 19% and 19% respectively in terms of factors that would encourage people to buy an electric car. Another surprising fact is that 27% of licence drivers think that nothing would make them buy an electric car.

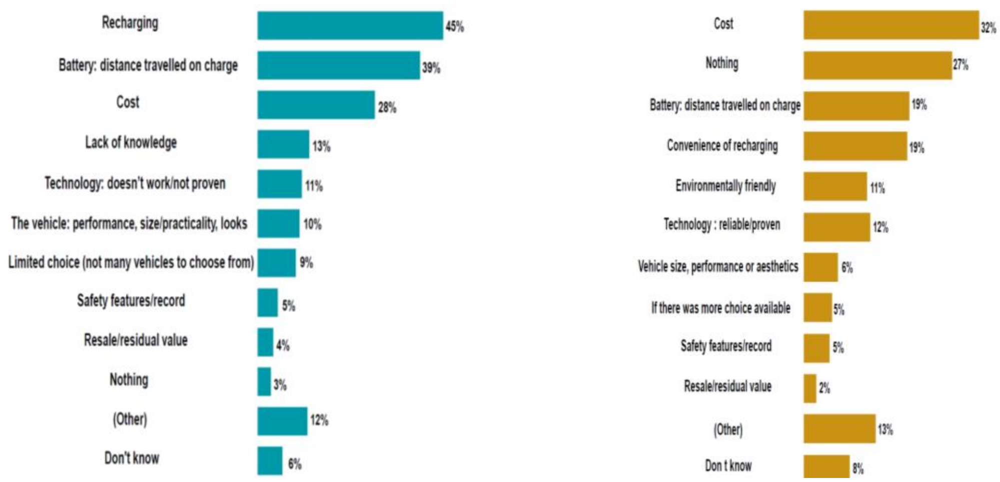


Figure 10. Factors deterring people from buy an electrical car vs factors that would encourage people to buy an electronic car. Up to 3 responses coded from each respondent hence total will add up to more than 100%.

Finally, a survey about factors that are considered important when buying a car (figure 11) showed that 50% of the people prefer low CO2 emission vehicles as the main feature. In addition, 6% wanted their car to be electric.

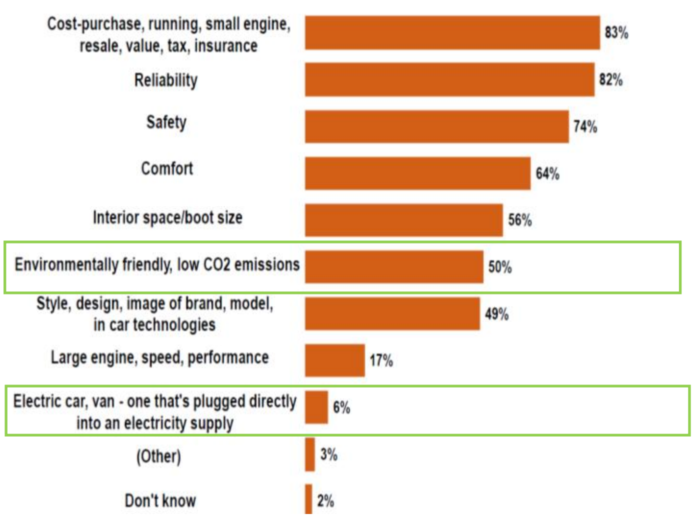


Figure 11. Factors considered important when buying a car or a van, driving licence holders. Up to 3 responses coded from each respondent hence total will add up to more than 100%.

3. STATE OF THE MARKET UK

3.1. PURPOSE

In order to understand the growth of alternatively fuelled vehicle market it is important gain insight into the market trends regarding the registration of new electric and hybrid vehicles. With this in mind analysis was carried out into the sales figures of the varying types of electric and hybrid vehicles in the UK from 2010 to the present day by utilising and condensing information from The Society of Motor Manufacturers & Traders (SMMT)

In the last 3 years, the UK market has witnessed considerable growth in the EV segment, with registrations of electric vehicles surging upward this year to twenty-five times that of 2013. [18] This surge in market growth is the result of numerous factors, of which the most important are: mass expansion of electric options in the ranges of worldwide car manufacturers and increasingly favourable public perception toward reduced emissions.

Employing figures obtained from the SMMT Figure 12, illustrates the growth of vehicle registrations defined segments of the ULEV market:

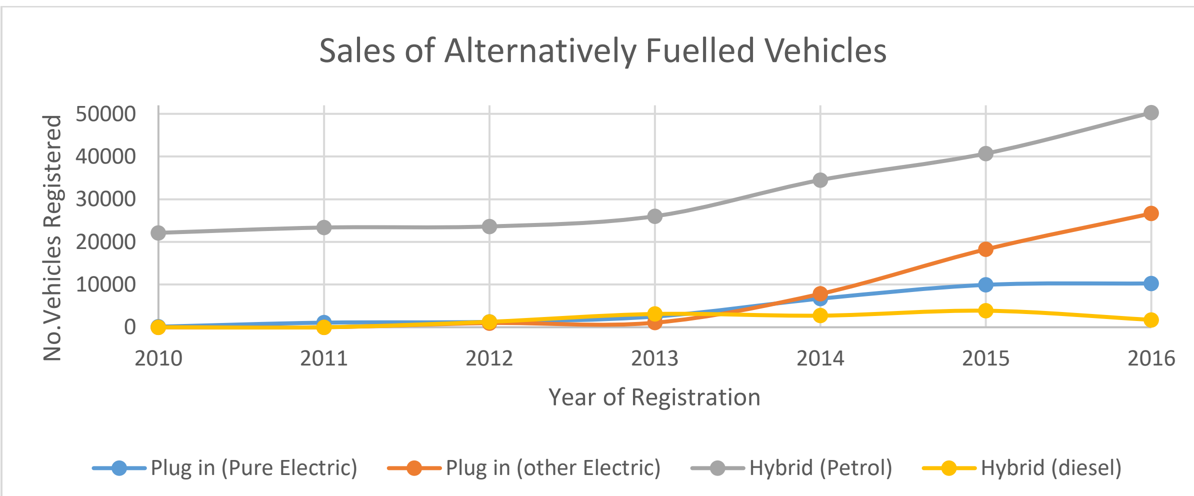


Figure 12- *Sales of Alternatively Fuelled Vehicles in the UK (2010-present)*

Considering Figure 12 it is clear that the variance of ULEV being sold in the highest volumes are those hybrid vehicles constituted of both electric and petrol powertrains. One can elucidate this trend further when considerations are made regarding the increased size of this segment, resultant of the vast majority of vehicle manufacturers offering hybrid electric versions of their more traditional internal combustion powered units. The European governmental bodies have put in place regulation which demands that all new vehicles emit no more than 130g/kg of carbon dioxide by 2020, with further legislation reducing this to just 95g/Kg by 2030. [19] This ever more restrictive legislation challenges manufacturers to innovate in the production of vehicles which are not only efficient, but also maintain the performance and reliability expected of any modern vehicle.

3.1.1. DIESEL HYBRID

Notably from Figure 12, it is clear that the sales of diesel-electric hybrid vehicles has decreased. This trend is unexpected when considering the general view that diesel engines are more efficient, producing better miles per gallon figures than their counterparts. The weak sales figures of diesel-electric vehicles are explicated when considering the following most pertinent points:

3.1.2. COST

Diesel engines on average cost 15% more to manufacture than their petrol powered equivalent. [20] When this excess is combined with the high cost of high voltage batteries, electric motors and auxiliary electronics the overall cost of the powertrain is considerably more than the alternative petrol combination and this in turn increases the sale price of the vehicle. For example the Mercedes E class Bluetec diesel hybrid costs £1000 more than its petrol-hybrid sister, even though it produces 81 horsepower less and average miles per gallon is almost half at 67.3MPG [21] compared to the petrol hybrid's 134MPG. [22]

3.1.3. TORQUE CURVES

The majority of modern petrol-electric hybrid vehicles employ variable valve timing technology so that the engine, instead of the more traditional Otto cycle, runs off the far more efficient Atkinson cycle. While this grants improvement to the maximum power levels and efficiency that can be developed, losses occur in the torque generated at low RPM. These features are perfectly complimentary to the hybrid electrical system, which makes up for the torque lost on the low end of the RPM range. Diesel engines however produce the majority of their torque at low RPM and therefore any additional low end torque would be extraneous. As well as this point the diesel engine would require broad gearing ratio's to certify engine efficiency at high speed. [20]

3.1.4. EMISSIONS

Although diesel engines produce favourable figures in terms of high MPG, the volume of carbon dioxide produced by the motor remains more than that of a gasoline equivalent. [23] Diesel engines have a propensity for the production of toxic nitrogen oxides which are severely toxic pollutants. The International Council on Clean Transportation (ICCT) conducted a study in Germany and Finland which showed that heavy duty vehicles such as Lorries and busses emitted 210mg NOx per kilometre of distance driven, compared to 500mg/Km produced by modern diesel cars. NOx pollution is responsible for thousands of deaths in Europe every year. [24]

3.1.5. PUBLIC PERCEPTION

Diesel power units have been under a huge amount of scrutiny since it was uncovered that the Volkswagen group had devised a method by which it misrepresented the respective emissions levels produced by its diesel powered variants. [25] Since the scandal was publicised, the public perception of diesels has become considerably worsened. Plans have also been made clear from local governments in 3 major European cities to introduce a complete ban of diesel vehicles by 2030.

3.2. ULEV REGISTRATIONS UK

Registration of vehicles in the UK generally takes place in March and September as these are the dates at which the latest registration plates are distributed. Figures from the SMMT indicate that in the initial registration period of 2014 around 500 cars per month were introduced. More recently in the same period of 2016 that figure reached almost 3000 units per month, figures from the last two years are illustrated in Figure 13

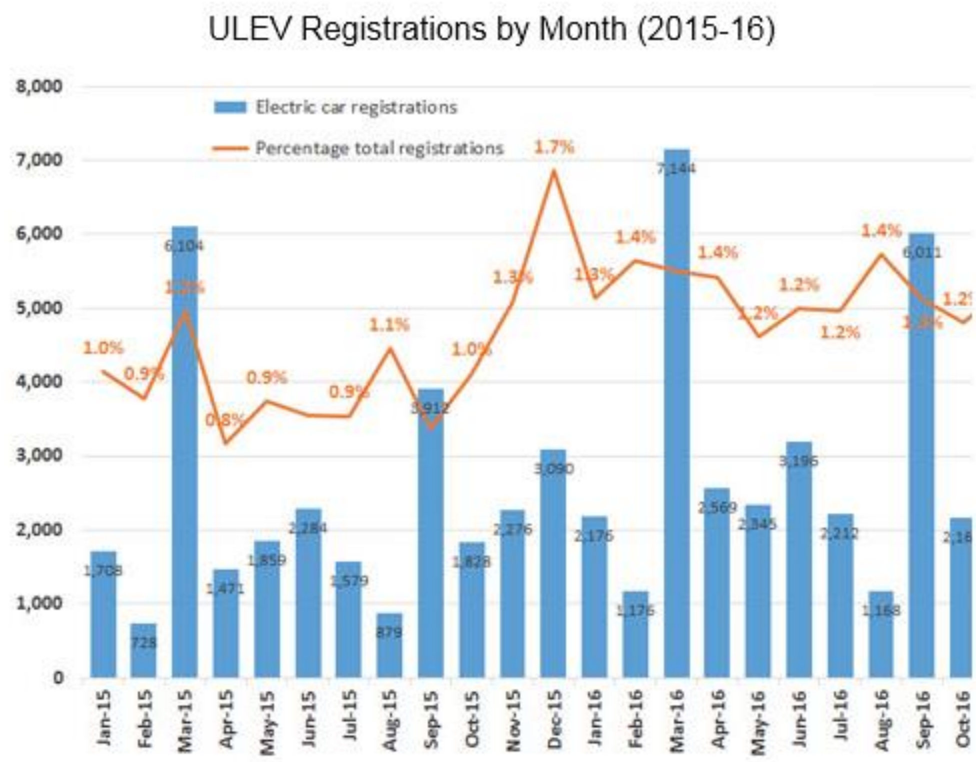


***Figure 13**- ULEV Vehicle registrations per month with total market percentage*

While there is clearly massive growth within the ULEV segment in the UK, one must remain aware that even in 2016, the percentage of electric vehicles sold with respect to the total vehicle market is a mere 1.3% and in the third quarter of 2016 growth was down slightly to 30%, this lull however is predicted to end as Mitsubishi launch the redesigned version of its bestselling Outlander PHEV which will be discussed further in the remainder of the report.

3.3 BUSINESS MARKET UK

Government incentives have propagated the rapid take-up of ULEV's in the business and van sector by offering a 20% reduction in vehicle cost (up to a max of £8000) [26]. This incentive combined with favourable running costs (156 MPG) has seen ULEV's for business use, dominate the UK market, propagating Mitsubishi's PHEV Outlander become the number one selling ULEV in the UK for two years running, with more than 20,000 units sold from 2014 to 2016.

Category	CO2 emissions	Zero emission range	Grant	Maximum grant
1	Under 50g/km	At least 70 miles	35% of cost	£4,500
2	Under 50g/km	10 to 69 miles	35% of cost	£2,500
3	50 to 75g/km	At least 20 miles	35% of cost	£2,500
Motorbikes	0g/km	At least 31 miles	20% of cost	£1,500
Mopeds	0g/km	At least 19 miles	20% of cost	£1,500
Vans	Under 75g/km	At least 10 miles	20% of cost	£8,000

***Figure 14**- UK Government Subsidy Scheme* [27]

As of October 2016, the UK government pledged an additional 4 million pounds to the UK plug-in van grant scheme, which further extends scheme eligibility to larger commercial vehicles. The aim of this extended grant is to improve the local air quality of cities and towns across the UK by promoting grants of up to £20,000 for electric trucks surpassing 3.5 tonnes in weight since these vehicles spend more than 96% of their time in city and town centres. [27]

3.4. GLOBAL MARKET

The plug-in vehicle market has seen a 42% growth between 2015 and 2016, with 773,600 units sold worldwide. [28] This figure is inclusive of all global sales of both passenger vehicles and light commercial vehicles. The global market for light vehicles grew by 2% reaching a total of 90 million units sold. [29] While the sales of ULEV's grew at a rate 20 times faster than that of the traditional ICE powered vehicles, the market share granted globally was still a paltry 0.86%. Plug-in vehicle sales surpassed 2million by the end of 2016 with 61% accounted for by pure electric vehicles, in no small part due to the push of sales in the Chinese market and the remaining 31% accounted for by vehicles with a hybrid powertrain. [30]

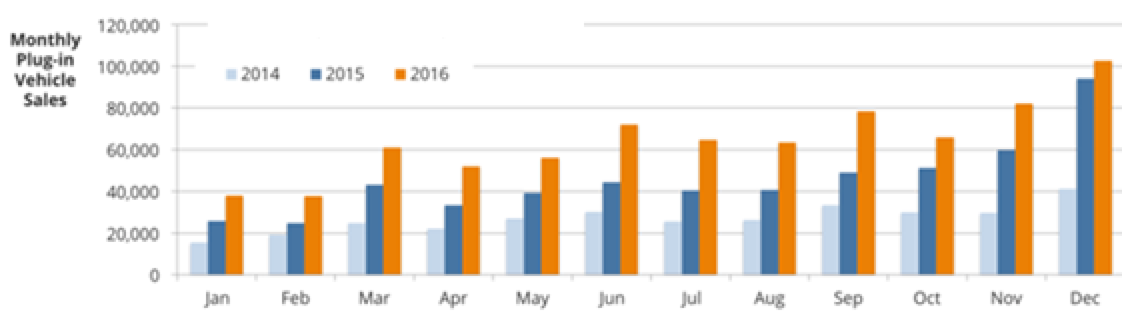


***Figure 15**- Worldwide Sales of Plug in Vehicles* [31]

December of 2016 recorded the highest ever volume of monthly sales of electric vehicles according to independent sales database EV Volumes. China in particular has demonstrated a large amount of growth as the government has taken the initiative to develop a manufacturing base for what they refer to as "New energy vehicles" [31] this plan has resulted in China representing a massive 45% of the global electric vehicle market, which is a 10% improvement upon the figures from 2015. [31] Figure 16 demonstrates the percentage growth of plug-in sales worldwide.

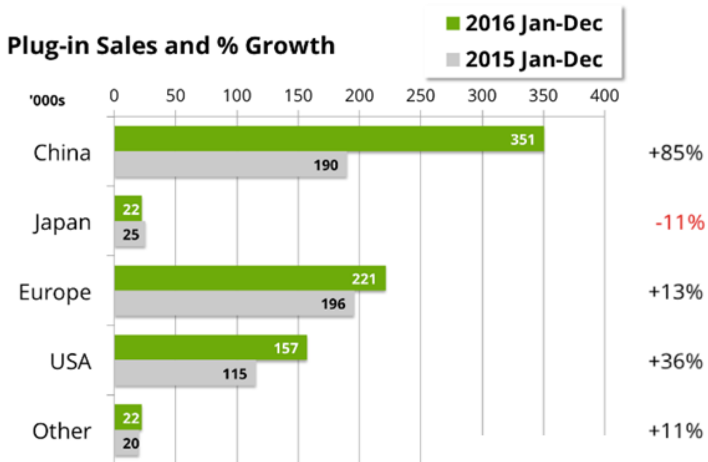


***Figure 16**- Regional Sales of plug-in vehicles globally* [31]

3.5. CHINA PROPAGATING GROWTH

From Figure 16 one can determine that the largest growth of plug-in electric vehicle sales in 2016 occurred in China, with an 85% increase compared to the previous year. EV Volume figures demonstrate over 350, 000 "New Energy Vehicles" sold in the passenger car segment as well as a further 160,000 commercial vehicle sales which include both vehicles for business use as well as fully electric busses. [31] This trending growth is a direct result of debilitating traffic congestion and smog levels within major Chinese cities, instigating the government to develop policies with the aim to increase the Chinese electric vehicle market share to 10% of total automotive sales by 2020.

3.6. TYPES OF ULEV

Insight into the different types of vehicles being sold is key to understanding consumers and aids the process of defining a vehicle design. From assessment of UK data it was deduced that the ULEV being sold in the highest volumes is the Mitsubishi Outlander PHEV with over 23,000 units sold in just 3 years. As demonstrated in previous text the success of the Mitsubishi can be attributed to its versatility as a commercial vehicle and inherent savings in running and buying costs associated earning the vehicle 47% of the total ULEV UK market. The Nissan Leaf is the second most popular ULEV on sale in the UK, displaying marked differences from its main commercial competitor. Nissan's Leaf is a small hatchback which runs purely on electricity. While not sold in the same volume as the Mitsubishi, the Nissan still holds an authoritative 24% of the total UK market with over 14,000 units sold, placing it far ahead of the next bets competitor, the BMW i3.

Plug-in hybrid vehicles are quickly taking over the UK market due to great increases in the electrified model range of many manufacturers. 63% of all ULEV purchases were for the hybrid variant, leading to an unexpected 4th place ULEV, the Mercedes-Benz C350e, with almost 5000 units sold in just a year and a half. Figure 17 indicates the most popular electrified vehicles being sold today.

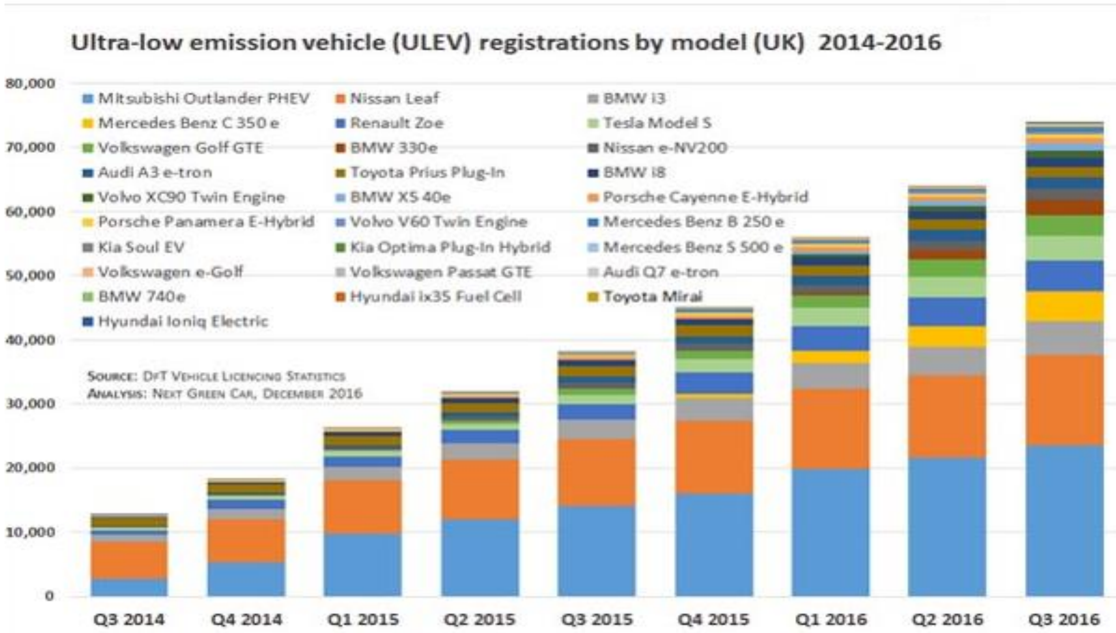


Figure 17: *UK ULEV registrations by model 2014-16*

To help contextualise the growth of the UK market one must consider the variety of segments filled by currently available ULEV models. Compared with 2011, in which there was a mere 4 body styles available with electrified powertrains (city/small family cars, small vans and sports cars) there are now over ten variants of vehicle which can be purchased, encompassing everything from high end executive cruisers to 4x4's and estate cars. This diversification of model variant and respective body type has played a key part in instigating market growth as consumers.

3.7. A SUMMARY OF INVESTMENT FROM MANUFACTURERS

3.7.1. PURPOSE

With the exception of mass innovators, Tesla, the largest vehicle manufacturers worldwide have been relatively slow to make the change from traditional gasoline powered vehicles to electric. However with mass public interest the demand for greener alternatives has grown substantially in the last decade, prompting manufacturers to invest in the technology. As such here is an outline of some of the largest vehicle manufacturers in the world and their respective investment into electric vehicle technology.

3.7.2 TESLA

The, relatively young, electric car company Tesla, led by entrepreneur Elon Musk, is currently the market in electric vehicles, promoting innovation in the segment and prompting larger vehicle manufacturers to follow suit. 'The Gigafactory' Tesla's new base of operations has not been fully completed. However the cost of construction has been estimated 5 billion US dollars. This far surpasses any of the competition with regard to scale of investment and the scale of the factory itself, which is the largest of its kind in the world. The factory is purpose built to produce 500,000 vehicles per year when operating at full capacity. The inherent economies of scale involved result in Tesla products which are more affordable than could be otherwise possible, finally resulting in a growing uptake of alternatively fuelled vehicles in the personal transport segment. [32]

3.7.3. DAIMLER/MERCEDES

Daimler/Mercedes-Benz has introduced plans to invest 11 billion euros into vehicle and battery technology, shifting a large portion of company focus into the electric vehicle industry. [33] Up to this point Mercedes have only offered electrified versions of their traditionally powered vehicle range with models such as the C-Class, however chief executive Dieter Zetsche has now marked plans to "launch an electric product offensive that will cover all vehicle segments, from the compact to the luxury class." [34] The electric offshoot of Mercedes has been branded EQ which will greatly increase the brand visibility in creating only electric vehicles of a standard to compete more directly with current market leader Tesla, of which the Daimler group was an early investor. This EQ is a massive leap for Mercedes, leading to predictions of 25% of total Mercedes deliveries accounted for by electric vehicles.

3.7.4. BMW

In 2011 BMW created it's 'i' sub brand with the sole intent of producing plug in electric vehicles. The BMW i3 resultant from this offshoot has grown to become one of the top selling electric vehicles after being introduced to the market in 2013 with over 10,000 units sold in the UK alone.

BMW are further innovating by using the old batteries from their 'i' vehicles to create energy storage solutions in line with competitor Tesla's power-wall. In combination with Bosch, BMW have created a new energy storage facility in Hamburg, which utilises over 2500 battery modules from electric vehicles to create a facility with an electrical storage capacity of 2.8MW/h and deliverable power capacity of 2MW. [35]

BMW I Ventures, a shoot off from the sustainable vehicle manufacturing plant has also increased its investment fund to 500 million euros to aid in the development of automotive start-ups [36] Suggesting potential plans for BMW to expand their electrified range with a wealth of new technology in the near future.

3.7.5 NISSAN

After an initial investment of 420 million pounds into Nissan UK's Sunderland plant, the company has pledged to invest a further 26.5 million into a UK battery production facility. [37] Plans from the company to continually reinvest in electric vehicle technology pose exciting prospects while the company has also indicated plans to release 4 variations of autonomous vehicle to be released before 2025.

3.8. HEV TECHNOLOGY ASSESSMENT

3.8.1. PURPOSE

There are a wide variety of electrified powertrain systems available to be implemented in road going vehicles. This section will provide a summary of these variations whilst addressing the manners in which each respective system is applied.

3.8.2. HEV VARIANT DEFINITIONS

HEV powertrains are separated into a set of 4 categories whereby the sizing of both ICE and electric powertrains is defined by addressing respective 0-60 acceleration capabilities (Z60) as well as gradeability whereby the power units are sized in terms of their ability move a vehicle forward when on a gradient. (Reference and include further detail)

3.8.3. PARALLEL GRID-INDEPENDENT FULL HYBRID (FHEV)

In this case the internal combustion engine is sized purely for a specific, constant gradeability upon which specifications are made by the vehicle manufacturer. In combination with this, the electrical powertrain constituted of battery, motor and necessitated auxiliary components is sized to meet a prerequisite Z60, again defined by the manufacturer to meet the performance goals set for each respective vehicle. The battery in this variant is charged directly via the internal combustion unit in combination with a regenerative braking system.

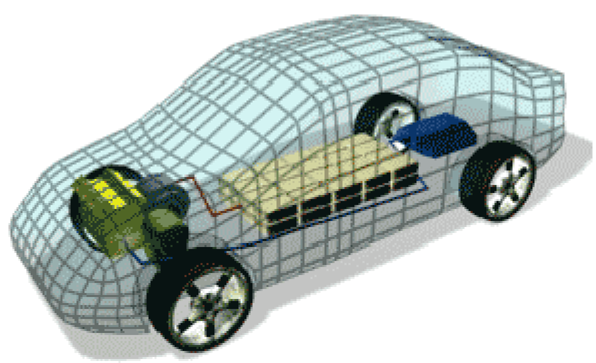


Figure 18- *Parallel Grid Independent plug-in Hybrid Illustration* [38]

3.8.4. PARALLEL GRID INDEPENDENT MILD HYBRID

Mild hybrids generally combine an internal combustion unit with an electric motor/generator mounted in parallel. This provides the power unit with greater overall efficiency due to the deletion of both the starter motor and alternator while simultaneously increasing overall power as the electric motor delivers extra torque to the conventional engine under acceleration. The powertrains in mild hybrid vehicles are therefore sized to minimise Z60 time, and require less substantial motors and batteries, resulting in lower overall weight. A good example of this is the Ferrari LaFerrari. There are however drawbacks to the system in that it does not allow the vehicle to travel on electrical power alone and the increases in fuel efficiency are nominal when compared to other electrified powertrain variances.

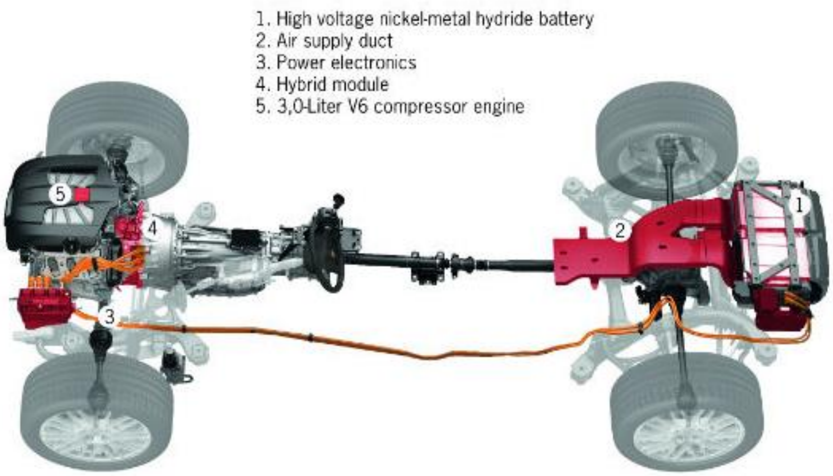


Figure 19- *Parallel Grid Independent Mild Hybrid Illustration* [39]

3.8.5. SERIES GRID INDEPENDENT

Also referred to as extended range electric vehicles this hybrid variant has no direct connection between the internal combustion unit and wheels. Instead the powertrain is replaced with an electric motor from which all drive is derived. In this case both the engine and motor are sized for gradeability in that the motors must be of a suitable size to move the vehicle on a predefined gradient while the internal combustion unit is required to provide enough energy to meet the requirements without placing demand on the battery. Since the electric motor provides sole drive to the wheels it must simultaneously be sized to deliver the desired acceleration specifications predefined by the manufacturer. Since power to the motors can be derived from the ICE, batteries need not be as large with specific sizing focussed more upon boosting acceleration than increased range capability.

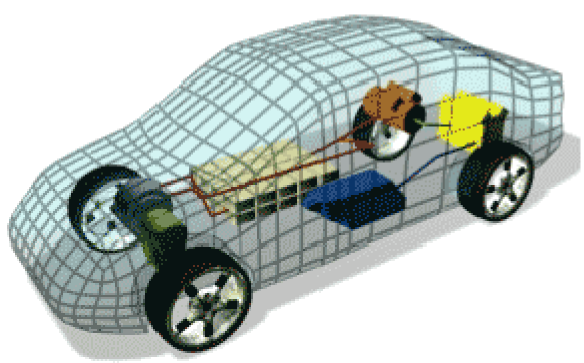


Figure 20- *Series Grid Independent plug-in Hybrid Illustration* [38]

3.8.6. PARALLEL AND SERIES GRID-DEPENDANT HYBRID

These variants are also known as plug-in hybrid systems. Both have the capability of full electric operation and therefore both batteries and motor are sized appropriately. The ICE in both cases is sized for gradeability. For the parallel variant the engine must produce enough power to drive the vehicle up a pre-defined gradient and as above in the series variant the engine must be able to produce enough power to supply the motors under the same circumstances.

3.8.7.HEV TRADE-OFFS

Resultant of the inherent inefficiency of an internal combustion unit during slow, sporadic driving cycles, the largest gain in fuel economy pertaining to hybrid vehicles occurs when driving in the city.

Contributory factors include but are not limited to:

1) Energy losses when braking
2) Energy losses when vehicle is at idle
3) Thermodynamic inefficiencies at low driving speeds.

3.8.8. PARALLEL VS SERIES

As current technology stands, parallel HEV powertrains are more efficient than their series counterparts as the losses from converting mechanical energy to electric and back are minimised.

In terms of production cost, parallel powertrains also have an advantage in that they require smaller electric motors and batteries. However overall, hybrid electric vehicles incur higher lifecycle costs than traditional ICE vehicles due to the added expense of the relatively young electric drivetrain technology. Plug-in variants have the intrinsic benefit of being able to function as part time fully electric vehicles and top up electrical range from the grid which therefore reduces ICE carbon emissions and is beneficial to air quality.

3.9. ENGINE VARIANCES

3.9.1. PURPOSE

To guide the selection of the most pragmatic engine type to be utilised it was necessary research the respective advantages and disadvantages of each engine variance respectively. Utilising this information the group could then make an informed decision regarding the architecture with which to advance.

3.9.2. INLINE 4

Figure 21- *Inline 4 engine illustration* [40]

3.9.2.1. ADVANTAGES

The inline 4 is one of the simplest engine configurations in terms of componentry. It has the innate benefits of having only one bank of cylinders which in turn require a single valve-train and cylinder head which in turn allows more efficient and less expensive mass production, whilst also allowing easy access into the engine for any repairs, modifications or maintenance.

The engine is compact, allowing fitment in almost any engine bay whilst simultaneously saving weight, a key factor in modern vehicle performance. The singular head infers less moving parts than a configuration with more than one bank of cylinders which in turn reduces dynamic complexity, helping to conserve energy and reducing the likelihood of malfunction synonymous with more complex power units. Primary forces due to the movement of cylinders are innately balanced as the proximal and distal cylinders fire opposite the two centre cylinders.

3.9.2.2. DISADVANTAGES

While the primary forces within the engine are innately balanced the secondary forces are not causing large vibrations in configurations with large displacements unless balancing shafts are installed. Similarly due to their upright characteristics with the cylinder bank vertically adjacent to the cylinders, the engine has a high centre of gravity and lacks the rigidity of its V-shaped cousins.

3.9.3. HORIZONTALLY OPPOSED (BOXER)

Figure 22*: Subaru Boxer engine* [41]

3.9.3.1. ADVANTAGES

Resultant of the opposed nature of the cylinders, both the primary and secondary forces are well balanced, promoting a smooth power delivery. As there is no need to add weight to balance the crankshaft, less power is lost to rotational inertia than that of vertical displacing cylinders. The centre of gravity incurred by the power-plant also sits much lower than that of conventional set ups, promoting improved handling in the vehicle.

3.9.3.2. DISADVANTAGES

As can be seen in Figure 22 the opposed cylinders make the boxer engine very wide when compared to its upright counterpart which can incur packaging difficulties within an engine bay and by extension makes servicing and maintenance more challenging.

There is inherent complexity in this engine as it requires two set of valve trains and cylinder heads and therefore development costs associated are higher than that of an upright engine.

3.9.4. V- CONFIGURATION

Figure 23- *V6 engine illustration* [42]

3.9.4.1. ADVANTAGES

Commonly used with displacements larger than those associated with inline engines, the V-configuration has the benefit of being compact and powerful. The compact geometry is also very rigid, allowing it to be installed as a vehicle stressed member (such as in formula 1) saving weight.

3.9.4.2. DISADVANTAGES

Similar to that of the boxer engine, V-configurations have two valve-trains and cylinder heads which makes them more complex than a straight line set-up simultaneously incurring higher manufacturing costs and extra weight. The larger number of moving parts also creates higher levels of internal friction and rotational inertia. Further weight is incurred when one considers that two exhaust manifolds are necessary as well as balancing of secondary forces on the crankshaft.

3.9.5. GAS TURBINE

Figure 24- *Gas turbine powered Indy Car* [43]

3.9.5.1. PRO'S

When considering a gas turbine to power a road going vehicle there are many attributes to take into consideration, the first of which is the high levels of efficiency intrinsic to the system. Gas turbines are highly efficient as they create power using the Brayton Cycle [44] whereby work is done by a combination of adiabatic and isobaric processes. This cycle produces efficiencies as high as 60% which by extension would result in high returns in terms of energy output compared to the volume of fuel being used. Gas turbines also have the innate benefits of simplicity. With very few moving parts, the chances of malfunction tend to be low.

3.9.5.2 CON'S

Servicing and maintenance of gas turbines is a time consuming and costly process [45] when compared to that of an internal combustion engine or electric motor, which are for all intents and purposes maintenance free.

Another major issue for gas turbines is particulate dirt and debris on the road, which would be sucked into the intake causing wear and tear of internal components or in some cases may even result in catastrophic failure of the power unit, unless an advanced air filtration system is installed, which could be both costly and complex.

The exhaust temperatures produces by a gas turbines are capable of reaching near 1000 degrees Celsius. On the road these extreme temperatures would melt body parts of any nearby vehicles and also pose a significant health and safety hazard to pedestrians.

For these reasons as well as infinitely more, the gas turbine does not meet criteria required for utilisation in a road going vehicle.

3.10. DEVELOPMENT OF CHASSIS TECHNOLOGY

3.10.1 INTRODUCTION

As a result of ever more stringent governmental rules regarding vehicle emissions, automotive engineers face constant challenges with regard to making their vehicles more efficient. There are many options which can be utilised to meet these challenges but perhaps the simplest is the reduction of weight. Figures from the United States Environmental Protection agency indicate that for every 45 kilograms of weight saving measures the average vehicle will display an increase of 1-2% in the number of miles it can cover per gallon of fuel. [46] EU regulations dictate that vehicles must comply with emission limits of 130g/Km of carbon dioxide by 2020 and a mere 95g/Km by 2030.

3.10.2. MATERIAL DEVELOPMENT

Over the past century vehicle chassis have been traditionally constructed using steel, due to its favourable mechanical characteristics and comparatively low cost. However, resultant of a global push in vehicle efficiency from manufacturer's worldwide, focus has been placed on the research and development of new materials which provide mechanical properties which match or surpass that of steel whilst simultaneously incurring less weight. The intrinsic mechanical properties of the most common modern materials utilised in automotive construction are illustrated in Table 8.

Material	Modulus of Elasticity (GPa)	Tensile Strength (MPa)	Density
Carbon Fibre	120	2550	1570
Alloy Steel	205	1275	7850
Aluminium	71.7	570	2810

Table 8*- Mechanical Properties of commonly used automotive materials*

Table 8 demonstrates clearly that carbon fibre has significantly more favourable mechanical characteristics than that of its competitors with a measured tensile strength double that of steel and more than four times that of aluminium whilst its density remains significantly lower than both metals.

3.10.3. MATERIAL PROPERTIES

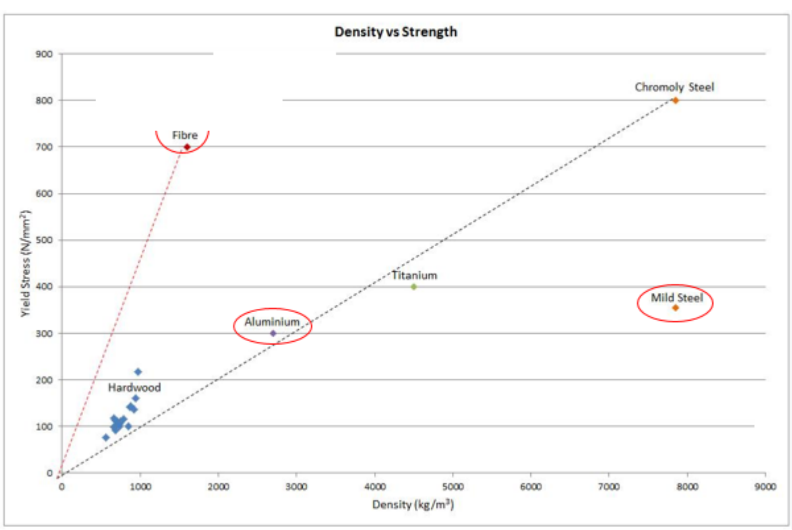


Figure 25- *Yield Stress v Density* [47]

3.10.3.1. STEEL

Steel remains the most commonly applied material in the production of vehicles to this day due to its inherent strength and low cost. With a Young's Modulus of almost double and triple that of carbon fibre and aluminium respectively one can infer that steel has the most desirable characteristics for a vehicle, however this inference is made redundant when considering steels low strength to weight ratio when compared to that of aluminium and carbon fibre, further demonstrated by Figure 25 as an equivalent yield stress infers far higher density.

3.10.3.2. ALUMINIUM

The use of aluminium has been steadily increasing within the automotive industry with high end manufacturers such as Jaguar- Land Rover and Porsche. It's high strength to weight ratio and favourable corrosion resistance properties make it ideal for the construction of vehicles. Due to its metallic nature aluminium can also be formed using the same processes as steel and so re-tooling is not necessitated for automotive manufacturers. The cost of raw aluminium material however is higher than that of steel.

3.10.3.3. CARBON FIBRE

Of all the most commonly used materials in the manufacture of vehicles, carbon fibre is by far the most advanced. The manufacturing process for carbon fibre is far removed from that of its metallic counterparts, with specialised methods necessitated for production. However carbon fibre exhibits a significantly more desirable strength to weight ratio than that of both steel and aluminium and therefore is the most pragmatic material choice under circumstances where cost saving is not a prerequisite.

3.10.4. END OF LIFE OPTIONS

3.10.4.1. ALUMINIUM

Figures procured from the Global Aluminium Recycling Committee indicate that between 85-95% of Aluminium is recycled for re-use [48] This is an important characteristic in that manufacturers now make serious considerations with regard to end of life options so that a vehicles footprint is accounted for when in use and as well as after its usefulness has expired.

3.10.4.2. STEEL

The American Iron and Steel Institute recorded the recycling of steel to be as high as 92% for automotive vehicles. [49] The point can therefore be made that although steel may incur more weight in a vehicle and therefore reduce overall efficiency, the footprint left by the material directly is infact nominal.

3.10.4.3. CARBON FIBRE

Currently there are no effective means by which thermoset carbon fibre can be recycled whilst maintaining its structural integrity. This is a major issue in that the majority of carbon fibre at the end of its life cycle is disposed of in landfill.

3.10.5. WHAT IS A CHASSIS?

Traditionally the chassis of a vehicle is the physical frame of a vehicle, upon which the engine, suspension and body are mounted. It is a load bearing structure which provides mechanical stability to the vehicle as well as a level of protection for the internal constituents such as the motor and running gear.

In more recent times vehicle manufacturers have developed chassis design past the simple frame and included load bearing body parts which significantly reduces weight and thus improves efficiency. This section will discuss the variations in chassis design as well as the more exotic materials utilised in the production of modern vehicles.

3.10.6. TYPES OF AUTOMOTIVE CHASSIS

There are 4 chief types of modern automotive frame which differ from each other in terms of both mechanical properties and applied use.

3.10.6.1.BODY ON FRAME

Preceding the development of more advanced chassis methods the frame on body construction type was utilised in almost every automotive vehicle. Traditionally consisting of two main side rails connected by cross members the frame provides the ‘backbone’ of the vehicle upon which the body and major vehicle constituents are mounted. This method has since fallen out of favour with automotive manufacturers due to the inherent weight associated with the construction however it is still employed in the manufacture of trucks and large commercial vehicles due to its simplicity whilst simultaneously allowing for easy access to engine and drivetrain components.

Figure 26- *Frame Chassis* [50]

3.10.6.2. UNIBODY

The majority of vehicles on the market today consist of a Unibody construction whereby the chassis, frame and floor of the vehicle are constructed in one piece. This arrangement has the inherent benefits of being more lightweight and rigid when compared to the more traditional 'body on frame' architecture utilised in the past and are commonly constructed in metal.

Figure 27*- Unibody Chassis* [51]

3.10.6.3. MONOCOQUE

With origins in Formula 1 the monocoque chassis has a reputation for being utilised in expensive high performance vehicles. The frame is essentially a carbon fibre shell which supports load by distributing tensile and compressive forces across its surface. Since all of the dynamic load is supported by the shell there is no necessitation for a load bearing frame and thus results in huge savings in weight when compared to a more traditional vehicle.

Figure 28- *Monocoque Chassis* [52]

3.10.6.4. SPACE FRAME

Space frame construction consists of a multitude of geometrically interlocking struts which provide load bearing support for the vehicle. Unlike the designs previously mentioned, the space frame has no requirement for body panels instead sharing similarities more akin to that of the traditional vehicle frame, albeit much stronger and lighter.

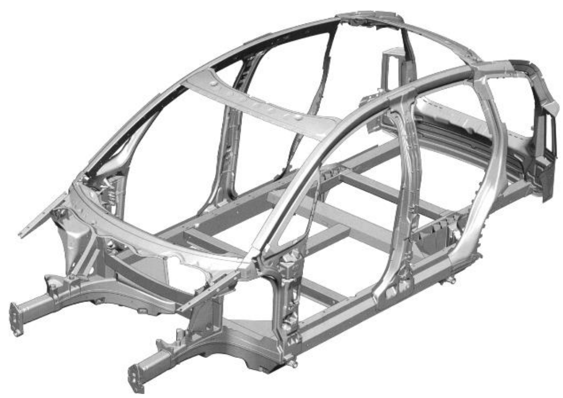


Figure 29- *Space Frame Chassis* [53]

3.10.7. VEHICLE CHASSIS

It was concluded that while the chassis of a vehicle only accounts for roughly a third of the total vehicle weight, the development of more lightweight structures is an essential part of overall weight reduction. With a primary reduction in the chassis, vehicle components such as the engine, drivetrain and suspension need not be as large and, by extension, as heavy as they would be otherwise, these secondary weight reductions give rise to approximately double the manufacturing benefits in that for each kilogram of weight saved in the chassis, a further kilogram can be shaved off by using smaller constituent parts. [54]

3.11. VEHICLE SEGMENT JUSTIFICATION

3.11.1. PURPOSE

In order to justify the choice of vehicle type recommended in the conclusion of this report, it was necessary to identify the vehicle body style which would appeal to the largest sales demographic. Research was therefore carried out into the vehicle segment with the most desirable sales trends in order to guide decisions made later in the project.

3.11.2. RISE OF THE SUV

As of 2015 there has been a notable rise of SUV sales in the UK and European markets. Figures from automotive business intelligence expert JATO indicate that the market share accounted for by this class rose from 19.8% in 2014 to 22.5% in 2015 indicating a 24% rise and leading the sector to outsell both compact and subcompact segments for the first time in history.

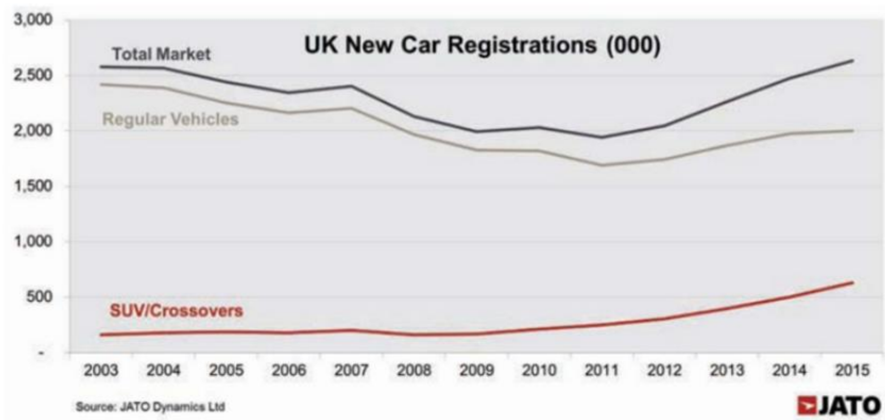


Figure 30- *Suv/Crossover sales trends* [55]

This notable increase in SUV sales can be attributed to the rising popularity of small/compact SUV's and the ever expanding SUV ranges offered by almost all major vehicle manufacturers. Figure 31 demonstrates the given sales of SUV variants as a percentage of total SUV sales.

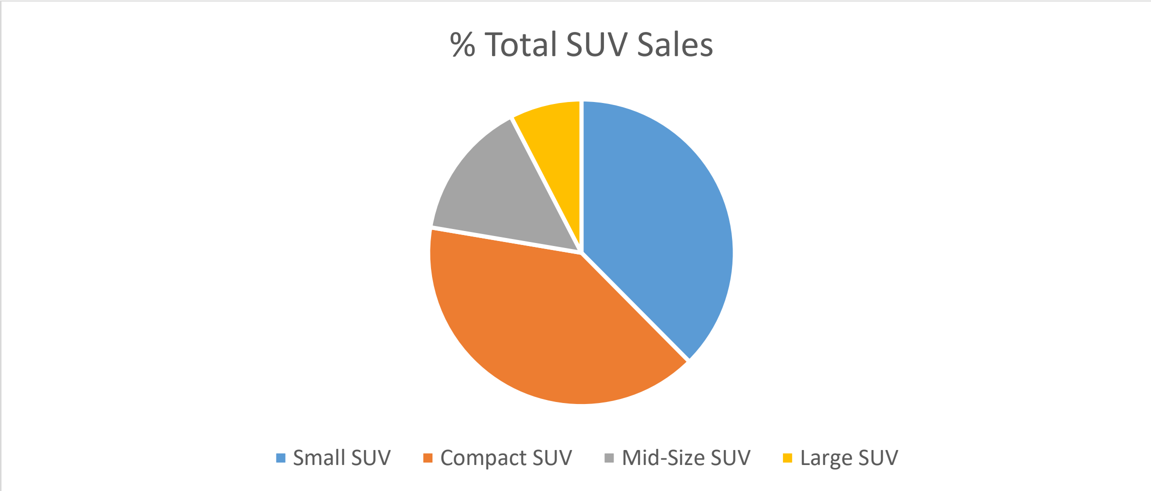


Figure 31- *SUV variances as percentage of total segment sales*

3.11.3. SUV SIZE

Traditionally when referring to sport utility vehicles one imagines large, cumbersome four wheel drive vehicles with well-established off road credentials and masses of interior space. However vehicle sales in the segment have established that larger vehicles sell fewer units than their smaller cousins, accounting for only 15% of the segment.

The arguments favouring the purchase of a small sized SUV when compared to a hatchback or estate car can be demonstrated as follows:

3.11.3.1. ACCESS

Small SUV's have the intrinsic benefit of easy access whereby their taller ride hide combined with larger doors and short sills provide less obtrusion to entry and exit. Generally interior and storage space in SUV vehicles far surpasses that of its smaller counterparts and so practicality benefits are clear.

3.11.3.2. SEATING POSITION

The taller ride height granted by SUV's promotes a more commanding seating position than that of its lower counterparts, granting the driver far more visibility with regard to the road ahead whilst also demonstrating improvements in all round visibility due to their intrinsic square sided design.

3.11.3.3. COMFORT

Taller suspension is useful on the road, especially in the UK where surfaces are prone to pothole damage. Longer travel suspension accommodates these discrepancies promoting a smoother ride than would otherwise be possible in a smaller vehicle whilst simultaneously promoting greater driver confidence in adverse weather conditions such as sleet and snow.

3.11.3.4. CHOICE

The vast majority of vehicle manufacturers have significantly increased the size of their SUV range or developed SUV versions of their current models, offering all sizes and styles to meet consumer needs, some examples of these large ranges are demonstrated in Table 9 below.

Manufacturer	SUV Variant	Total Number Variants
Audi	Q1 (TBA), Q2, Q3, Q4 (TBA), Q5, Q6 (TBA), Q7	7
BMW	X1, X2 (TBA), X3, X4, X5, X6, X7 (TBA)	7
Mercedes	GLA, GLC, GLE, GLS, G-Wagon	5
Land Rover (Range Rover)	Evoque, Velar, Sport, Vogue	4

Table 9- *SUV variants by manufacturer*

As evidenced in the previous text, the most pragmatic option in terms of body style for a new vehicle to compete on the global market is the small or compact SUV.

4. INFRASTRUCTURE DEVELOPMENTS

4.1. INFRASTRUCTURE SECTION INTRODUCTION

This section addresses infrastructure developments with respect to HEV, EV & alternatively fueled vehicles and is focused predominantly upon the UK in-line with the stated obligations within the Statement of Purpose. Both to-date developments and those future developments which are within a reasonable short to medium-term outlook are presented and assessments made with respect to potential significance towards the proliferation of emerging automotive technologies. In addition, where relevant the influences of both centralized & local governments, such as city-level policies & pilot schemes, are incorporated.

Explicitly, the contents of this section include an overview of trends in global charging & refueling infrastructure development, focusing again on the UK; an overview of a methodology employed in case study city selection; presentation of a summary of infrastructure developments & planned investment within numerous major UK cities and finally, where relevant extensive discussion of proposed disruptive technologies & network architectures which may synergize with alternatively fueled vehicle uptake.

Please turn overleaf for access to the infrastructure discussion section's main body.

4.2. INFRASTRUCTURE TRENDS – NATIONAL LEVEL

4.2.1. INFRASTRUCTURE TRENDS INTRODUCTION

Prior to performing a thorough assessment of case study cities and investigating numerous emerging, potentially disruptive technologies, the group identified that it is imperative to first understand general trends in infrastructure which are supporting the growth of HEV, EV and alternate fuel vehicle market penetration. Therefore, an extensive assessment was performed with regards to the growth of supporting alternative transport infrastructure, with a focus placed upon both recent existing developments & announcements for significant developments to come within a short-medium term outlook. To enable meaningful data extraction, the group elected to also perform a focus on three major European nations who each reflect the varied stages of the development process for HEV & EV infrastructure and the up-take of such vehicles. The first of these was Germany; a region where-in there growing fiscal incentives but only small pockets of existing supporting infrastructure. Currently Germany's HEV & EV market is in a very infantile stage of maturity in reflection of this. The UK was next, where there are substantial fiscal incentives as a percentage of baseline vehicle price & larger pockets of supporting HEV & EV infrastructure. The UK was also chosen as it had been a focal point in the initial task assignment with four UK cities to be assessed in detail & as it had a comparably higher market penetration of HEV & EV vehicles than Germany. Finally, the third nation selected for case study was Norway; selected as it has significantly high fiscal incentives as a percentage of baseline vehicle price, a substantial supporting infrastructure and historically very strong market penetration of pure EV vehicle architectures.

Within this section, an overview of HEV & EV charging infrastructure & technology shall be presented, with supporting discussion regarding numerous technical standards deployed within industry & brief a summary of trends in consumer behavior & infrastructure exploitation. Following this, the three nations outlined shall be investigated with summaries of infrastructure density provided. Identification of near-maturity technologies shall be performed, where appropriate, which shall include in-works improvements to existing infrastructure & potentially disruptive utilities. In addition, consumer behaviors are discussed.

4.2.2. EXISTING INFRASTRUCTURE TECHNOLOGIES

4.2.2.1. PHEV & EV CHARGING TECHNOLOGIES

At present, there are numerous infrastructure standards adopted by industry bodies & manufacturers for PHEV & EV charging. Within this section, an overview of the most prominent standards shall be presented with typical specifications & estimated capabilities outlined where relevant; a focus upon the leading European standards will be employed. In addition, distinctions between standards employed within the EU, US and Chinese markets shall be referenced briefly to conclude the section.

Before this may be performed, it is required to distinguish between a charging point/unit and a station;

Charging Point (or Outlet / Unit); A single upstand or wall-mounted unit offering a socket outlet &/or tethered connection for EV charging [56] [57]. **Charging Station;** A site containing at least two charging points, suitable for charging at least two PHEV or EVs simultaneously. A station may either be ground or wall-mounted and could utilize one or more of several distinct AC or DC connection standards deployed (refer to information below) to deliver power to a compatible vehicle [56] [57].

Figure 32 depicts both a Charging Point and a Charging Station for comparison purposes [58] [59].

Figure 32 LHS *A charge point with EV connected.* ***RHS*** *A collection of points comprising a charge station* [58] [59].

At present, “slow charging” is the most prevalent method of PHEV & EV charging; with all commercially viable electric vehicles capable of utilizing such infrastructure for recharging purposes. A consumer could be expected to be familiar with most slow charging infrastructure supply-end connectors as typically, a three-pin BS1363 plug is employed to connect a compatible vehicle to an AC single-phase ring main circuit [56] [57] [60]. The power rating of such slow charging infrastructure is therefore limited by that of the BS1363 plug at 3kW [56] [57] [61]. However, though capability for up to 13A of current exists within the bounds of BS1363, slow charging infrastructure for EVs is commonly limited to just 10A for safety purposes; limiting deliverable power output of three-pin-based slow charging infrastructure to just 2.4kW [57] [62]. A Mode-2 electronic controller is employed to enable adequate communication between the vehicle & charge point system and to initiate the recharging process as dictated by the applicable European standard EN6151-1. In alternative systems, an EN60309-1 “Commando” connection may be employed at the supply-end of slow charging infrastructure. More suitable for outdoor installations, this connector is rated for up to 3.6kW with an amperage of 16A safely achievable; therefore such charging may be faster [57] [60] [63].

The most prevalent connection types employed at the vehicle-end of slow charging infrastructure systems is either that of the five-pin SAE J17772-derived Type 1 or seven-pin EN62196-2 Type 2 connectors, although a Commando plug may be employed if severe conditions are expected at outdoor charge points [57] [60] [64]. Power ratings for both exceed that of slow charging infrastructure capabilities. In regards to typical application, due to the low power rating of “slow” charging infrastructure it can be estimated that to supply a 24kWh battery with a 0-100% state of charge swing would require 8-12hr depending upon efficiencies of connectors & control systems employed. Thus, slow charges are commonly deployed at home and at work where-in long stop-overs are common place [57]. These chargers are being phased out.

Figure 33, overleaf, depicts all connectors discussed regarding slow charging infrastructure section [56] [65].

***Figure 33 LHS-RHS** 3-pin plug head, 16A Commando, Type 1 and Type 2 connectors* [65] [56].

"Fast Charging" systems enable significant reduction in required charging durations in comparison to slow charging infrastructure. Such is accomplished through provision of up to twice the available current of slow charging systems, with a typical single-phase AC amperage of 32A delivered by fast charging systems [57] [66]. Within the domestic home environment, fast charge systems are often deployed as garage wall-mounted, dedicated charging units which typically extract power supply from a local, dedicated 16-32A radial AC circuit and can supply between 3.6 and 7kW when employed as single-phase systems [56] [57]. Both the SAE J17772 Type 1 and EN62196-2 Type 2 connectors may be deployed, though the latter is most common within the EU due to backing by the European Commission as the dedicated European standard (refer overleaf) [67] [68]. In public area, including workplaces stations, increased power rating chargers of 7kW, 11kW & 22kW systems are more prevalent, though the former is most commonly deployed [57].

Unlike slow charge systems, fast chargers employ Mode 3 controllers to both initiate charging and maintain adequate communication between the compatible vehicle and the charging station [68]. This is in-line with EN61851-1 & as such, no Mode 2 controllers are present within fast charger cable assemblies. In regards to typical application, due to the higher power rating of "fast" charging infrastructure in comparison to "slow", it can be estimated that to supply a 24kWh battery with a 0-100% state of charge swing would require 3-4hr depending upon efficiencies of connectors & control systems employed [57]. These chargers are experiencing proliferation as they offer strong trade-off between cost & rate of charge.

Figure 33 above depicts both Type 1 and Type 2 connectors that are employed for these systems. Notable however is that although the connectors remain consistent, physical bulk of the unit increases [56] [65].

The next segment of charging systems deployed are those of the classification of "Rapid Chargers". A distinction shall be made between rapid AC & rapid DC systems are performance capabilities are different.

In the case of rapid AC chargers, power ratings of up to 43kW power ratings can be implemented, which is a significant improvement upon both slow and fast charging infrastructure. To accomplish this, three-phase 63A per phase is employed; with Type 2 connectors dominating the existing infrastructure [63] [57] [68] [64]. This additional load requires significantly more cooling & control infrastructure hence the bulk of the system grows to represent that of a conventional fuel pump in terms of physical size. Again Mode 3 controllers are deployed within rapid AC systems. In regards to application, due to bulk and cost limitations, such systems are better suited to public infrastructure such as motorway service stations. Rapid AC is estimated to be capable of performing a 0-80% state of charge swing for a 24kWh battery in 30 minutes [67] [58] [68].

Rapid DC charging is the final classification of charging infrastructure which is in operation to-date. Power ratings for such systems range from 20 through to 50kW systems; capable of 0-80% state of charge swing in approximately 30 minutes, with the remaining 80-100% taking an additional 30 minutes to perform [56] [57] [63]. Within this system, current is limited to that of the vehicle's on-board battery rating, which can hinder charging rates for vehicles utilizing the system. Mode 4 controllers are employed, again serving to initiate charging & maintain communication between the charging unit and the connect vehicle [60] [62].

In terms of connectors, rapid DC is distinct. The CHAdeMO compliant JARI JEVS/G105 plug and the Combine Charging System (CCS) Combo2 connectors are both deployable for rapid DC systems. Within Europe, the Combo2 system is more prevalent; this standard is rated to up to 90kW and as such is future-proofed to a greater extent than its competitor [68] [65] [66]. Also, Tesla offer their own propriety "supercharger" system which has an operational 145kW rating, though proliferation of this system is more limited and of less significance to EV & PHEV up-take as use is limited to Tesla owners only [63] [69].

Figure 34, below, depicts three available rapid DC connector types, as described above, for reference.

Figure 14 LHS-to RHS *Combo2, CHAdeMO and propriety Tesla Supercharger connectors* [60] [63].

In terms of future developments, whilst the Type 2 connector is future-proofed to a rated 90kW maximum power output, a collection of EU-based automotive & electronic product manufacturers claim to have developed a competitor system capable of power deliveries of up to 350kW [70] [71]. Formed as an alliance involving companies such as Audi and BMW, the system is to be deployed across 25 sites across the Trans-European Transport Network (TEN-T) and is claimed to be capable of performing full 0-100% state of charge swings, sized for up to 190mi range, in under 20 minutes; this would translate to roughly a 40kWh capacity if current technical limitations of battery specific densities are considered. Representing a £11.5m investment, the system is not yet operational with an estimated ETA sometime win 2018; which would be towards the later end of the group's short-medium term outlook [58] [70] [71] [69].

In terms of adoption, within European markets the prevailing standard for PHEV & EV plug-in charger connections is that of the "Mennekes" IEC 62196 Type 2 (refer to Figure 34 for reference) [56] [67]. So-called after the manufacturer who developed the connector, the Type 2 charging platform was selected by the European Commission in 2013 to be the future de-facto connector deployed across Europe; beating out the Type 1 connector and a rival developed in Italy by the EV Plug Alliance [67] [58] [68]. In the US, the Type 1 connector remains dominant however. Furthermore, although China selected the Type 2 connector for future use, it elected to utilize a previous iteration of the system to Europe and hence is currently incompatible [57] [67] [68] [72]. To summarize, Table 10 presents a summary of the outlined standardized connectors, focusing on the UK [63] [60] [57].

Table 30 *Table outlining the properties of various connector standards for EV charging* [63] [60] [57].

PROPERTY	THREE-PIN	COMMANDO	TYPE 1	TYPE 2	CHADEMO	CCS COMBO2	TESLA S
RATES SUPPORTED	Slow	Slow, Fast	Slow, Fast	Slow, Fast, Rapid AC	Rapid DC	Rapid DC	Rapid DC
LOCATED	PRIVATE	PRIVATE, PUBLIC, WORKPLACE	PRIVATE, PUBLIC, WORKPLACE	PRIVATE, PUBLIC, WORKPLACE	PUBLIC, WORKPLACE	PUBLIC, WORKPLACE	PUBLIC
POWER (KW)	3	3-3.6	7-22	7-43	50	50 (90)	145
0-100% SWING (hr)	8-12	8-12	3-4	1-4	1	1	0.5-1
UK INSTALLS (MAR ’17)	1468	181	325	9223	893	590	391
UK LOCATIONS (MAR ’17)	898	136	188	4168	735	538	161
COST PER INSTALL	-	<£2k (Slow) & £10-15k (Fast)			£38-45k (Rapid)		>>£50k

4.2.2.2. PHEV & EV CHARGING BEHAVIOURS & UTILISATION

Of importance to the Groups conclusions to the infrastructure requirements of any future commercially viable HEV or pure EV architecture is the typical behaviors & preferences of existing & potential consumers with regards to vehicular charging. Within the scope of this section, the UK market will be explored with general trends in existing charging infrastructure usage & consumer behaviors & preferences identified. The US market will be briefly compared as substantial studies have been performed which provided in-sight into typical behaviors. The scope of this section will be exclusive to that detailed; with more general infrastructure details for the UK assessed within a subsequent report section; Refer to Section 4.3..

As aforementioned, the group took into consideration the findings of several respected studies to draw conclusions with regards to public behavior & PHEV / EV charging infrastructure utilization. A significant study indicated that the time of day for which EVs may be capable of charging is highly flexible as they may be idle for, on average 95% of a typical day within the UK [73]. Such a study is corroborated in that an equivalent study for the US indicated that a typical vehicle will be stationed at home for up to 85-90% of a typical day; stating that only 4% of total US registered vehicles are on the road simultaneously [74]. A substantial, 6-month duration study performed within the UK utilizing several distinct consumer types indicated that home, work and public charging infrastructure systems are all utilized extensively; though with location of charging event significantly sensitive to the ownership & intend usage of a vehicle. As depicted in Table 11 overleaf, private owners relied upon home charging to a greater extent, with slightly reduced reliance upon work infrastructure & significantly reduced reliance upon public infrastructure observed over the six-month period [75]. This supports findings of the Plugged-in-Places scheme where-in although private charging accounted for just 4% of installations, over 16% of all charging within the scheme was performed domestically [76]. In comparison, both industry ownerships (Read: fleet users) were found to depend less upon private charging infrastructure, with work-based charging observing significantly more use. This is shown to be particularly true for car-pool based industry ownerships. The conclusions which can be drawn from this study are that to sustain successful penetration of PHEV & EVs in both the private and fleet markets, sufficient private infrastructure will be required in conjunction with work-based charging. Several significant studies assessing vehicle charging throughout varied timeframes were assessed by the group; these unambiguously supported conclusions drawn [73] [74] [77] [78] [79].

Notable to is that availability of a strong network of workplace chargers, supplemented by adequate public infrastructure can sustain those with off-street parking; estimated to be around 40% of UK drivers [80]. Furthermore, studies indicate that ownership of an EV does not limit consumer flexibility; with average miles performed by EV drivers in some UK-based studies exceeding the UK averages although realistically rare, long distance journeys will require additional journey time due to requirements for recharging [75].

Table 11 *Vehicular charging habits representative of those found across numerous studies* [75].

	AVG. NUMBER OF CHARGING EVENTS					**AVERAGE EVENT DURATION (HR)**			
LOCATION	**PRIVATE**	**FLEET**	FLEET-POOL	**COMBINED**		**PRIVATE**	**FLEET**	FLEET-POOL	**COMBINED**
HOME	41.6	26.3	17.4	24.8		3.1	3.0	3.2	3.1
WORK	36.9	51.3	54.9	50.4		3.6	3.6	2.4	2.9
PUBLIC	18.8	38.5	33.7	32.5		3.2	2.7	3.3	3.1
TOTAL	97.3	116.1	106.8	107.6		3.4	3.2	2.9	3.1

Furthermore, most studies indicate that the typical duration of stop-overs, non-inclusive of long distance travelling such as significant motorway commutes, would suggest that fast charging infrastructure (7-22kW) would be adequate; recall a charge of 3-4hrs required for a 0-100% swing [75]. However, as discussed within the perceived barriers section (Section 3.), journey distances won't often require 0-100% state of charge swings for reasonably sized PHEV & EV powertrains; '11 statistics indicate that 80% of EU motorists drive under 63mi daily, with the UK daily distance less than 25mi [80]. In support of this, within the UK studies found that UK owner EV mileage of EVs slightly exceeds comparable CV mileage [75].

In support of the UK-focused findings, within the US regional market there are clear similarities to the UK in terms of PHEV & EV charging infrastructure exploitation. The group employed the results of several infrastructure usage models and real study findings to identify trends in US-based charging [81] [82] [83] [84]. One such study indicated that across domestic & workplace charging systems, 90% of US EV users could sustain their daily usage, with no reliance upon public infrastructure; with 85% of charging found to be performed at domestic charging stations within this study which focused on private ownerships [85]. It must be noted however that this study looked at pure EVs exclusively, thus the reduced reliance upon public charging could be attributed to a reduced requirement to charge mid-journey since pure EV capacities & range are typically significantly larger than comparably priced PHEVs; indicating differing requirements for public & workplace infrastructure for effective "clean" use of PHEV & EV architectures. This is evidenced in further studies where-in average US-based distances driven per day are well within the bounds of the capabilities of pure EVs operating on a single-charge yet mostly are at the upper limits of the typical capabilities of a PHEV vehicle (typical capabilities of between 10-35mi) – see Figure 35 [86].

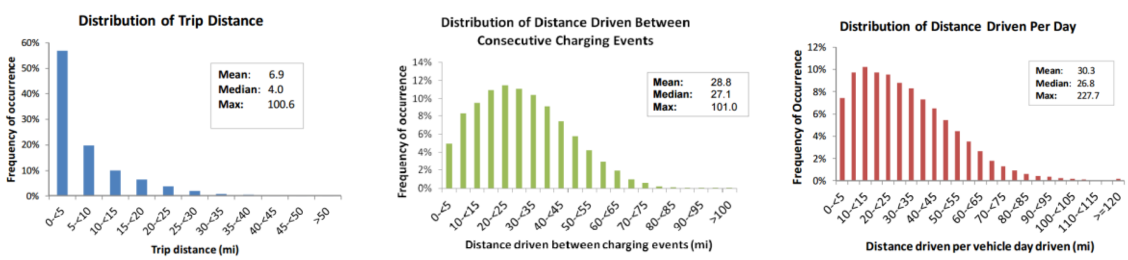


Figure 35 *Summarized daily driving behaviors as found by several US-focused studies* [86].

The EU recently announced that by 2019 all new or refurbished homes will require installation of charging facilities and that by 2023 10% of all parking bays in new buildings will require provision of charging supporting growth of both home and public charging utilization, further alleviating range limitations [87].

Although it shall not be presented within detail for sake of conciseness of report; the group members spent a significant period investigating the trends in vehicle loading upon the grid network through daily use. Substantial studies were identified as thoroughly assessed, inclusive of home-only and varied studies. These include sensitivity analyses to storage capacity, vehicle age & weekend vs. weekday loading models. Most modeling studies investigated were found to have produced similar conclusions, with little regional bias. Figure 36 depicts one study & compares grid loading predicted by varied charging strategies [74].

Figure 36 LHS *Avg. vehicle load vs. capacity* ***CENTRE*** *Avg. vehicle load vs. charging strategy simulations* [74]*.* ***RHS*** *UK Government predictions for UK domestic power demand under max up-take scenario* [88]*.*

A significant conclusion from analysis of such studies was that at present typical home charging behavior coincides with that of domestic energy usage across the UK (Figure 37 below); where-in persons are most commonly initiating charging in the early evening [89] [90] [91] [92] [93] [94]. Though Figure 36 above demonstrates that provision of adequate supporting workplace charging infrastructure can reduce evening EV charging demand, the reduction is not so significant that potential peak demand management issues are alleviated [74]. Therefore, the conclusions that the group have drawn, when briefly summarized, are that to enable mass-market penetration of PHEV & EV vehicles charging behaviors must be adjusted in conjunction with development of supporting infrastructure such as smart meters which could facilitate adequate automatic demand-side management to be performed (e.g. delaying of charging until the early hours of the morning), increased proliferation of localized energy storage facilities and growth of distinct smart-grid networks. Emerging technologies e.g. induction charging (Section 4.8.) could facilitate growth of "smart" domestic charging through increased automation of the process [91] [73] [75].

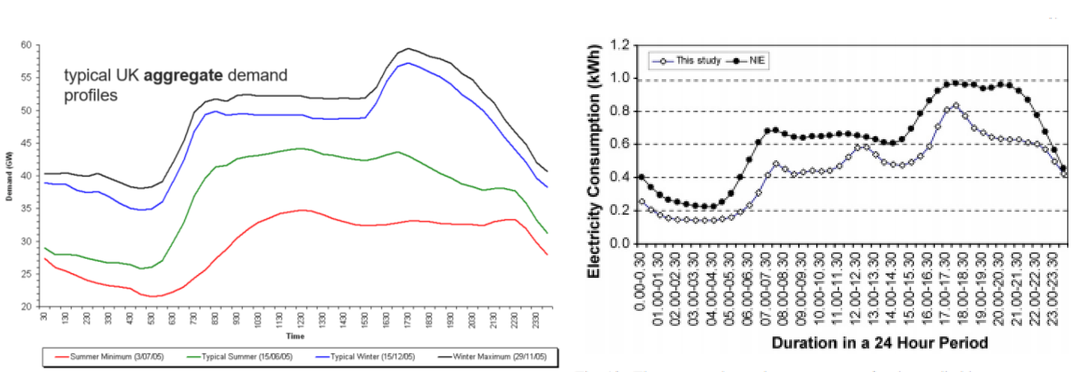


Figure 37 *Avg. profiles for UK daily energy hourly usage as found by numerous studies* [90] [89]*.*

4.2.2.3. HYDROGEN REFUELING TECHNOLOGIES

Though limited in terms of market penetration and infrastructure implementation, hydrogen-based refueling is reaching a stage of maturity where-in preliminary roll-out of infrastructure can be sustained. As with conventional plug-in charging of HEV & EV vehicles, already there are established standards for H_2-based refueling systems which have the backing of both manufacturers & regulatory bodies (Figure 38) [95] [96]. The standards are that of SAE J2799 & SAE J2601 which define 70 MPa Compressed Hydrogen Surface Vehicle Fueling with Optional Vehicle to Station Communications and Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles respectively. These standards are currently adopted by all major proponents of H_2 refueling including the European Hydrogen & Fuel Cell Association, the UK's H_2Mobility, the US Department of Energy and the Japanese Association of Hydrogen Supply & Utilization Technology. Figure 38 depicts the proponents of both standards within the UK, as well as J2799's fueling interface [96].

***Figure 38 LHS** H_2Mobility; adopting standards* [95]. ***RHS** Overview of J2799 & an operational station* [96].

Though access to specification of the standards was limited by both paywall & the relative novelty of the standards, the group was able to ascertain several key specifications for modernized H_2 refueling stations through research of existing operational platforms and literature. For example, it was determined the required extreme conditions for temperature testing (-40°C *min* to 50°C *max*), maximum dispenser pressures (87.5 MPa & 43,8 MPa for both categories of dispenser) and dispenser flow rate limit (60 gs^{-1}) [97] [98] [99]. Table 12 depicts the data for the five capacity categories defined within J2799 [100].

***Table 12** Table depicting the specifics for H_2 refueling provided by SAE J2601* [100] [99].

DISPENSER PRESSURE [MPa]	VEHICLE PRESSURE [MPa]	MASS H_2 @TANK (100% SOC) [Kg]	VOL. H_2 @TANK (100% SOC) [L]
43.8	35	2.39-4.18	99.4-174.0
43.8	35	4.18-5.97	174.0-248.6
87.5	70	2.00-4.00	49.7-99.4
87.5	70	4.00-7.00	99.4-174.0
87.5	70	7.00-10.00	174.0-248.6

Unlike the case of conventional plug-in charging for HEV & EVs, in the case of Hydrogen refueling systems there is very little in the way of data nor statistics regarding consumer preferences & behavior; predominantly due to the distinct lack of market penetration for H_2-powered vehicle & infrastructure. However, from literature it became clear that it was targeted for H_2 refueling to be performed similarly to conventional fossil-fuel refueling; J2601 declares a target of sub-3 minutes to be targeted with short-term forecasted H_2 refueling station capabilities estimated to be at around 3 minutes for a 5 kg refuel [96] [100] [101] [102]. Unlike transfer to plug-charging, H_2 refueling would not be a large deviation from conventional behavior, which is beneficial to future up-take in comparison to plug-in charging HEV & EV models. Below, Figure 39 summarizes estimates from 2015 of H_2 refueling capabilities; likely to be accurate today [103] [104].

Vehicle types	
C/D	Family saloon/estate
E	Executive
J	SUV
Commercial introduction	
Date	2015
Powertrain	
Power source	Hydrogen Fuel Cell
Transmission	Electric Motor
Peak power	100kW (135bhp)
Continuous power	75kW (100bhp)
Torque	300Nm (220 lbft)
Fuel	
Pressurised hydrogen gas	
Tank pressure	70MPa (700bar)
Capacity	5kg
Consumption (NEDC)	1kg/100km (62miles/kg)*
Range (NEDC)	500km (320miles)
Performance	
Top Speed	160km/h (100mph)
Acceleration 0-100km/h (0-62mph)	12s
Emissions at tailpipe	
Carbon Dioxide	Zero (0gCO_2/km)
NOx (Oxides of Nitrogen)	Zero
Sulphur Dioxide	Zero
Particulates	Zero

Vehicle filling	
Hydrogen purity	To standard ISO 14687-2
Maximum filled pressure	70MPa (700bar)
Filling time	3 minutes (for a 5kg fill)
Daily capacity	80-1,000kg (i.e. 16-200 full fills)
On-site fuel storage	
Pressure	Cascade storage system with highest pressure tank at 85MPa (850bar)
Capacity**	3 days supply

Station size	Daily H_2 capacity	Capacity (FCEV fills/day)
Small	80kg	16
Medium	400kg	80
Large	1,000kg	200

Figure 39 *Estimated capabilities for Fuel Cell Vehicles & refueling stations as of 2015* [104] [103].

As is visible within Figure 39, Hydrogen-powered vehicles and infrastructure has reached a maturity level which facilitates comparable performance to conventional equivalents [104]. However, at present a significant barrier yet to be overcome is that of large scale FCEV refueling economics. Though FCEVs are cheaper to run than conventional diesels (£/mi), they require significantly greater *initial* capital investment [104] [99]. Though this can largely be attributed to economies of scale and required research & development & retooling costs on the part of manufacturers, it presents a significant barrier to FCEV up-take. As depicted within Figure 40, it is not until 2030 that forecasts predict that total cost of ownership (TCO) for FCEVs will be comparable to that of conventional diesels [104]. In addition, at present there is inadequate infrastructure in place to support mass up-take of FCEVs; even by 2030 total stations will amount to less than 1/7th of todays combined conventional refueling stations [96] [100]. Estimations by proponents of H_2 transportation applications indicate that 65 stations are required to kick-start the UK's FCEV market, however just sixteen are operational to-date. Estimations are that it will not be until at least 2020 that required stations are installed. Emphasizing this is that across Europe, just thirty-one stations are operational [105]. Also, forecasts indicate that break-even for FCEV infrastructure will not be reached until the "late 2020's" & that £62m of investment is required by 2020 to achieve forecasted growth [104].

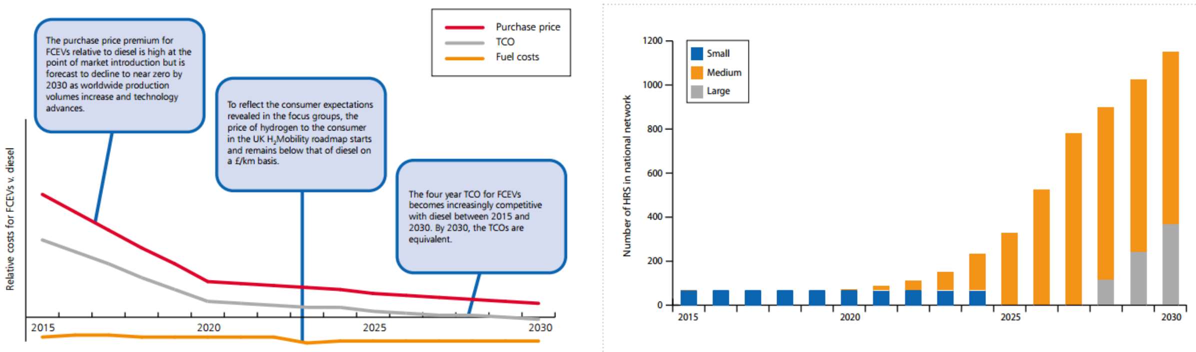


Figure 40 LHS *Comparison of cost of FCEV vs. Diesel where-in x-axis represents diesel.* ***RHS*** *Forecasts for gradual deployment of FCEV-capable refueling stations within the UK under the H_2Mobility scheme* [104].

4.2.3. INTER-NATIONAL INFRASTRUCTURE TRENDS – GERMANY, UK & NORWAY

As presented within the section introduction, three major European nation's infrastructure developments were investigated at national level; Norway which leads Europe in terms of EV market penetration & infrastructure, the UK which is experiencing reasonable growth of HEV & EV up-take with larger pockets of supporting infrastructure and Germany which, though having comparable fiscal incentives to the UK, has both reduced HEV & EV market penetration and supporting infrastructure networks than the UK. Here, summative assessments of infrastructure developments within these three countries shall be stated with comparisons noted where relevant. Noteworthy is that group members spent significant periods assessing the infrastructure of these three nations, and indeed many other globally including the US. However, to provide comprehensive information would yield an excessive report; hence the decision to focus on aforementioned three nations which enables demonstration of the significance of infrastructure.

Germany would be the first nation to be assessed within this condensed, summative section of the report. As presented previously, the German HEV & EV market is currently within an infantile stage of maturity in direct comparison to both the UK & Norway; especially true to say for the latter. Estimates indicated that of 3,206,000 new vehicle registrations in Germany throughout 2015, a paltry 43,000 were HEV or EV variants; achieving a combined HEV, PHEV & EV market share penetration of 1.35% of new registrations. This compares unfavorably to the UK, discussed in far greater detail within Section 4.3. of this report, where throughout the 2015 calendar sales period, alternatively fueled vehicles achieved a market share penetration of 2.8% of all new vehicle registrations (est. 0.0727m of 2.6m new vehicle registrations) which was stated in the section introduction. In terms of market penetration trends of HEV & EV variants within Germany, the breakdown by architecture of new registrations is as is depicted within Table 13, overleaf; showing strong growth of Plug-in (PHEV) & fully electric (BEV) variants but a decline in market penetration of grid-independent HEV variants. Such growth is indicative of the future direction of the German market.

Germany is presently struggling with reference to satisfactory achievement of EU regulations pertaining to vehicle fleet emissions; the EU had previously decreed that by 2015 new national vehicle fleets were to attain average CO_2 emission of no greater than 130 (g/km) yet Germany has achieved 132 (g/km) [106].

To aide in the accomplishment of 2021 EU regulatory targets of 95 (g/km), the German government is significantly pushing for 1m HEV & EVs by 2020 and a further 6m by 2030 [106] [107] [108]. A major driver of this is the development of public infrastructure to support HEV & EV up-take, in conjunction with significant fiscal incentives [106] [109] [110]. The focus of the following shall be investments.

Table 13 *German registration architecture breakdown for '14 & '15 year* [111] [112] [113] [114] [115].

		NEW REGISTRATIONS BY DRIVETRAIN ARCHITECTURE				
SALES YR.	**PROPERTY**	**HEV**	**PHEV**	**BEV**	**PETROL**	**DIESEL**
2014	Sales (thous.)	22.9	4.5	8.5	3,001 (est.)	
	Share	0.7%	0.16%	0.3%	98.8%	
2015	Sales (thous.)	22.5	11.1	12.3	1,600 (est.)	1,500 (est.)
	Share	0.6%	0.36%	0.4%	50.9%	47.7%
	%Change	-14.3%	+125%	+33%	-	-

Figure 41, below, presents the state of German public charging infrastructure as of 2015; as is visible there are numerous minor pockets of high public infrastructure density, mostly in cities (e.g. Berlin & Hamburg) [106] [116]. As of data publicly available for June of 2015, within Germany there are 5771 publicly located charging stations available for consume use; achieving average density of 0.14 chargers per thous. vehicles on German roads. As depicted within Figure 41, currents trends are that year on year the ratio of HEV & EVs to publicly available infrastructure is increasing; with ratio growth also increasing in rate [106] [116].

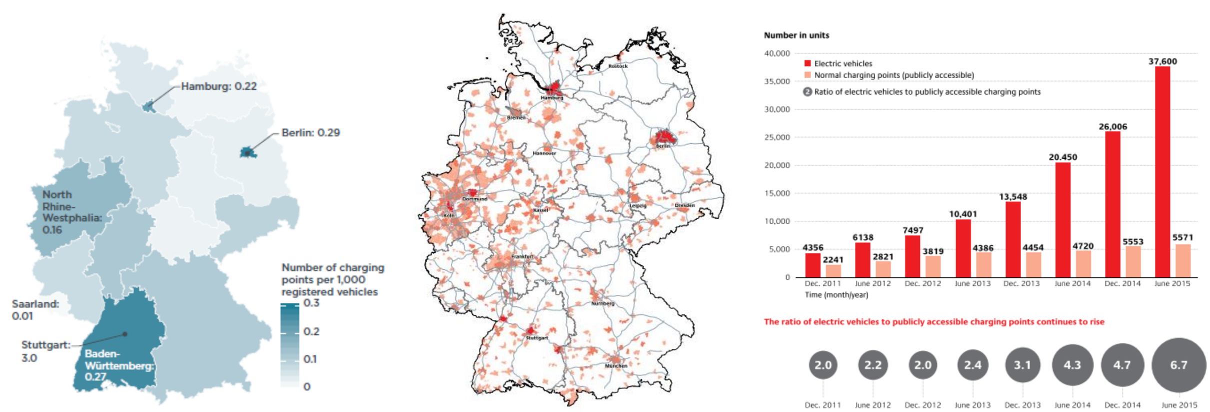


Figure 41 *Public charging infrastructure density in Germany (2015) & HEV & EV sales growth* [106] [116].

Estimations indicate that to ensure adequate availability of charging infrastructure to sustain targeted & forecast HEV & EV sales growth, through the period of 2017 through 2020 an additional 5,700 fast charging stations will be require to be installed within Germany's road infrastructure [116] [117]. Notable is that proposed installations are far below those declared by the EU Commission where-in Germany were targeted to install in excess of 150,000 public charging stations by the year 2020, though such targets were declared in 2013 where forecasts for HEV & EV up-take was significantly over-estimated [68] [67]. At present, there are both localized & centralized investment schemes pertaining to infrastructure development. For example, the EU Commission recently approved proposals for a £262m investment in German public charging infrastructure through till 2021 (four-year rollout of scheme) [118] [119]. On a local level, in Stuttgart, £3.2m of public funding was employed to install 80 public charging stations [106].

Furthermore, regional policies feature heavily in Germany, where-in for example in Stuttgart, HEV & EVs are permitted free parking on publicly owned parking lots; a policy which extends until end of 2017 [116].

It should be noted that at present much of the investment into German public charging infrastructure is focused upon *both* expansion of the capacity & rated power output of existing infrastructure and on the installation of both DC & AC fast charging stations [67] [117] [116]. Such investment is in-line with the findings of Section 4.2. where it was found within the UK, typical HEV & EV stop-overs are 3-4 hours which is suited to fast & rapid charging infrastructure capable of 0-100% SOC in 0.5-4hrs (See Table 11) [67].

With regards to hydrogen refueling infrastructure, current proliferation within German is low. Initial German targets were for a total of 50 hydrogen refueling stations to be installed by 2015 however by mid-2016 just 20 had become operational and a proposed milestone of 100 stations is not anticipated to be achievable with a revised target of 2018 [120]. A total of 400 stations are to be installed under the banner of the H_2 Mobility scheme; a cooperative development by energy giants such as Shell & automotive manufacturers such as BMW & Daimler which will deliver an investment of over £450m to EU hydrogen [105] [99] [121] [122]. By 2019, classified by the group as a short-medium term outlook, only 40 stations are anticipated to be built however, limiting potential up-take of H_2 fueled vehicles within Germany [105].

The UK is the next country to be assessed within this section of the report. As presented previously the market penetration of HEV & EV vehicles within the UK region is significantly greater than that of Germany; accounting for 2.8% of new vehicle registrations within the 2015 calendar year. As prepared for Germany, Table 14, below, presents a summary of vehicle sales by architecture in the UK [123] [124] [125].

Table 14 *UK registration architecture breakdown for '14 & '15* [124] [126] [127] [123] [125] [128].

		NEW REGISTRATIONS BY DRIVETRAIN ARCHITECTURE				
SALES YR.	**PROPERTY**	**HEV**	**PHEV**	**BEV**	**PETROL**	**DIESEL**
2014	Sales (thous.)	28.3 (est.)	7.8	6.7	1,283 (est.)	1,276 (est.)
	Share	1.1%	0.59%		48.8%	48.5%
2015	Sales (thous.)	24.8 (est.)	19.3	9.9	1,253 (est.)	1,261 (est.)
	Share	0.9%	1.1%		48.2%	48.5%
	Share Change	-19%	+133%	+48.3%	-1.2%	-

Continuing the investigation of infrastructure & incentives at a national level, hydrogen refueling stations in the UK will be explored, with assessment of UK public charging infrastructure performed subsequently.

At present, within the UK estimations as to the extent of H_2 refueling infrastructure vary however fall within the range of 6 operational refueling stations (HRS) as of mid-2015, 12 by end-2016 and around 16 HRS as of March of 2017 [56] [105]. Recent estimations indicate that said 16 HRS are currently serviced by 24 individual fuel pumps [105]. Such infrastructure is stated to have been constructed under the banner of an Office for Low Emissions Vehicles scheme; where-in £11m of public sector money was invested [129]. Future proposal, backed by leading energy firms such as Shell & ITM Power, indicate that by 2020 there will be 65 HRS across the UK and by 2030 proposals indicate growth to up to 1,150 UK-based HRS [105] [130] [131]. Figures pertaining to the required capital investment required to achieve such aggressive infrastructure installation proved elusive; suggesting that the targets are realistically unfeasible. Considering the above, in conjunction with information presented within Section 4.2., it can therefore be stated that it is highly unlikely that a growth of UK hydrogen infrastructure, to a point where-in support of mass market H_2-fueled vehicles can be sustained, is highly unlikely in a short-medium outlook. Such a conclusion is validated in that the DECC 2050 Pathway suggests that by 2050 just 20% of UK fleets will be comprised of H_2-fueled vehicles, accounting for 7m vehicles with today's forecasts [104].

At present within the UK there is a public infrastructure capable of sustaining HEV & EV up-take for a short-medium term outlook such as that considered within the scope of this investigation. As presented within Table 11 of Section 4.2., there are some 13,000 publicly available charging points within the UK; with an estimated 35-40% located in public car parks or at on-street parking bays [57] [60] [63] [132]. Estimations indicate on average 0.31 charging stations are available publicly across the UK per thous. vehicles; which is a ratio that is +100% greater than that achieved by Germany (refer to Figure 41) [106]. Reps of industry have represented that UK infrastructure is maintaining pace with HEV & EV growth [133].

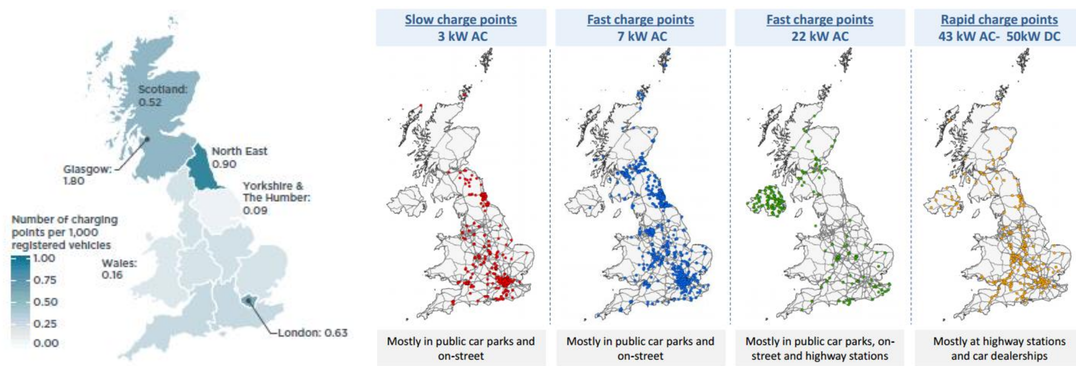


Figure 42 LHS *UK charging infrastructure density.* ***RHS*** *UK infrastructure by charging rate* [106] [88].

However, there is a growing threat that the UK's charging infrastructure growth, while adequate presently, requires to be improved to ensure satisfactory provision for future increased demand of HEV & EV uptake [134]. To combat this threat, the UK government has declared that a significant portion of a £600m investment in ultra-low emission vehicles between 2015 & 2020 shall be dedicated to improving availability of suitably rated charging point infrastructure [106] [135]. An estimated £32m of this fund shall be dedicated directly to public installations and with supporting schemes receiving additional funding; incl. £15m for expansion of home charging infrastructure & £11m towards "innovative" research [57] [136]. Expanding, the electric vehicle home charging scheme facilitates availability of up to 75% (or £750) of installation costs for private, home charging infrastructure [106]. In additional, a total of £9m in funding has also been set aside for maintenance & improvements to existing infrastructure networks [57]. On a localized level, there is also significant investment; e.g. in London, there is an on-going investment of £2.5m to develop a zero emissions zone within the city center, baring entry of conventional, non-HEV or EV vehicles, installation of EV-only charging bays & improvements to general charging points [137]. In addition, vehicles with tailpipe emissions below 75 [gkm^{-1}] In-direct incentives, such as the permission for HEV & EVs to utilize bus lanes & high occupancy lanes is prevalent within local authorities, with Glasgow being a direct example of this; Nottingham planning a 6mi EV-exclusive lane in late 2017 also [106] [138]. In addition, under the Go Ultra-Low scheme, 25,000 free parking bays will be assigned for EVs, which under current estimations could be capable of saving a city-based commuter upwards of £1,300 per annum [135].

With reference to targeted expansion of the UK's charging infrastructure, similar to Germany, current proposals are significantly reduced in comparison to EU Commission targets; however recall such targets were set under circumstances where-in HEV & EV uptake had been drastically overestimated [67] [68]. A target of 122,000 publicly available charge point by 2020 was dictated by the EU Commission in 2013, however current proposals indicate that the UK's target is set to addition of 8-10k points in-line with studies pertaining to assessments of adequate coverage of road network & the economics of installation costs [88]. Some regional & national level agencies are developing investment proposals of their own; e.g. the Highways England is preparing to invest significant funds (£23m, £8m of which is publicly sourced) to achieve charging stations every 20mi along UK motorways and Transport Scotland is investing £2.7m to secure development of workplace charging infrastructure across Scottish businesses [139] [140].

Finally, the status and future of Norwegian infrastructure developments shall be presented. As alluded to, at present Norway's is experiencing a boom of HEV & EV sales; significantly greater than the accepted European averages, & indeed greater than all nearby EU Member states. In 2016 sales of HEV & EV vehicles experienced a growth of 39.6% on previous year's total and comprised in excess of 40% of total new vehicle registrations within Norway [141] [142]. In terms of architecture specific sales, plug-in vehicles rose 63% year-on-year where-as fully-electric model sales fell 6% year-on-year; however fully-electric continues to sell greater volumes than plug-in hybrids with sales of 24,265 compared to 20,663 units [141]. Figures 44 & 45, overleaf, depict the architecture breakdown across a period of January 2015 through November 2015 within Norway, expressing the trend in growth plug-in sales & stagnation of EV sales [141]. As of January 2017, reports indicate that the market share of diesel-vehicles within Norway is sub-13%; with the national government investigating potential future restrictions on the use of said fuel [143]. With year-on-year growth of 129.5% & 71% from '13-'14 and '14-'15 respectively, the growth of HEV & EV sales within Norway is on par with targets for all registrations electrified by 2025 [143].

With respect to hydrogen infrastructure, at present the foothold in Norway is near non-existent with just five operational stations (HRS) within the borders of the country; four of which are in Oslo & its immediate surroundings [144]. H_2 Logic, a Norse HRS manufacturer, has indicated plans to develop 20 HRS across the country by 2020, therefore, whilst anticipated to remain too small to sustain mass-market adoption of H_2-powered FCEV vehicles, hydrogen refueling infrastructure within Norway is at least growing [144] [145]. Figure 43, below, depicts current locations of operational Norwegian hydrogen refueling stations [146].

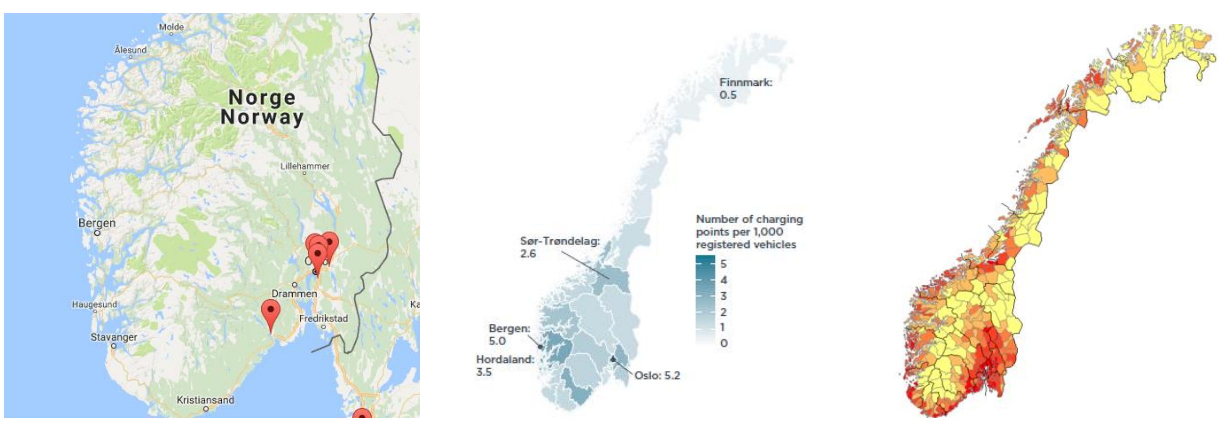


***Figure 43 LHS** Positioning of Norway's 5-operaitonal HRS. **CENTER** Norwegian charging infrastructure density. **RHS** Norwegian population density, where-in red indicates high population density* [106] [94].

With regards to charging infrastructure, at present, Norway averages around 2.4 publicly available charging points per 1,000 registered vehicles within the country [106] [115]. As is visible within Figure 43, existing infrastructure is focused in pockets of extremely high charging infrastructure density, such as Oslo at 5.2 & Bergen at 5.0 points per thous. vehicles; however, such is reflective of Norway's population density where-in 80% of Norway's population lives in urban environments (e.g. towns & cities) [106] [147].

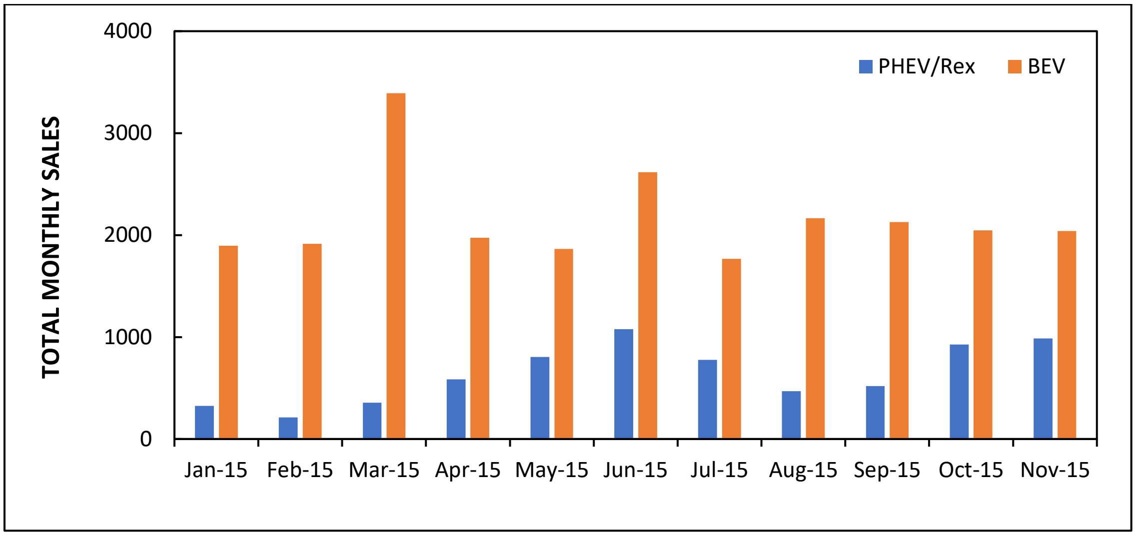


Figure 442 *Total monthly sales of both Plug-in / Range extender models and fully electric BEV models.*

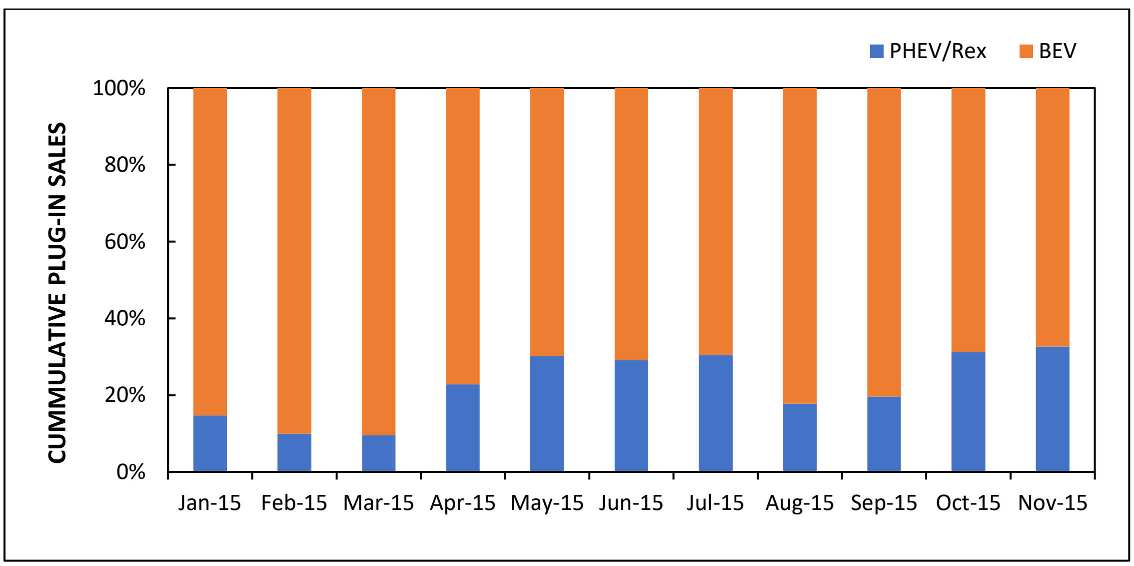


Figure 45 *Plug-in sales depicting the growth of plug-in hybrid sales (PHEV) vs. fully-electric (BEV).*

With regards to developments & investment in Norway, since infrastructure is already significantly large & mature, there are currently few national policies nor projects targeting HEV & EV infrastructure growth. However, details of historic investments are known. For example, throughout 2009-10, £5m was invested in subsidizing public charging infrastructure; with charging point installations estimated to have cost

£2,750 per unit, a significant number were likely installed, though totals remain unpublished [106] [148]. In addition to several other national investments in infrastructure, regional policies support the adoption of both HEV & EV vehicles; within Oslo, BEVs are facilitated free access to the city's toll-roads, which would otherwise cost around £3.50 per passage. Similarly, BEV owners are permitted access to the cities bus lanes and are afforded subsidized free parking and charging of vehicles within public carparks [115] [149]. In other regions, such as Hordaland, where-in the city Bergen is located, it is mandated that 20% of all new public parking spaces must have facilities for HEV & EV charging & ferry crossing rates are subsidized [106]. With regards to current developments, Norway recently constructed the largest charging station in the world; the facility houses 20 Tesla superchargers, four 50kW DC and four 22kW AC chargers [150] [151].

The main conclusions drawn via this assessment and comparison of European nations, for which the HEV & EV markets are at various levels of maturation and where infrastructure density differs, are as follows;

- As German fiscal incentives are comparable to those of the UK yet HEV & EV market penetration is significantly reduced by comparison, the group has concluded through consideration of the above that to enable commercial viability of a new HEV or EV concept, adequate pre-existing & compatible infrastructure must be provisioned in conjunction with significant fiscal incentives to enable sustainable up-take. This conclusion is supported by the secondary comparison of both the UK & Germany to Norway; where-in significant infrastructure and fiscal incentivization are present and both HEV and EV vehicle registrations are significantly larger the UK & Germany, growing rapidly year-on-year.

- Hydrogen infrastructure, whilst growing through significant European investment and whilst at an adequate level of technological maturation, cannot sustain short term mass-uptake of fuel cell electric vehicles (FCEV) without significant subsidization; total cost of ownership will remain a barrier till 2030.

- Plug-in charging infrastructure has achieved a level of standard maturation where-in mass up-take of plug-in and fully-electric vehicles (BEV) can be sustained. Demonstrated within studies, power output of current infrastructure has been proven to be sufficient for driving distance & stop-over behaviors. Type-2 is anticipated to dominate European regions due to both policy & preexisting proliferation.

- Though largely sufficient within the UK today, further investment is required to facilitate adequate future provision of charging infrastructure; especially work & public points to reduce exacerbation of grid-demand spikes. Disruptive technologies e.g. induction charging (see Section 4.8.) could aide in this regard. Also, as demonstrated by Figure 36, use of smaller EV capacities can reduce grid demand.

- Though not discussed within the text, in Norway educational & behavioral improvement schemes were demonstrated to enable growth of HEV & EV sales; alleviating range anxiety & unfamiliarity [106]. This supports arguments made previously within Section 3., where-in barriers to up-take were considered and recent investments in centers for excellence & education were concluded to be worthwhile.

4.3. INFRASTRUCTURE TRENDS – REGIONAL & CITY LEVEL

4.3.1. SECTION INTRODUCTION

Required within the agreed contract, the group performed an investigation into and summarized HEV & EV infrastructure developments within four major UK cities; one of which, as required, was Glasgow. Within this section a brief overview of the methodology for additional city, or township, selection will be outlined, a detailed summary of Glasgow infrastructure developments shall be presented and in support, a detailed summary of the most promising additional city, Milton Keynes, shall also be presented. Highly condensed summaries for both Bristol & London, the two remaining cities, shall be presented also[1].

4.3.2 METHODOLOGY FOR SELECTION OF UK CITY CASE STUDIES

As outlined within the Statement of Contract & above, a significant component of the long-term research task was that of identification of a summary of infrastructure developments within four major UK cities. Although exploration & discussion of Glasgow was explicitly stated as a requirement, the remaining three cities were at the discretion of the Project Group. Therefore, a structured methodology was implemented to facilitate meaningful selection of case study cities. The approach undertaken is summarized as follows;

- ✓ Identify key criteria for city &/or township selection through preliminary research
- ✓ Identify a shortlist of cities, or townships, which satisfactorily meet identified criteria
- ✓ Perform preliminary research for all shortlisted cities; attempt to identify USPs
- ✓ Assess value to project specific outcomes & merits of each shortlisted city, or township
- ✓ Conclude on city, or township, selection & reflect on success, or failings, of process

Regarding criteria applied to identify prospective cities & townships, that which was utilized was follows;

- ✓ City must be a commuter hub; where-in more person's commute in than out
- ✓ City required to be engaged with significant national level HEV, EV schemes or both (or alt. fuels)
- ✓ City required to have some form of research or public outreach hub – e.g. Glasgow's AFRC
- ✓ City must be congested or have an equivalent issue potentially fully, or partially, alleviated by HEV / EVs

Ultimately, the above criteria-based methodology for major UK city case study selection proved successful in regards to its intended purpose of provision of justified & meaningful identification of regions of HEV, EV and alternative fuel infrastructure development. Such will become visible in corresponding sections of this report where-in each case study city is assessed. Cities identified throughout this process were that of London, capital of the UK & located in South East England; Bristol, located in South West England; and Milton Keynes, located in the southern third of England, though remaining North West of London. Overleaf, Figure 46 expresses geographic locations of the identified cities & Tables 16-18 present high-level statistics, relevant to above criteria, to facilitate inter-city comparisons [152]. Throughout the following passages, summaries of these cities, in additional to Glasgow, Scotland, shall be presented.

[1] **N.B.** All cities investigated to similar depths; details for all to be published on group website in due course. A decision was made that to avoid an excessively large infrastructure section, detailed presentation would be limited.

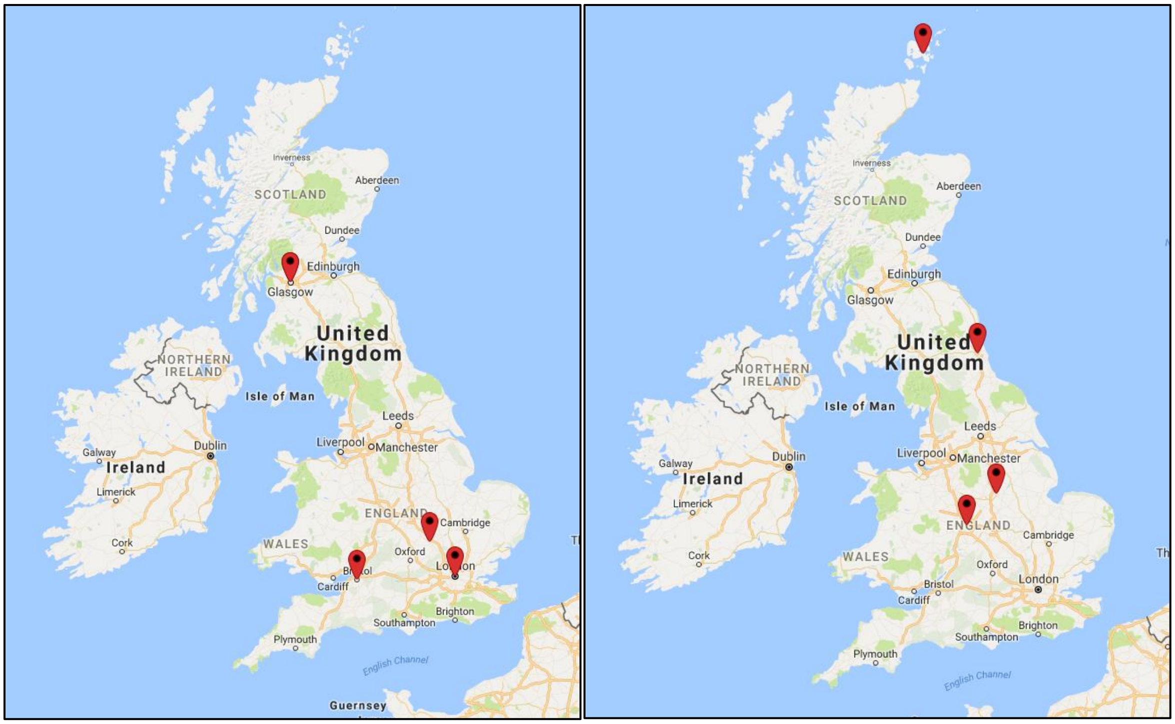


***Figure 46 LHS** Cities investigated within the UK (North to South: Glasgow, Milton Keynes, Bristol & London).*
***RHS** Cities considered & later neglected (North to South: Orkney, Newcastle, Nottingham & Birmingham).*

4.3.3. GLASGOW DETAILED ASSESSMENT

***Table 15** Tabulated data for Glasgow; population, area and infrastructure* [153] [154] [155] [156] [106].

PROPERTY	MAGNITUDE (Various Units)
Population (thous.)	1,200
Net size (km^2)	370 (est.)
Population Density (km^{-2})	3,250 (est.)
Net Commute (day^{-1})	115,597
Electric Vehicle Charge Points	**Standard & Fast:** 71; **Rapid:** 9
Regional Charge Density **(thous. Vehicle^{-1})**	1.8

Greater Glasgow's charging infrastructure compares well to the UK's national average density of 0.3 charging stations per thous. registered vehicles; the city & surrounding borough, as depicted in Table 15, achieves sextuple the current UK average at 1.8 charge points per thous. registered vehicles [156] [106]. Below, Figure 47 depicts the distribution of residential populations in comparison to the distribution of public charging infrastructure within Greater Glasgow. This comparison, in conjunction with a fundamentally high level of familiarity with Greater Glasgow enabled in-sight into strategy employed by city planners with respective to HEV & EV charging infrastructure deployment; namely that within the commercial city center where-in short-medium duration stays are the norm (e.g. shopping, work & university parking) a focus is for fast charging infrastructure, which as presented within Table 11 of Section

4.2., is capable of servicing modern HEV & EV from 0-100% SOC in around 1-4 hours (depending upon exact charge rates). Rapid charging is employed to supplement fast infrastructure along major roadways. Noteworthy is that a low presence of public charging within known residential regions suggested an expectation, or reliance, upon private charging infrastructure for HEV & EV servicing to the group.

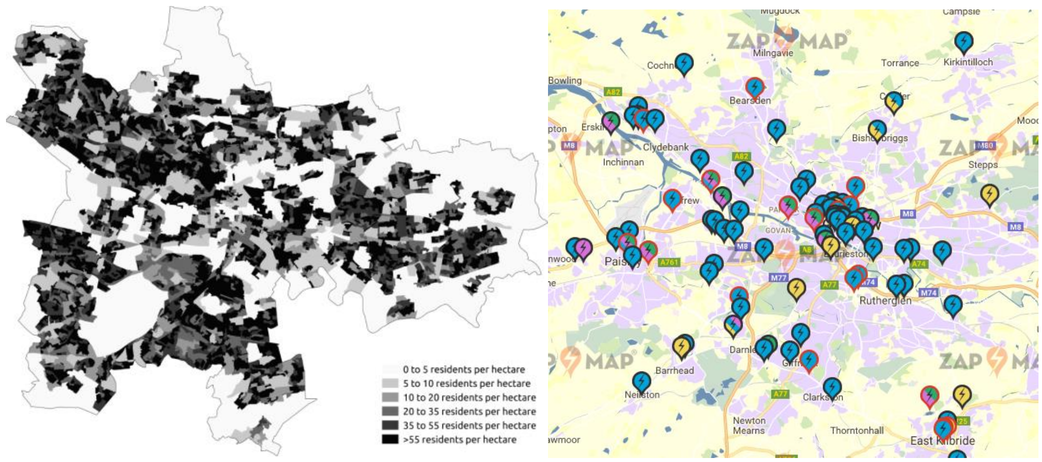


Figure 47 LHS *Population density heatmap image of Greater Glasgow region (White=Low & Black=High).* ***RHS*** *Charge point distribution for Greater Glasgow (Yellow=Slow, Blue=Fast & Green=Rapid)* [56]*.*

With respect to infrastructure developments, Glasgow, & indeed Scotland, has benefited greatly from investment from both the Scottish & UK governments historically. For example, as per the Energy Saving Trust & Transport Scotland, who oversee Scotland's transport infrastructure development, public and private organizations which can demonstrate significant need for on-site charging infrastructure may apply for & receive supportive funding [106] [157]. In addition, though the fiscal details are inconsistent, a corridor of infrastructure servicing the route from Glasgow to Edinburgh was installed under the UK's, at the time premier, Plugged-in-Places program through funding of between £1.5m-£2.2m [106] [158] [159]. Furthermore, within Scotland & there-in servicing Glasgow, there are non-fiscal and non-physical developments such as the Electric Vehicle Network where-in potential HEV or EV buyers can contact an established network of existing owners to request details of everyday experiences with said vehicle architectures [106] [160]. In addition, within Glasgow city center, located nearby the Hydro Exhibition Centre, there is a relatively unknown "Power of Now" Center for Renewable Excellence where-in prospective HEV or EV buyers may short-term lease vehicle to experiment & gain hands-on familiarity with the technology [161]. Considering too, the development of automotive-related expertise within Glasgow, research centers such as the Advanced Forming Research Centre are aiding in developing Glasgow's reputation & level of expertise; e.g. successful development of manufacture quality assessment techniques for Terex industrial trucks [162]. Noteworthy however, is that recently Glasgow City Council repealed incentives where-in HEV & EVs could park for free in publicly funded charging bays, which was a decision made to reduce consumer demand as at present estimations, within Glasgow, provision of charge points cannot satisfy demand due to issues pertaining to bay use, since they offer free parking to HEV & EVs, when no charge is needed [163]. In addition, in September 2015, Glasgow participated in Scotland's first EV rally, where-in sixty vehicles journeyed from Sterling to Glasgow; demonstrating a £1.50 cost vs. £9 equivalent for petrol [164], as presented within Figure 48. In addition, car clubs are developing where-in significant numbers of vehicles are available.

Figure 48 *Two images taken from the Stirling to Glasgow EV Rally held in September of 2015* [164].

With respect to conclusions pertaining to Glasgow, it is evident that development of increased familiarity & public-level confidence in HEV & EV vehicles can be achieved within Glasgow; schemes, such as the Power of Now expertise center & short-term leasing schemes, growth of car clubs (Section 4.4.) and the presence of national schemes where-in exiting & prospective HEV & EV buyers can engage in dialogue. Publicly-promoted events too, such as the electric vehicle rally scheme will also aide in decentering HEV & EVs within the public domain. Success is already achieved as early 2017 saw a poll indicating support for investment in EV buses; indicating growing confidence & appreciation for alt. powertrains [165]. In addition, growth of expertise within the city is likely to be supported through existence of strong research hubs such as the Advanced Forming Research Center. Such a knowledge base growth is vital in insuring that services for maintenance & up-keep of existing & future HEV or EVs on Glasgow's roads are adequately developed to match consumer demand, as EV up-take grows. In terms of a significant learning outcome, Glasgow highlighted the importance of well-structured & robust supportive policies & legislation; where-in the current issues pertaining to charge bay availability demonstrate that even with adequate provision of charge point numbers, the intra-city networks require to be managed effectively.

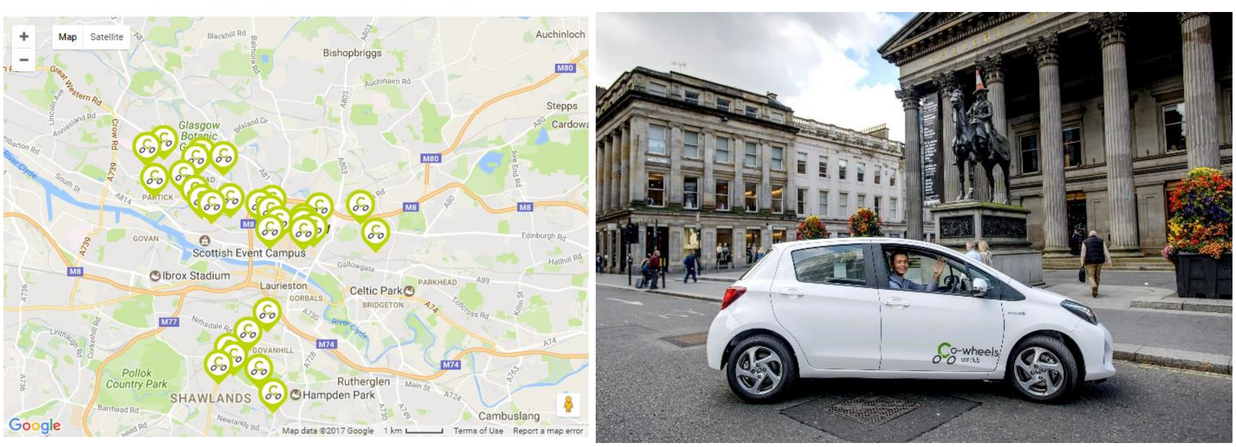


Figure 39 LHS *Spread of car club locations.* ***RHS*** *A typical vehicle employed within Glasgow clubs* [166] [167].

To conclude, although assessed in detail due to contractual requirements, the group elected to reflect on Glasgow's degree of acceptance of the stated criteria employed to identify additional towns for assessment. Though generally performing well, Greater Glasgow suffers in that it is no longer a beneficiary of a premier, national-level investment scheme e.g. Go Ultra Low Scheme (GUL); where historically it has [106] [158]. For reference of an example of acceptance of most criterion, Glasgow satisfies both the first & third criterion significantly well; net commuting is +115,597 & resident retention rates are significantly high and both the Advanced Forming Research Centre & aforementioned "Power of Now" Scottish Hydro Centre for Renewable Excellence demonstrate both research & outreach. In addition, within Glasgow there are an estimated 306 deaths related to air pollution and an estimated 3,333 associated life-years lost per annum [168] [169]. When considered in conjunction with general failings to meet air pollution targets & with some of the worst levels of airborne pollution in the UK, it becomes evident the fourth criterion is also satisfactorily met as growth of HEV & EV could reduce localized particulates. Therefore, as stated within the above, though holding generally rather well against the selection criteria, the lack of participation, or investment from, premier national-level schemes such as "GUL" dictates that Glasgow does not satisfy the 2nd criterion & would therefore likely not have been assessed if not required by contract. The group however are glad that Glasgow was chosen; primarily due to preexisting familiarity.

4.3.4. SUMMARIES OF ADDITIONAL INTER-CITY INFRASTRUCTURE DEVELOPMENTS

4.3.4.1. BRISTOL DETAILED ASSESSMENT

Table 16 *Tabulated data for London; population, area and infrastructure* [154] [170] [171] [172].

PROPERTY	MAGNITUDE (Various Units)
Population (thous.)	449.3
Net size (km^2)	115.4
Population Density (km^{-2})	3,892
Net Commute (day^{-1})	26,326
Electric Vehicle Charge Points	**Standard & Fast:** 100+; **Rapid:** 15
Regional Charge Density (thous. $Vehicle^{-1}$)	0.25

At present the region in which Bristol is located falls short of UK's average charging infrastructure metric; where just 0.25 charge points are available per thous. registered vehicles, in comparison to 0.3 UK-wide [106]. Figure 50, overleaf, provides distribution of both population & charging infrastructure spread within Bristol City; from comparison & general knowledge of the area, it is clear that infrastructure is targeted to service industry (North-Fast), residencies (Center) & new-build commercial (North-Rapid) [56].

Regarding highlights of historic investment & development across the Bristol City region;

- ✓ £100k investment for 36 charge bays in 12 locations across the city in 2012 [173]
- ✓ £1m investment in over 100 charging bays within Bristol in 2014 [174]
- ✓ Performance of autonomous vehicle trials as part of a 3-yr, £5m R&D program beginning 2016 [175]
- ✓ Research schemes conjunction with regional universities (Bristol & Bath) pertaining to autonomy [175]

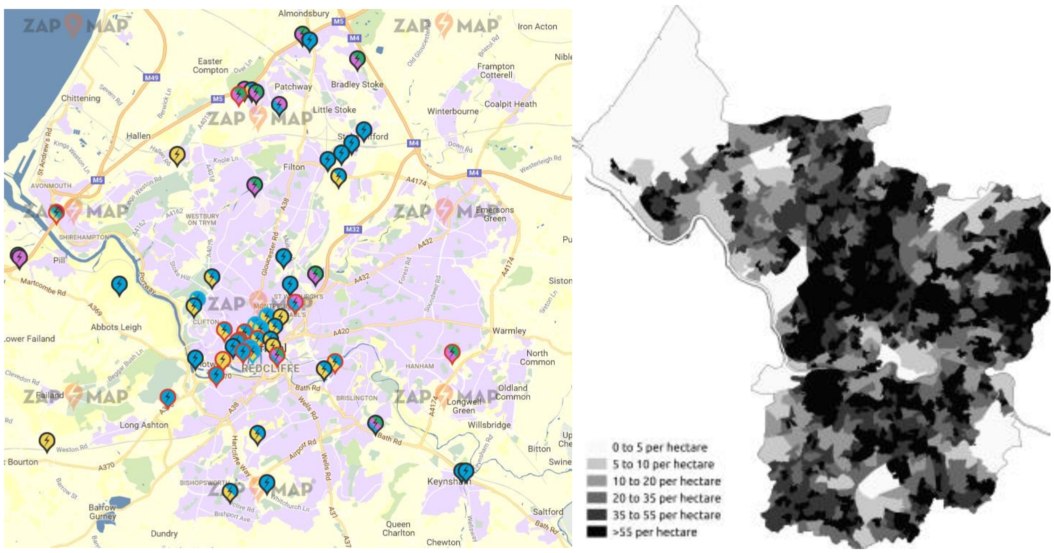


Figure 50 LHS *Distribution of charging infrastructure of Bristol (Yellow=Slow, Blue=Fast & Green=Rapid).* ***RHS*** *Population density heatmap of Bristol; White=Low & Black=High population density* [56].

With regards to future investments & infrastructure developments within Bristol;

✓ Tendering towards becoming UK's first 5G-connected city; an enabler for autonomous vehicles [176]
✓ £7m investment with UK's Go Ultra-Low scheme; provision of free residential ULEV parking [177]
✓ As per the above scheme; investment in provision of ULEV access to three car-pool lanes [177] [178]
✓ As the above scheme; investment towards 80 new rapid chargers across the city [178]
✓ Provision of a short-term (4 wk.) plug-in leasing scheme within the city [177] [179]
✓ Targets for 5,000 HEV or EVs on Bristol's roads by 2020; in conjunction w/ "clean air" zone [180]
✓ Continued expansion of UK's National Composites Center; developing CFRP & GFRP manufacturing.

The most significant learning outcomes of Bristol was that throughout periods of initial investment; though there was available infrastructure, it proved to be rarely utilized, suggesting that even with fiscal incentives and adequate infrastructure, HEV & EV sales had failed to mature. For example, in 2015, though £1m had been invested in local infrastructure utilization rates were, on average, less than once per month [174]. The group concluded that the lack of prominent national-level investment, such as that experienced by other cities under the Plugged-in-Places program in conjunction with a lack of prospective buyer support networks were major contributors to the initial lack of utilization; reinforcing the group's suggesting of improve STEM outreach & consumer awareness to mitigate up-take barriers (Section 3.). In terms of future growth of HEV & EC ownership within Bristol, the group has concluded that the aforementioned measures undertaken as part of the Go Ultra-Low scheme should be satisfactory.

With regards to satisfaction of the required criteria for selection, the group firmly believes the above demonstrates adequate provision of requirements. With respect to the potential for mitigation of issues through growth of HEV & EV sales, pollution is the biggest influencer; An estimated 196 persons die prematurely per annum due to air pollution within the city, with up to 2048 associated life-years lost [181]. As Bristol congestion results in double journey times due to stop-start; synergy with EVs is achievable [182].

4.3.4.2 MILTON KEYNES DETAILED ASSESSMENT

Table 17 *Tabulated data for Milton Keynes; population, area and infrastructure* [183] [184] [185].

PROPERTY	MAGNITUDE (Various Units)
Population (thous.)	264.4 (est.)
Net size (km^2)	89 (est.)
Population Density (km^{-2})	2,971
Net Commute (day^{-1})	25,000 (est. 2009)
Electric Vehicle Charge Points	**Standard & Fast:** 170; **Rapid:** 56
Regional Charge Density (thous. Vehicle^{-1})	0.6

Milton Keynes public charging infrastructure compares well to the UK's national average density of 0.3 charging stations per thous. registered vehicles; the city & the surrounding borough, as depicted above in Table 17, achieves double the current UK average at 0.6 charge points per thous. registered vehicles [106]. Figure 51, below, presents the distribution of charging infrastructure within Milton Keynes in comparison to residential densities; such comparisons facilitate identification that the current strategy of deployment is for slow & fast charging infrastructure to be localized to the city center & industrial heartland regions, where-in extended durations are expected for stop-overs (e.g. 9am-5pm working hours), with supporting rapid charging facilities distributed near major road infrastructure & junctions for short-term stops [186] [187]. Low dispersion rates of public charging in residential regions indicates reliance on private funding.

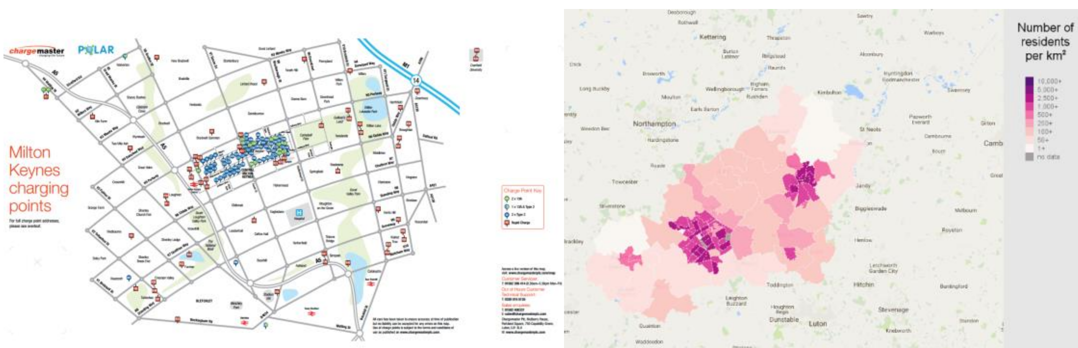


Figure 41 LHS *Charge point location distribution in Milton Keynes (Green=Slow, Blue=Fast & Red=Rapid).* ***RHS*** *Population density heatmap for Milton Keynes (White=Low Pop. & Purple=High Pop.)* [186] [187].

With regards to the development of existing public infrastructure Milton Keynes has benefited from participation in the UK's Plugged-in-Places program; as one of an original three participating cities, funding for the program initiated in 2010 and continued until the designated end-of-life in 2013 [159]. At scheme end, there were 168 fast charging points & 5 rapid points within the borough, again with most situated in city center with conventional 3-pin and Type 2 connector standards comprising the entire network [159] [188]. Estimations are that around £180,000 was invested into Milton Keynes throughout the first three years of the scheme [189]. In 2014 a further investment in a further 50 rapid charging points was committed to Milton Keynes, with funding principally sourced from public enterprise investment schemes [188]. Though growth of the Milton Keynes charging network has stagnated somewhat, investment has not faded; most recently demonstrated in the awarding of a £9m share of a combined £40m in funding under the UK's premier HEV & EV scheme, "Go Ultra-Low" [135] [177]. The founding principles of the borough's successfully tendered bid were as follows; construction of a city center Electric Vehicle

Experience Center which shall provide consumer advice & short-term EV vehicle leases under a test-scheme, provision of 20,000 parking bays free to EVs, provision of near-to-home public charging infrastructure for residents without off-street parking, provision of plug-in access to low-emission lanes (read: bus lanes) and lastly provision of the same priority at traffic lights as local buses for plug-in vehicles [177] [135] [106] [190]. In addition to the above, the council is pushing for development of Milton Keynes reputation for automotive & alternatively-fueled vehicle excellence, where-in significant conferences such as the 2016 Landor's Annual National Smarter Travel Exhibition and the 2016 Sustainable Transport Conference [191]. In addition, in a bid to further become a region of technical expertise, the UK's highest-capacity HEV & EV testing facility was opened; pertaining to deliver "cutting-edge" plug-in vehicle technology. Develops state that up to 100 jobs will be generated through the development and the investment will support "thousands" of more highly skilled jobs across the low emissions vehicle sector [192]. Furthermore, at present, a fleet of eight electrically-powered buses have been operating in Milton Keynes since 2015. Though the principles of the scheme are discussed in detail within Section 4.8., the scheme has proven successful servicing an estimated 800,000 passengers per annum across a 15mi route. So, successful, in fact, that recently a commitment was made to invest £1.75m for expansion [193] [194] [195] [196]. Finally, two car club schemes, whose operation & merits are assessed within Section 4.4., are heavily promoted by the borough council [197] [198].

With respect to the group's primary task of identifying the most sustainable HEV or EV package within a short-medium outlook within the UK, consideration of the above indicates unambiguously that developments in infrastructure within the Milton Keynes borough are both substantial & significant. The hosting of international & trans-national conferences & the presence of the UK's largest testing facility within the region will, in the group's view, develop a feedback loop offering benefits to availability of technical expertise availability which can support HEV & EV drivers (e.g. growth in availability of servicing). In addition, prominent schemes such as the EV bus routes, car clubs and the Electric Vehicle Experience Centre will aide in familiarizing the general populace with alternative fueled vehicles & should significantly aide in demonstrating both benefits (e.g. reduced emissions & running costs) and viability of modern HEV & EV ownership which, ultimately, should promote increased up-take of alt.-fueled vehicles. That charge point use near-doubled between Q4 of '15 and Q1 of '16 gives indication of the successes thus far [184].

In terms of acceptance of the criteria implemented throughout the township selection process, Milton Keynes comfortably achieves all required, hence its selection for detailed assessment. As is depicted within Table 17, net commuting is +25,000 by 2009 estimations with an estimated 80% daily retention ratio for its permanent residents [185]. As described previously, the second criteria pertaining to participation within national-level HEV & EV schemes is satisfactorily met. Reiterating, significant fiscal investment through the UK's premier HEV & EV scheme, "Go ultra-Low", of £9m in conjunction with the operational induction charging electric bus pilot scheme and historic participation within the "Plugged-in-Places" scheme exemplify adequate achievement of the stated criteria. With regards to the criteria pertaining to local involvement with outreach & research, that Milton Keynes is constructing an Electric Vehicle Experience Centre offering direct consumer support & advice, in addition to hosting of both trans-national & international automotive & alternative fuel vehicle events is testament to satisfactory achievement. And finally, with regards to the presence of an issue which HEV & EV vehicles may alleviate in part, or in full, air pollution remains the biggest factor. Though not presented, 2010 statistics indicate that there are 89 deaths per annum due to air pollution in the region, with estimated 1047 associated life-years lost [181].

4.3.4.3. LONDON DETAILED ASSESSMENT

Table 18 *Tabulated data for London, considering population, area and infrastructure* [199] [200] [201].

PROPERTY	MAGNITUDE (Various Units)
Population (thous.)	8,700
Net size (km^2)	1,572
Population Density (km^{-2})	5,491
Net Commute (day^{-1})	519,000
Electric Vehicle Charge Points	850+ public stations
Regional Charge Density (thous. Vehicle^{-1})	0.63

To briefly summarize, as depicted within Table 18, London has a charging infrastructure density per thous. registered vehicles in-line with the UK national average; 0.63 for London and 0.6 UK respectively [106]. As shown within Figure 52, investment within public infrastructure are focused within central London, where-in both population density is at its highest & where-in a significant number of person(s) work. This is supported given that future installations (yellow) are also centrally-located. At present, non-centralized infrastructure is largely distributed along main road infrastructure connecting the ring road & city center.

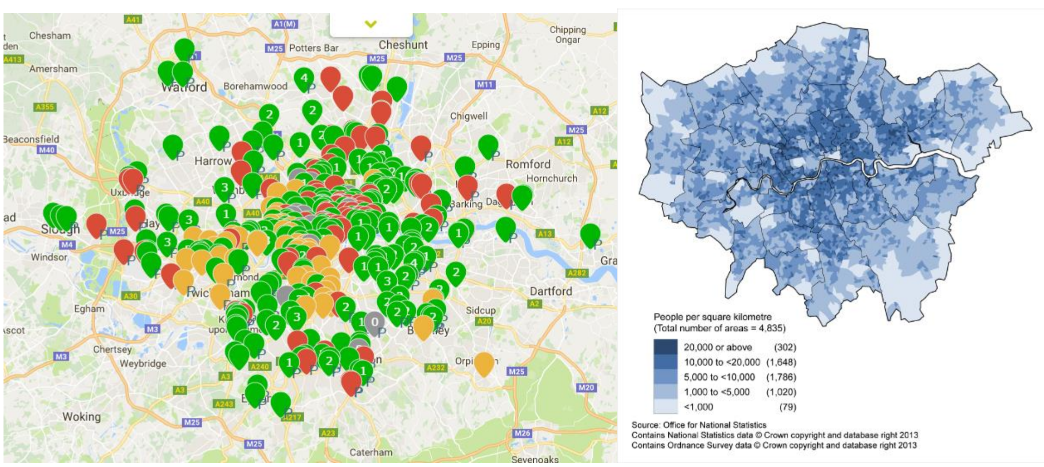


Figure 52 LHS *Distribution of London charging stations.* ***RHS*** *Population density of London* [202] [203].

With respect to highlights of pre-existing infrastructure & historic investment, see as follows [106];

- ✓ £9.3m of funding through Plugged-in-Places scheme; installation of public charging infrastructure
- ✓ £9.3m of funding from a private-public consortium, incl. Transport for London; charging infrastructure
- ✓ Establishment of motorway-located H_2 refueling stations; backed by ITM Power & Shell (Section X)
- ✓ Free or reduced cost parking for HEV & EV drivers within the borough; e.g. Westminster
- ✓ Majority exemption of EV from congestion charge (£11.50 p.d.); sub-75g/km CO_2 required

With respect to both recent & future infrastructure developments, highlights on London include [106];

- ✓ £20m public funding via "Go Ultra-Low Scheme; localized charging infrastructure & parking priority
- ✓ Maintenance of a subsided free parking program at Westminster; delivering 70,000 ULEVs by 2020
- ✓ Partnership with inter-city knowledge sharing group Electric Vehicles in European Cities (EVEC)
- ✓ £8m investment in trials of innovative infrastructure & close-to-home charging city-wide
- ✓ £4.5m investment into retrofitting 1,000 charging points to support car club infrastructure growth
- ✓ £4m investment towards expanding rapid charging infrastructure across the city; 30 charge points
- ✓ £3.5m for trial schemes in eight boroughs, incl. street-side lighting-based charging infrastructure
- ✓ Share of a £31m investment in H_2 refueling infrastructure across Europe under the HyFive scheme
- ✓ Requirements for 20% of all public parking to facilitate HEV & EV charging by 2030

Notable is Transport for London accessed the viability of access for ULEVs to existing bus lanes, similar to aforementioned Milton Keynes, however decided it would potentially negatively impact congestion [204].

Regarding conclusions for London, the most significant findings were those of the promising future for HEV & EVs within the region; fiscal investment in conjunction with significant supporting policy incentives such as provision of free parking bays should enable greater up-take of alt.-fueled vehicles. In addition, it was of note that private-public consortiums were raising capital; indicative of promising economics [106].

The group are confident that all of the above adequately satisfies most defined criteria for city selection. With respect to the potential alleviation of issues within London through up-take of HEV or EV sales, pollution again remains the largest influence; an estimated 9,300 early deaths occur in the capital (1-in-10) & with Public Health England advising persons not to exercise outdoors [205] [206]. Figure 53, expresses a distribution heatmap for NOX emissions within London, emphasizing the issue at hand. Clearly the up-take of general HEV & EV vehicles would be of beneficial as tailpipe emission reductions are achievable.

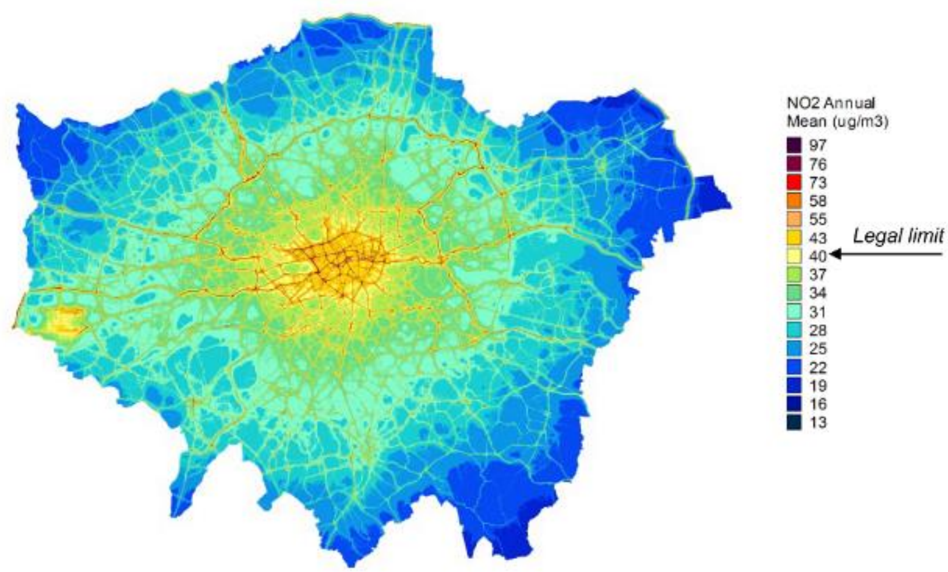


Figure 53 Heatmap of London-based NOX emissions; showing regions breaching legal limits [207].

4.4. SOCIAL ENTERPRISE INFRASTRUCTURE

4.4.1. SOCIAL ENTERPRISE INTRODUCTION

Across the globe, there is growing expansion of an innovative business model known within commercial circles as automotive car clubs. The model provides consumers with a service where-in for fixed, pre-determined & pre-agreed rates, typically per hour or per day charges, the consumer can obtain short-term, private access to a communally shared vehicle. Within this brief report section, an overview of the business model & some of its variations shall be provided in conjunction with a summary of existing schemes, with a predominate focus upon both the UK and European markets. A conclusion regarding the relevance towards the mass up-take of HEV, EV and alternate fuel vehicles shall also be provided.

Though not initially obvious, the relevance of car clubs to the project is that, as will be discussed in an upcoming segment, promotion of HEV & EV technologies could be achieved through car club proliferation.

4.4.2. SOCIAL ENTERPRISE CAR CLUB BUSINESS MODEL & OPERATION

Car Clubs provide an alternative to conventional private vehicle ownership and their fundamental operating principles are that upon performing a request, club members are granted short-term, though for the period of access still private, access to communally sourced vehicles. Club members typically pay a flat monthly or annual access charge and then pay an agreed cost in relation to their actual club usage; typically, per mile, per hour or per day rates are charged. The business model is applicable for both commercial fleet and private ownership applications and can be likened to that of bicycle hire schemes which have operated successfully for several decades, though these are notably more reliant upon tourism than their emerging automotive-based counterparts. At present, most schemes operate with systems in place which facilitate club member requests for vehicle access to be raised through several convenient methods; principally through online websites, telephone or, in some of the more advanced cases, through mobile apps. Requirements for fulfilling requests are ideally short & simple to perform though do typically include stating the type of vehicle required, a proposed duration of access and provision information regarding the intention for access. Notable is that durations for vehicle access can be varied; hourly, daily, overnight, weekend & even weekly or monthly rates are commonly available which enables the degree of flexibility required for consumer convenience [208] [209] [210] [211] [212] [213] [214].

Assuming suitable vehicle availability, often guaranteed by fleet operators through provision of large numbers of vehicles within a club's fleet, approved requests are then actioned by the consumer by travelling to fixed locations across the relevant town or city and collecting the relevant vehicle; windscreen-mounted RFID chips & personally identifiably access cards typically provide means of member verification and provision of vehicle access. Users are assigned a specific vehicle within the fleet for their requested usage and common pick-up locations include commercial & transportation hubs such as shopping centers and railway stations. For larger clubs, networks of collection points across numerous cities facilitate inter-city & one-way journeys, though most journeys remain two-way return [208] [213].

Upon conclusion of the agreed access term, the club member returns the vehicle to an agreed location where-in the next member may access the vehicle as required. As a courtesy to other club members, typically there is an agreement for service users to use provided pre-paid cards to fill up depleted vehicle fuel tanks when on-board range is low. Proposed benefits to consumers is that payment is fixed prior to vehicle 'hire' and that traditional costs of private ownership such as insurance, road taxation, fuel, parking permits and maintenance are avoided. However, unlike public transport, flexibility of conventional private ownership of a vehicle is not lost, enabling what proponents argue is an ideal combination of flexibility & cost. Currently, the major demographics Utilising car club schemes have been found to be inner-city graduates (19%), older singles occupying residences in city suburbs (14%), wealthy households in accessible suburbs (11%) & persons living within regions of student accommodation (9%). Figure 54 below presents a typical process for usage & is taken from a prominent provider [215] [216] [217].

It should be noted that, as will be discussed under the potentially limitations of the car club system, a principle means of ensuring general member compliance with specified club rules is the agreement that if terms are not adequately met by the user, fines can be charged. For example, late fees for vehicle returns can be applied as well as for failure to abide by refueling conditions. Furthermore, policies for accidental and in some cases, unavoidable, damage can be costly. For instance, a prominent car club provides insurance coverage up to £750 for damages however members are expected to contribute all additional costs required to rectify a vehicle. Flooding and other damages are typically not covered at all.

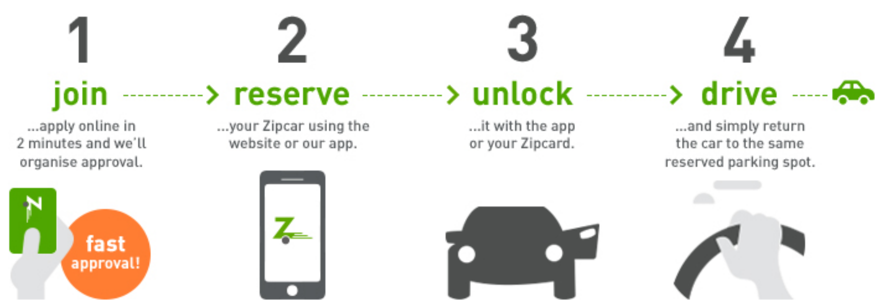


Figure 54 *A simplistic overview of the process of securing access to a vehicle of a Car Club (Zipcar)* [215].

4.4.3. SOCIAL ENTERPRISE CAR CLUB INFRASTRUCTURE DEVELOPMENTS

Car clubs have experienced significant growth across Europe since inception and are continuing to do so. For example, in Scotland recent reports indicate that car club membership has grown by over 23% over a 2-year period, with both England and Wales experiencing a respectable 9% growth over the same period. Within Scotland alone there are now an estimated 7,000 car club members with an additional 102 persons joining with each passing month [211] [212] [213]. A further example of car club growth is a club in Leeds known as City Car Club which has experienced fleet growth of 27% over the past 12-months; expanding into additional cities such that its fleets now services 16 locations across the region. In London, too, there are currently 171,000 car club members serviced by a fleet of 2,480 vehicles and predictions indicate that this will grow to 1m by 2025 [211] [217]. Furthermore, forecasts by independent bodies foresee that membership across all of England shall grow to 0.75m by 2025 without policy & subsidy influences and 3.3m with supportive incentives [210] [211] [217]. Reports by independent bodies now estimate that a typical car club within the UK now operates a sizable fleet of 24 vehicles. In total, there are over 8 major car clubs in the UK, including Co-Wheels, Hertz 24/7, Zipcar and Go Drive, with numerous smaller scale, local operations in existence. As stated, car clubs are also proving successful within Europe. In Paris, major car club Autolib' has over 100,000 members with 16,000 rentals processed on a typical day by a fleet of 3,500 vehicles. In addition, with the flexibility of inter-country travel across Europe, several companies such as DriveNow, Car2Go and Ford's GoDrive are rapidly deploying networks of vehicles across major hubs in the likes of Munich, Berlin, Stockholm & Milan [208] [211] [213].

The deployment and growth of car clubs is having a minor, yet still observable, difference upon road use, behaviors and extent of private vehicle ownership, though most significantly for its members. Surveys have indicated that within the UK car club members have reduced the number of vehicles owned by their household since joining the car club. Additionally, close to 25% indicated that had they not joined a car club, they would otherwise have purchased a new vehicle. Furthermore UK-focused studies indicate that on average a car club results in 13 vehicles being sold by owners and a further 9 not being purchased as new from a dealership [211] [217] [216]. Carplus, a major club within the UK, reports that its members make more trips using public transport; relying on car, lift or taxi just 23.5% in contrast to non-members 66%. However, it should be noted that many of these studies could be biased as it can be expected that members of car clubs are more likely for the scheme to be there sole access to an automobile. Furthermore, it is claimed that car club members reduced their driven mileage by up to 36% upon joining; likely a direct result of the journey to & from collection of vehicles & the prominently visible cost per mile compared to private ownership deterring use. Surveys also suggest that car clubs achieve higher average occupancy per trip (2.3) than private (1.8). A staggering statistic claimed by Autolib' is that in Paris there has also been an 11% reduction in private car journeys achieved since launching the club [217] [210] [216].

Concluding, at present car clubs do offer a potential avenue for synergy with HEV & EV vehicles; potentially vehicles could be charged when not in use and during the grace period between reservations. However, at present car club penetration by EVs & HEVs has been limited. Surveys indicate that ICEs still dominate with over 85% of the car club fleets across the UK comprised of conventional vehicles. This compares to just 4% and 11% for EVs and HEVs respectively [217] [216]. It should be noted though that this is a significantly greater component than that of the UK private and fleet automotive sector; 1.1% & 0.9% respectively. Furthermore, it is reported that car clubs are having a significantly positive impact on the growth of familiarity and confidence in HEV & EV vehicles (Figure 55). Of 1,000 car club members within Scotland, 68% had tried a club owned EV & 87% had reported a positive experience [217]. Therefore, the conclusions drawn about this infrastructure are that whilst small today, there is potential for significant growth of HEV & EV car clubs across both the UK and European markets. In addition, considering the published surveys described above, clubs have demonstrated a significantly positive impact on perceptions which is likely to improve further as range limitations are overcome, supporting familiarization & growth of HEV & EV sales.

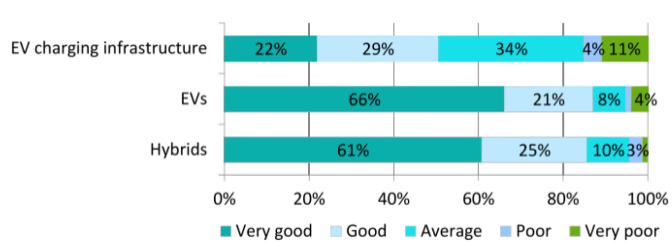


***Figure 55** A survey of 1,000 Scottish Car Club users indicating positive experiences with EV & HEVs* [217].

4.5. BATTERY SWAPPING INFRASTRUCTURE

4.5.1. BATTERY SWAPPING STATION (BSS) INTRODUCTION

The predominant consumer-perceived issues with HEVs &, more specifically, pure-EVs are those of strict continuous range limitations, lengthy or complicated charging requirements in conjunction with a lack of available infrastructure & a high initial cost of ownership in comparison to conventional ICEs [218] [219] [220] [221]. With adequate & thorough planning, in conjunction with an effective business model, battery swapping station (BSS) infrastructure can potentially be deployed to address such issues. Though operation shall be discussed in detail, BSS infrastructure presents a service where-in depleted batteries embedded in a driver's vehicle can be conveniently & rapidly exchanged with compatible, though fully charged, batteries [222] [223]. Within this section of the report, the fundamentals of BSS infrastructure shall be provided in conjunction with proposed advantages & applicable hindrances. In addition, notable historic & existing pilot schemes shall be discussed, with references to lessons learnt, and a conclusion as the potential influence upon HEV & EV uptake within a short-medium term outlook shall be presented.

4.5.2. FUNDAMENTAL PRINCIPLES OF BSS OPERATION

The fundamental operating principles of battery swapping stations is as the name suggests. However, the first step to the service is provision of both compatible vehicles to consumers & a pre-agreed payment scheme; where-in vehicle compatibility in this case refers to the presence of a, typically under-side mounted, removable automotive-scale battery pack [223] [219] [224] [225]. Regarding battery pack capacities (kWh), to maximize effective mitigation of range anxieties and to maximize both convenience for consumers & emissions reductions, studies of both economic and operation-oriented models of BSS infrastructure indicate that larger capacity batteries are recommended to be used in conjunction with fully electric powertrains [223] [226] [227] [228]. Operating as a 'standard' EV throughout typical use, upon near-full depletion of the on-board storage capacity or when significant range increase is required at a rapid rate, a user of a battery swapping technology enabled vehicle should be capable of readily identifying and accessing a nearby, strategically located BSS. Once a BSS is accessed & upon confirmed receipt of a required payment, a process should be undertaken which involves rapidly, safely and reliably removing the embedded, depleted, on-board storage and exchanging it for a suitably pre-charged equivalent of similar quality and architecture; utilizing on-site charging facilities to pre-prepare battery packs. The process should be comparable in duration to that of filling a conventional vehicle at a petrol station (typically five minutes) to maximize consumer incentive and should be performed without direct involvement of the consumer where possible, targeting maximum autonomy for both safety & economic reasons [224] [227] [229] [224] [230]. Within the system there are typically three principle states for batteries; charging, depleted & fully-charged (refer to Table 19) [223]. Following completion of a successful battery exchange & performance of adequate safety & quality checks, the consumer should be capable of safely exiting the BSS and returning to typical operation of their vehicle.

Figure 56 provides a simplistic overview of a proposed battery swapping station; where-in the red battery represents a depleted pack being transferred for storage & subsequent pre-charging and green indicates a pre-charged battery being embedded in the compatible vehicle for propulsion energy [231] [232].

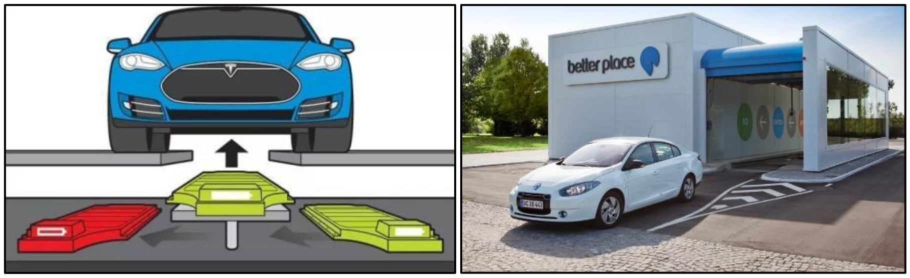


Figure 56 LHS *Overview of the battery exchange process.* ***RHS*** *View of an operational station* [231] [232].

Several techno-economic feasibility studies have been performed and software-based models developed to represent proposed battery swapping station infrastructure. These models primarily focus on automation-heavy schemes, outlining information such as key software inputs and architectures. One such tool investigated thoroughly by the group was developed by [223] within JAVA script and provides an overview of a suitable automated process architecture in conjunction with detailed estimations of required on-site infrastructure & equipment to satisfy given consumer demand levels. Figure 57 depicts one such software scheme outlining the process workflow for handling a depleted battery packs arrival & charge completion [223]. Comparative usage to that of a conventional petrol station is assumed within most studies & its indicated that to guarantee an adequate charged battery supply, a minimum of 13 batteries supported by 8 or more 40kW chargers or 4 chargers supporting 17 or more batteries are needed [223]. The group also made significant reference to studies addressing the cost-effective location of BSS and several studies on profitability, site density requirements & sensitivity to external influences such as fuel costs [228] [221] [224] [223] [227] .

A common area of interest within studies was the model for battery ownership employed by the battery swapping station operators. There are two predominant routes which have been assessed as economically feasible; that in which the vehicle owner maintains ownership of their original battery and that where-in BSS service providers hold ownership, leasing battery access to the consumer instead. These models will briefly be discussed through reference to two existing swapping schemes (Better Place & Tesla), however the principle advantages for each is the transfer of battery cost to the manufacturer reducing fiscal barriers to EV ownership or alternatively increased quality assurance & flexibility for the consumer for the battery access leasing and consumer ownership schemes respectively [233] [222] [234]. A further advantage proposed to operators is the ability to employ BSS as grid-connected energy storage devices which could generate income through offering demand-side management of grid infrastructure [228] [235] [236].

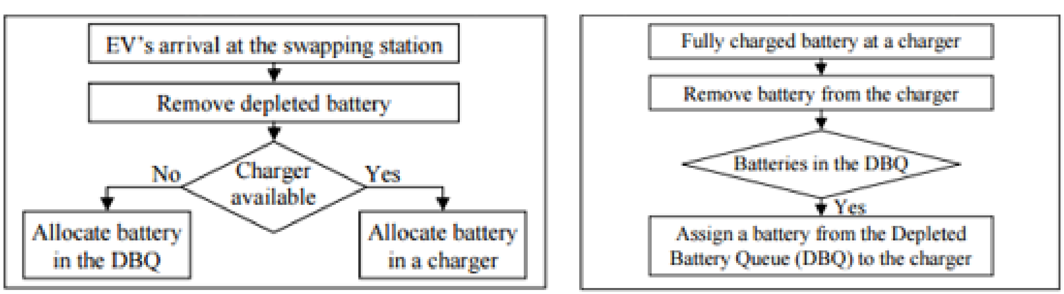


Figure 57 LHS *Overview of battery arrival process.* ***RHS*** *Overview of battery charger assignment* [223].

Table 49 *Table outlining the three principle states of BSS batteries* [223].

BATTERY STATUS	DESCRIPTION
CHARGING	Battery is connected to an appropriate charger, increasing charge with time.
FULLY-CHARGED	Battery is finished charging and is stacked awaiting embedding in a vehicle.
DEPLETED	Battery is awaiting placement upon a charger – stacked in a Battery Queue (DBQ).

4.5.3. SUMMARY OF BSS INFRASTURCTURE DEVELOPMENT

At present, there is little in the way of developed operational battery swapping systems within UK, and indeed the global, automotive road infrastructure network. However, several niche schemes are either in development or preliminary operation, facilitating growing depth of knowledge and expertise of BSS operation. A brief overview of these small-scale systems and their distinct approaches, where relevant, shall be presented, with brief comments made as to the extent of success achieved.

The first niche system is that of a growing commercial EV fleet and services provider Greenway Operator. Established in 2011, the company offers an all-electric drivetrain light commercial vehicles (read: van) based on the Citroen Jumper & comparable in appearance to the widely recognizable Ford Transit. The vehicle drivetrain is comprised of an AC synchronous motor, powered through on-board Li-based storage; capacities of both 38 & 59kWh are available with claimed range of 120-140 and 180-220 km respectively. The unique functionality of the Greenway system is that to enable significant reductions to required infrastructure capital investment costs, the swapping function is performed manually by the operator using a series of safety locks and a manually driven stacker device. Up to 7hrs charging is required for the largest capacity battery packs however battery exchange can be performed in under 7-minutes. RFID tags are employed to initiated the exchange process and act as an operator identifier [237] [238] [239]. Though remaining a small-scale operation, Greenway recently raised £3.5m for expansion into Austria and the Netherlands [239]. However, the general conclusion is that whilst this system can potentially find a market in commercial fleets, where-in operators can be adequately covered by workplace insurance schemes & trained in system operation thorough training regimes, due to the requirement for operators to manual exchange batteries, it's unlikely this system can translate to private ownership & mass EV markets [239].

The next venture assessed was the recognizable Better Place (BP); an enterprise created in March of 2007 with a goal of developing an eco-system of charging stations & battery swapping facilities that would accelerate transition from conventional transportation modes, heavily reliant upon fossil fuels, to sustainable modes [240]. The business model adopted was similar in principle to that of the telecoms industry where-in consumers agreed to a long-term, or per month, subscription plans and in return received access to a network of pre-existing charging stations and BSS facilities [240] [241]. Though successfully raising over $850m in private capital over a series of three rounds of investment, BP declared bankruptcy in May of 2013 due to significant business & operating model failings which, although mostly non-technical in nature, are most of relevance to any proposed future BSS infrastructure [241] [225] [226]. A principle failing of BP was that proposed consumers were severely limited in terms of vehicle choice due to the infrastructure requiring compatibility with battery swapping facilities and only a Renault-Nissan alliance willing to develop such vehicles. Established manufacturers remained either unconvinced of the economic feasibility or felt different implementation would be more profitable. Such a failing indicates the significance of consumer choice & inter-manufacturer cooperation & standardization for future BSS. Less rapid expansion could have demonstrated the feasibility of the ecosystem & alleviated doubts [241]. A further failing of BP was that infrastructure development was significantly mismanaged; for instance, costs of swapping station installation rose from a predicated $500k to over $2m, with ex-employees declaring that such vast underestimations were commonplace within the context of the business model. Such economic woes were compounded; ex. one-offs such as a billing software glitch cost BP over $80m [241]. The last notable failing assessed was, though at a glance strategic locations appeared to have been chosen in Denmark & Israel, consumers there were found to be less motivated for cleaner transportation and found to travel far less distance of average than anticipated; requiring far less costly installations than was planned to be built as just 2,900 public chargers *could* service 98% of all Israeli vehicles [226] [241].

The next demonstration scheme assessed was that of US-based EV firm Tesla; where-in a small-scale pilot was developed to service a high-traffic route between Californian cities L.A. and San Francisco. However unique issues plagued the scheme and at to-date little success has been observed. Tesla initially began the scheme through invitation; 200 existing Model S owners were invited to participate in the scheme which became operation in mid-2015. Though the scheme offered rapid & safe battery exchanges, performed reliably in under 90 seconds, few invitees took up the offer; single figures with each of those involved each only utilizing the swapping facility a single time [234] [239] [222]. Tesla's approach differed from Better Place in that those involved in the scheme maintained ownership of the battery originally installed within their vehicle even after temporary swapping; such measures were taken to alleviate a perceived lack of consumer confidence in receipt of equivalent standard batteries (read: degraded batteries were thought to be potentially provided in exchange for near factory fresh equivalents) [218]. A fixed price of $80-$100 was paid per swap within the scheme enabling rapid addition of 200mi range, with a payment also made for the owner's battery to be stored on-site awaiting reinstallation upon completion of their return leg. Pay-as-you-go (PAYG) was a major deviation from Better Place's approach [226] [231].

The PAYG system enabled consumer flexibility and exploitation of existing, free at point of use fast charging infrastructure provided by Tesla; something which Better Place could not satisfy within their eco-system [241]. However, principally this flexibility was the core issue which has stunted exploitation of the swapping scheme; namely Tesla already has a substantial fleet of fast chargers available near the BSS and with capabilities for full 200mi range charges in under an hour available for the battery swapping pilot scheme members to use for free, Tesla has observed that there is little appetite for significantly more expensive charging facilities, even if significantly faster charges could be achievable through its use [231] [226] [222]. In addition, though swaps were initially performed in under 90 seconds, the system required to be adapted after underside corrosion was found to be a major issue for compatible vehicles which further hindered the claimed added convenience; a Ti-alloy plate now protects the battery undersides but has meant that the swap system is no longer fully autonomous and takes up to five full minutes to perform [222] [233]. This issue of consumer incentive is increasingly exacerbated as much of Tesla's infrastructure growth today comes from additional fast charging infrastructure installations funded by ZEV credits sold to direct competitors currently not achieving ULEV sales targets set by regulatory bodies [222] [233]. Exploitation of this system allows Tesla to fund their ecosystem through a period of direct competitor catch-up & explains why the battery swapping facilities are not currently under-going an expansion &/or promotion program.

Considering the aforementioned demonstration projects and conclusions of studies assessing the techno-economic feasibility of BSS & their operating models, the conclusion drawn is that within the context of a short-medium term outlook they are unlikely to contribute significantly to the market penetration of HEV, EV and alternatively fueled vehicles. Significant barriers include the required degree of manufacturer standardization & commitment, a prohibitively high capital investment requirement for implementation of infrastructure on the scale required to drive growth and apparent consumer preference for more numerous & flexible, significantly lower cost though comparatively slower, charging stations. Additionally, studies indicate that the proposed economics of the additional income stream gained by employing BSS as grid-connected storage units capable of use for demand-side management of grid networks is unproven & requires further development & assessment [224] [230] [227]. Significant sensitivity to location and to unpredictable consumer behaviors, evident with BP, are also a major barrier to future investment in BSS.

4.6. eHIGHWAYS INFRASTURCTURE

4.6.1. eHIGHWAYS INTROCUTION

At present, HEV & EV range limitations and anxieties remain a major obstacle to the mass market penetration of alternatively fueled vehicles within the global automotive private and fleet sectors (refer to previous Section 3.). However, a supporting infrastructure known commercially as eHighways and currently within a preliminary proof-of-concept stage for commercial HEV & EV haulage fleets may potentially provide a solution which facilitates overcoming of such technical limitations. Within this brief section, an overview of the potentially transferable eHighways technology operation and a discussion pertaining to the current state of readiness, focusing on on-going practical demonstration schemes within Europe & US, shall be presented & overall conclusions as to the short-medium term possibilities for supporting the growth of alternatively fueled vehicles, predominantly within the UK, shall be presented.

4.6.2. FUNDAMENTAL PRINCIPLES OF eHIGHWAY OPERATION

Published information regarding eHighways describes the infrastructure as an electric-powered system which supplies propulsive power to haulage vehicles throughout high-traffic freight routes via overhead contact lines, known within technical circles as catenary lines [242] [243] [244] [245]. At present, physical connections made via components known as pantographs support transmission of power between grid-connected overhead supply lines and compatible haulage vehicles. Throughout electrified segments of freight transportation routes, it is proposed that electric motors, to be embedded within future haulage vehicle drivetrains, shall be powered directly with energy supplied via said overhead lines; with any excess energy diverted to on-board high capacity storage units such as battery banks and/or ultracapacitors for later use. Hybrid diesel-electric drivetrains will then operate in combination with any on-board stored energy capacity to provide propulsive power throughout segments of freight routes which are not-yet electrified and where no eHighways infrastructure is present [246] [247] [248] [249] [250]. Currently the technology is within an on-road demonstration phase of technical maturity. However, the operational principle is not new; the system has been adapted from existing infrastructure such as electrified railways, trams and trolley buses, though the application of such technology to commercial haulage vehicles and potentially personal transportation vehicles is a rather innovative and novel concept [242] [251] [252] [253] [254]. Figure 58 overleaf presents a system architecture developed by Siemens & a contrasting conventional railway architecture for graphical illustration of system similarities [247] [246].

The development of the catenary system for on-road haulage is largely driven by decarbonization targets for transport and freight infrastructure; which shall require major innovation as global freight is anticipated to rise by over 200% from today through 2050 [247] [242]. Estimates are that over 2/3's of the increased freight is anticipated to be transported via road infrastructure, with related localized CO_2 emissions estimated to double. Proponents of the eHighways infrastructure argue that it provides a platform from which significant particulate & CO_2 emissions & operational cost savings can be reliably achieved; Siemens themselves claim an efficiency of two times that of conventional internal combustion powered drivetrains [247] [248] [242].

***Figure 58 LHS** Figure depicting operation of Siemen's eHighways scheme, where green indicates the energy flow path. **RHS** Figure depicting conventional electrified rail network architecture* [242] [255].

Siemen’s have demonstrated that sensors can be employed to automatically deploy the compatible pantograph, mounted to the roof of an otherwise conventional haulage cab, when the presence of a proposed two-pole overhead catenary line is detected to be present [250] [244] [243]. Alternatively, drivers can operate the system through a switch located in the cab’s dashboard, enabling manual pantograph operation. The catenary line is intended to be supplied via roadside substations and will utilize existing national grid infrastructure in the host country, with preference towards renewables where possible to increase decarbonization potential [246] [248]. ‘Active’ control systems enable the pantograph to handle both rapid height and positioning shifts, enabling maintenance of a stable connection throughout vehicle operation; it’s claimed stability controls dramatically improve both system efficiency & component longevity. In addition, the pantograph has been demonstrated to automatically detach from the catenary lines under evasive maneuvers, improving general system safety [250] [244] [249]. Demonstrations indicate that the pantograph can be both connected to and disconnected from the catenary lines at speeds up to 60mph (96km/hr). Regenerative braking systems are intended to be employed to facilitate recovery of energy within mountainous regions, with the overhead catenary system proposed to facilitate regular inter-truck energy transfer. Siemens claim that a system efficiency of above 80% can be reliably achieved along their two existing test routes [247] [248] [242] [250] [245] [256].

4.6.3. SUMMARY OF eHIGHWAYS INFRASTRUCTURE DEVELOPMENT

At present, there are two demonstration routes in operation; a Swedish-based system and a Californian system, both of which are developed by Siemens in collaboration with notable industry partners. In Sweden, a 2km stretch of the E16 highway which connects the regions of Dalarna and Gavleborg, to the north of Stockholm, has been electrified using eHighway infrastructure. Two trucks, developed principally by Scania to operate with a hybrid drivetrain, currently operate along the demonstration route which connects industrious lands known for steel, pulp and paper and mining industries [248] [247] [250] [257]. The trucks drivetrain specifications include a parallel architecture hybrid drive, with a 130kW AC motor operating in tandem with a 9L diesel engine, a 5kWh Li-based battery capacity and an estimated 3km all-electric range [243] [256]. The total funding for the project in Sweden is currently estimated to be in excess of £11m equivalent [250] [257] [244]. In comparison to this & regarding California, funding for demonstration projects in the ports of Los Angeles & Long Beach is more than £40m equivalent and is supporting creation of a 3.2km electrified eHighway route. A 43-vehicle fleet operates along the route, with the compatible haulage vehicles developed by Volvo; however, it should be noted that industry estimates indicate the route services several thousand haulers on a typical day of operations [258] [259].

Following the perceived success of the Swedish & Californian demonstration programs, with respect to the low emission haulage industry, eHighways have a clear promising future. The technology has been demonstrated to be at a maturity level capable of wide-scale successful implementation and similarities to existing infrastructure such as electrified railways facilitate availability of an existing technical expertise base which could be exploited for both initial eHighway construction and long-term system maintenance [255] [252] [243] [242]. Furthermore, such similarities to existing, proven infrastructure provide a platform for the demonstration of system reliability, as well as claimed reduced maintenance and servicing costs. Notable is that electrified rail networks are perceived as a major infrastructure improvement in comparison to conventional diesel-electric systems within the rail industry with significant on-going investment expanding the current infrastructure coverage within the UK [250] [260]. A further benefit of eHighway infrastructure is that unlike competitor systems such as inductive charging, eHighways can be retrofitted to existing roadway infrastructure without requiring major restructuring. Furthermore, overhead catenary lines do not pose a significant barrier to existing road users.

Numerous techno-economical commercial analyses performed by various bodies indicate that there are also significant cost savings to be achieved with regards to system scalability. Current estimates indicate that for a Li-based electrical drivetrain similar in architecture to those employed in emerging personal transportation automobiles to travel distances performed by conventional haulers today (typically up to 500km) would require a 23-tn on-board battery pack [257] [244] [250]. For comparison, Scania's successfully operational demonstrator trucks outfitted with a compatible pantograph have a total mass of just 9-tn, which includes structural materials, hybrid drivetrain & on-board energy storage; such mass savings would provide significant benefits from both a manufacture & materials costings perspective plus would offer general improvements to both performance & operational costs [246] [243] [256]. Furthermore, a comparative H_2-based drivetrain is estimated to be valued at over £2.3m per vehicle which would be prohibitively expensive. Estimations in support of eHighways indicate that to enable sufficient implementation for all of Germany's haulage fleet would require just 4000km of overhead lines; saving an estimated £250bn through 2030; which compares to the UK's rail network of total length 15,799km of which close to 6,000km is electrified [244] [257] [249] [250].

However, though clearly promising for commercial & haulage applications, there are major obstacles which would limit the effective transferability of the eHighway systems to private and fleet-owned vehicles. First and foremost, due to the physical size differences, a prohibitively long pantograph would be required for conventionally-shaped vehicles to be compatible with eHighways sized primarily to accommodate commercial haulage vehicles. Furthermore, at the scale of private vehicles where-in hybrid and pure electric drivetrains can be more efficiently implemented & where journey distances are significantly shorter than the typical 500km routes of haulage vehicles, the economics of eHighways degrade in the favor of greater reliance on-board energy storage [250] [257]. In addition, in comparison to alternative dynamic charging technologies such as induction coils embedded within road surfaces, although more maintainable, overhead catenary wires are significantly more vulnerable to disruption & outages; whether naturally caused by weather effects or whether due to intentional wiring theft [259] [246]. An additional obstacle to eHighway implementation for conventionally-sized vehicles is that already there is significant public push-back mounting against similar electrified railways infrastructure due to impacts to scenery [251] [253] [260]. Thus, the short-medium outlook of eHighway transfer to private & fleet owned automobiles is estimated to be insignificant; minimal impact beyond growth of EV technology investment.

4.7. POWER TO GAS (P2G) INFRASTRUCTURE

4.7.1. P2G SCHEME INTRODUCTION

Across the globe, nations are investing heavily in proliferation of renewable energy generation infrastructure. Such investment is largely driven by binding targets for decarbonization; the European Commission has targeted an overall 20% renewable energy contribution to EU Member State energy generation by 2020, for example [261] [262] [263] [264]. Furthermore, increasingly progressive regions such as the U.S. state California have declared more aggressive targets with aims of achieving 50% renewables contribution to energy generation by 2030 [265] [266] [267]. Though often behind schedule, particularly within the UK, at present strong growth of renewables has been observed; exemplified in that wind energy is currently providing the largest fraction contribution to domestic energy generation within both Denmark (34%) and Spain (21%) [268] [269] [270] [271]. However major issues are raised through the growth of renewables contribution to domestic energy generation, namely that such generation provides often non-despatchable, typically intermittent, uncontrollable nor predictable power generation [272] [273] [265]. With severe implications for infrastructure through extension of supply & demand matching, often renewables generation is curtailed when demand for energy is low (Read: turned off) [274] [275]. The issue of renewables curtailment can be said to be exacerbated due to a distinct lack of large capacity energy storage installations which may otherwise be employed to capture 'lost' generation of renewable sources for use when demand is increased above supply [265] [273] [276] [277]. Power-to-gas (P2G) technology may offer an elegant, future solution to the issue of intermittent renewable energy generation described above, facilitating greater exploitation of existing & future intermittent renewables infrastructure.

Within this section, the generalized operation of P2G systems shall be briefly presented in conjunction with an overview of existing infrastructure and pilot schemes, with a focus upon the UK. Relevance to emerging automotive technologies, namely that of alternatively fueled vehicles, will also be presented.

4.7.2. FUNDAMENTAL PRINCIPLES OF P2G OPERATION

The fundamental principle of operation of P2G systems is that surplus renewables generation, which would traditionally be wasted, is captured and employed to synthesize hydrogen [272] [278] [279] [273]. At present, the most effective means of hydrogen generation through P2G remains the well-documented electrolysis process [273] [272] [280] . P2G-produced hydrogen may then be employed through several practical applications; namely direct injection into existing natural gas infrastructure for generally 'greener' energy generation up to a limit of typically 20% by vol%, combination with either CO or CO_2 to produce methane (CH_4) which may be injected into existing natural gas infrastructure for generation or finally direct use in distribution networks such as automotive-targeted hydrogen-inclusive alternative fuels & privately owned fuel cell generators [273] [281]. Figure 59 presents a simplistic overview of a system architecture and depicts typical applications for P2G hydrogen systems [281].

Proponents of P2G would argue that proposed advantages of such generation are generally widely accepted. Through development of P2G infrastructure, provision of a practical use for surplus generation

- namely that of intermittent renewables - enables more effective use of existing 'green' generation [282] [283]. Such a use would be further supported given that the incremental cost of increasing P2G capacity is low in comparison to competing technologies and as such indicates that the required low cost bulk storage of the capacity & durations required for curtailed renewables mitigation is achievable [265] (Figure 60). Additionally, a major advantage proposed by P2G systems is that the technology synergizes well with existing proven infrastructure, reducing the required initial capital investment considerably [272] [278] [279] [277]. For instance, the practical use of existing natural gas infrastructure to either store or distribute P2G H_2 or CH_4 can be readily accomplished; where-in total global storage capacity for natural gas currently exceeds 3,600 TWh, compared to total world production of combined solar & wind of 639 TWh per annum (2012 data) [284] [285]. Further advantages are found in that P2G is a very flexible means of energy generation given that not only may it support various applications, including the near universally use of natural gas, but the technology enables rapid addition and removal of steady, predictable loads to energy distribution infrastructure, which offers distinct benefits for supply & demand management. Trials by leading proponent of P2G, ITM Power, have indicated systems achieve reliable "turn-on" of 800ms & "turn-off" of 140ms under high stress conditions, demonstrating supply & demand suitability [286] [287].

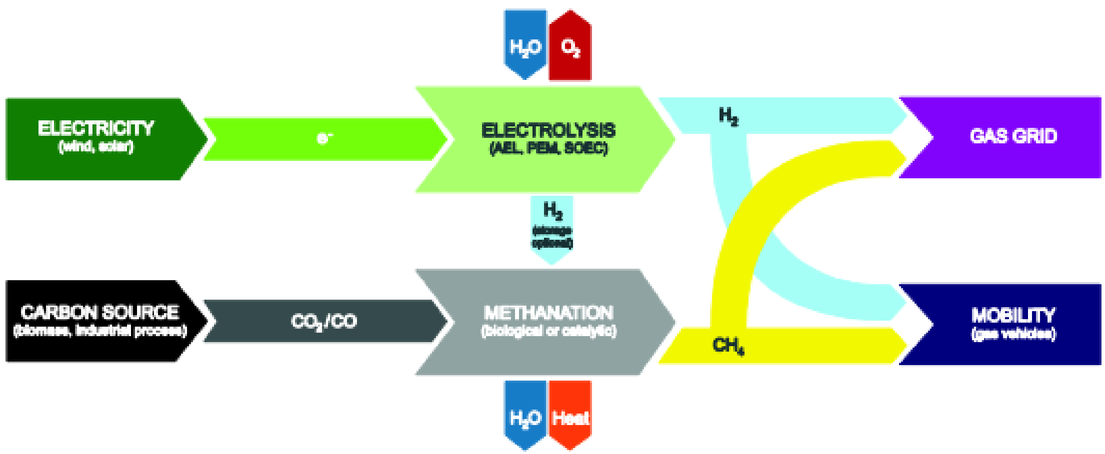


***Figure 59** A figure depicting a simplistic power to gas architecture* [273] [281].

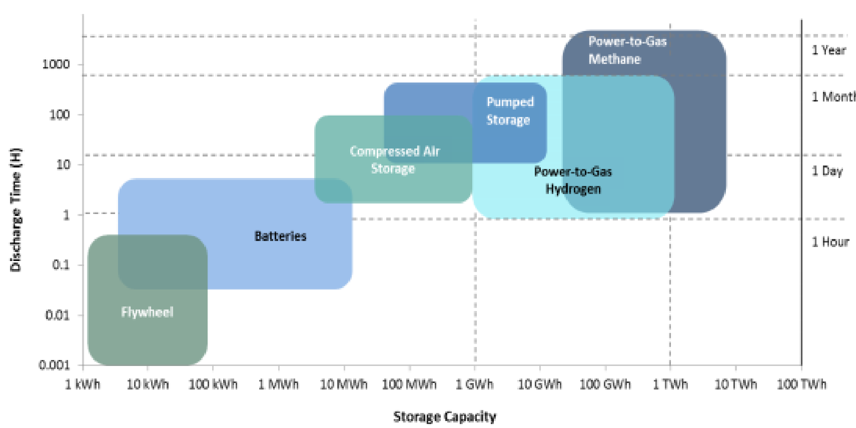


***Figure 60** Comparisons of estimated technology storage capacity and discharge durations* [265].

4.7.3. SUMMARY OF P2G INFRASTRUCTURE DEVELOPMENT

With respect to developing infrastructure and pilot schemes for power to gas (P2G), there have been numerous successfully implemented schemes within the UK and investment in the technology is growing. At present, through use of online European P2G demonstration scheme trackers, indication is that there are currently several operational schemes within the UK for which all of those with published data indicate applications producing synthesized hydrogen for transport & combined energy storage for local buildings.

Located within the Scottish city of Aberdeen, is the UK's largest P2G hydrogen production and bus recharging facility. Developed under the European Hydrogen Transport Project and with investment contributions stemming from a £19m green transport demonstration program, the site became operational on the 11th March, 2015 and is powering Europe's largest hydrogen bus fleet [288] [289] [290]. The public-private funded project is backed by numerous bodies, including Innovate UK, the Sottish Government and Scottish Enterprise, who have each committed capital of £2.4m, £1.7m and £1.7m respectively. Key commercial stakeholders BOC, Stagecoach and Aberdeen City Council have invested a further £1m, £1m and £2m respectively to the program [288] [289]. At present the project is experiencing major success of its primary goals of demonstrating the future viability of P2G driven hydrogen applications for transport applications, driving investment in hydrogen-based infrastructure [288].

There are currently 10 Van-Hool manufactured hydrogen fuel cell buses in operation; six of which are employed by Stagecoach on the X17 route and four of which are operated by First on the X40 park & ride route across Aberdeen city center [289] [288]. The buses are supplied through utilization of a 1MW electrolyzer supplied by Hydrogenics. Within the first year of operation, it was estimated that the fleet of zero direct tailpipe emission buses travelled over 250,000 miles and serviced over 440,000 passengers across both routes combined; averaging a passenger load of 36,700 per month. Supporting estimates indicate that the refueling station has been successfully employed over 1,600 times throughout the first year of operation and BOC have recently stated that the system has achieved availability rates of 99.99% throughout its operational life thus far, which is indicative of the P2G systems viability [288] [289]. Initial estimates also place system efficiency achieved at over four times that of equivalent diesel buses [291]. In addition to typical operation, H_2-powered buses have featured prominently at several transnational functions across the local region & city, promoting awareness of both power to gas technology & the specific proof-of-concept program. In addition to the development of public transport infrastructure, a successfully operated maintenance hub has been constructed which supports future growth of expertise in the technology throughout the local area which, again, should nurture and encourage the growth of P2G infrastructure. Combined, the successful implementation of the program provides a strong indication of the technology readiness level of power to gas infrastructure and is viewed as a "flagship" by Aberdeen City Council representatives. In the light of such success, sister schemes have been deployed across major European cities, including Antwerp and San Remo, and as of January 2017, Dutch city Groningen [292] [293]. All of three of these additional schemes were investigated to varied extents by the group & research indicated that thus far similar success to that of the Aberdeen scheme had been achieved.

As a further indication of the strength of backing P2G has within Aberdeen, the local council has recently partnered with Co-Wheels to unveil two hydrogen-powered automobiles; a first for a European car club [289]. Furthermore, a second refueling station was opened in early March of 2017 following further investment of £2.4m in capital and which coincides with the implementation of 10 hydrogen-powered automobiles to the local council's fleet. The second system contains four refueling stations and is thought to be capable of production of up to 130kg of hydrogen per day, with one kg estimated to facilitate 100km of driving [294] [295] [296]. Construction of such infrastructure and demonstration of successful operation shall serve to promote both investment into & uptake of hydrogen-based alt. fueled vehicles.

Coinciding with growth of P2G public transport schemes driving the development of wider P2G infrastructure, H_2 refueling stations similar in operation to conventional petrol & diesel stations are emerging within the existing UK road network [297] [298] [299]. Such stations theoretically offer significant benefit to consumers as it is often reported that the significant behavioral changes required to 'fill up' electric vehicles in comparison to conventional petrol & diesel based automobiles is prohibitive to EV uptake [300] [301] [302]. A prime example of one such station is ITM Power's joint venture with Shell to deliver the UK's first forecourt mounted hydrogen refueling platform. Situated in Cobham Services on the major M-25 road in south east England, the existing conventional infrastructure was estimated to service over 1m customers throughout 2016; indicating a stable platform from which hydrogen refueling systems can be both demonstrated & refined [303]. The site is one of three stations planned to be implemented within the UK throughout 2017 and follows several successful ventures by Shell in both California & Germany, where growth of hydrogen & P2G infrastructure has exceeded that of the UK considerably; within Germany targeting construction of more than 400 stations by 2023 [303] [304]. Such additional refueling schemes beyond the UK were investigated and found to be operating successfully, though do remain niche due to a lack of general hydrogen market penetration in both commercial fleet and privately-owned vehicle markets [305] [306] [307] [308]. Though too early to comment on in terms of success of the project, ITM Power are anticipating the Cobham services station to provide demonstration platform from which they can generate further investment and funding to expand. For instance, already ITM Power have successfully applied for planning permission for 16 sites similar in architecture to Cobham [309].

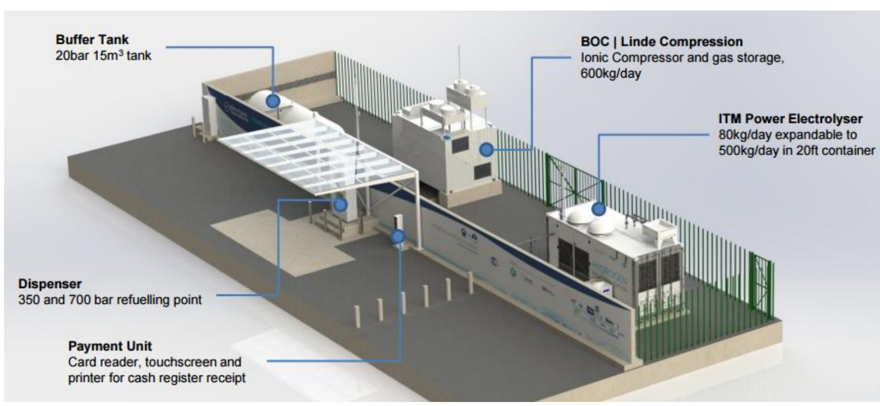


Figure 61 *An overview of the M25 Cobham Services P2G hydrogen refueling station* [309].

In the present day, the outlook for P2G technology and infrastructure can therefore be said to be promising. Firms such as ITM Power have recently experienced a 100% increase in funding, namely through grants, which is indicative of a rising interest in the technology across multiple industries [310]. Also, there is most certainly a requirement for large capacity storage if intermittent renewable energy sources such as wind and solar are to be exploited as efficiently as possible; with policies now dictating that utilities store power in regions where curtailment is prevalent [273] [265] [283] [311]. Case studies of Germany & Denmark indicate that the threshold for which supply & demand management becomes an issue is around 20% intermittent renewables contribution; a threshold that the UK breached in 2013. Furthermore, current estimates indicate that up to 1 TWh of UK wind is currently curtailed (read: 'lost') per annum and it is claimed by proponents of P2G that such a supply of energy could potentially constitute provision of adequate fuel supply for up to 3m hydrogen-fueled automobiles to each travel 350mi [309]. In addition, P2G hydrogen's proposed synergy with existing, substantial natural gas & biogas infrastructure arguably holds strong potential for significantly improving the sustainability of what is currently an incredibly integral component of the world's energy supply; in combination with the growth of carbon capture and storage, there is potential for creation of a, for all intents & purposes, renewable CO_2-based energy generation cycle. Furthermore, large capacity resources capable of rapid response rates such as those achieved by P2G and which can act as either a load or source on national grid infrastructure are advantageous to the national grid system from a supply & demand balancing perspective [286].

However, whilst there are numerous successful demonstration schemes in operation, under construction or in planning phases worldwide, there are significant barriers to the mass uptake and commercialization of P2G systems. First and foremost, whilst strong synergy with a hydrogen-based automotive fleet can be readily accomplished, there is at present very limited numbers of such vehicles on the roads which could be serviced by P2G systems & forecasts indicate that there shall not be until significant time has passed [273] [280] [294]. Furthermore, compounding the fiscal barriers to mass uptake of hydrogen-fueled vehicles is that currently P2G sourced H_2 is significantly more expensive than conventional fuels, thus driving up the overall cost of ownership. For example, whilst 1kg of H_2 can supply enough energy for a traditionally sized automobile to travel 100km, the unsubsidized cost to the consumer at current prices for such a journey would be £10. In contrast, to travel an equivalent distance with conventional fossil-based fuels at current prices is estimated to cost just £5.30 [294] [265] [273] [312]. In addition, several studies have indicated that the economics of injection into the natural gas cycle present a significant barrier to mass proliferation of P2G schemes without significant incentivization by centralized authorities and regulatory bodies; primarily due to additional inefficiencies throughout the proposed new cycle [273] [312] [313]. Whilst it should be noted that P2G is achieving significant cost reductions, exceeding targets set by the European Council, most economical studies indicate that a position of competitive pricing cannot be accomplished until at least early in the 2030's [272] [312]. Therefore, the overall conclusion on this technology if that whilst promising and offering distinct future advantages, power to gas infrastructure will likely not experience large scale commercialization, of the type required for supporting alternative fuel automotive applications for transport, in the short to medium term future.

The group would like to indicate that in addition to P2G schemes, investigations towards smart-grid connectivity & direct HEV & EV synergy with micro-grids (read: small-scale generation, local to demand) was also investigated in detail. Known as vehicle to grid (V2G), the operating principle is similar to that of P2G; where-in vehicle on-board energy storage is employed as residual dumps enabling capture of otherwise under-utilized, non-despatchable, intermittent renewables generation. As with P2G, benefits include greater exploitation of renewable energy generation & facilitation of greater supply-demand management of the grid network; though additional benefits such as increased energy security in remote regions are gained through decentralization of generation. However, as with P2G, such infrastructure, though possessing a bright future, is currently at an immature technology maturation level. With only a small number of small-scale demonstration projects in existence & technical barriers such as complex control system design, V2G is thus unlikely to support short-medium term growth of HEV & EV sales.

4.8. WIRELESS CHARGING INFRASTRUCTURE

4.8.1 WIRELESS CHARGING INTRODUCTION

In a similar vein to the revolution of personal communication driven by disruptive data transfer standards such as Bluetooth & Wi-Fi, wireless charging systems may hold potential to be a disruptive technology supporting the proliferation of alternatively fueled vehicles through future infrastructure developments. At present and in regards to automotive systems, there are two distinct variations of inductive power transfer (IPT); namely 1) static systems which are reliant upon stationary, often ground mounted, transmitters transferring power to compatible receivers embedded within stationary vehicles and 2) dynamic systems which are proposed to enable stationary transmitters to be embedded primarily in modernized major road infrastructure transferring power to receivers mounted upon moving vehicles.

Within this section, an overview of both static & dynamic technologies shall be provided and details of existing and future pilot schemes & off-road trials shall be given, with bias primarily towards UK infrastructure developments. Discussion regarding the status of the developing technology and numerous potential limitations, particularly interoperability of leading standards, shall be presented with comments providing judgement upon short-medium term outlook for inductive power transfer commercialization.

4.8.2. FUNDAMENTAL PRINCIPLES OF INDUCTION CHARGING OPERATION

Today there are three fundamentally distinct, principle classifications for wireless charging; radio charging, magnetic induction and magnetic resonance induction charging. Within this section, the fundamental operating principles and some examples of applications for each shall be brief summarized.

The operating principle of radio charging is similar to the far field principle employed for radio transmission; the transmitter outputs low-wattage radio waves and the recipient receiver captures the energy of the signal transforming it into usable energy. With present technologies, radio charging is employed in low-power devices with effective range typically within the bounds of a 10m radius of the transmitter. Common applications include medical implants, entertainment devices & RFID chips. Radio charging offers flexibility, namely with regards to the comparatively large effective range however does not see common use. Primary issues limiting proliferation are low power capture & production of electro-smog. The technology is therefore of little relevance to HEV & EV charging [314] [315] [316] [317].

The fundamental principle of magnetic induction charging is that alternating current within a wire loop will generate an alternating magnetic field, which in turn will induce an alternating current in a secondary coil of sufficient proximity to the first which may then be employed to drive a load. Though simple in principle, implementation is difficult. For example, a major barrier to the effectiveness of such systems is that the magnetic field generated by the primary coils distributes, approx. equally, in all directions (omni-directional power transmission). Therefore, flux losses during transmission increase rapidly with coil separation distance. Thus, to achieve effective power transmission, the secondary, receiver coil must be placed within close proximity of the primary transmitter coil. Additionally, studies have indicated that the effectiveness of the secondary coil to “capture” transmitted power is significantly sensitive to the cross-section presented to the magnetic field; with identical dimensions to the primary & secondary coils yielding optimum energy capture. Positioning with respect to the primary coil is also of significance to power transfer effectiveness, with studies indicating that parallel alignment is beneficial. For convenience, a coupling factor ranging from 0 to 1 & which accounts for separation, alignment and size of respective coils has been developed through extensive empirical research; perfect coupling where-by all generated flux is captured by the secondary coil is rated as 1 on this scale. Existing, closely-coupled systems have practical coupling coefficients of 0.3 to 0.6. In today's world, commercial phone chargers and electric toothbrush chargers often provide practical application of this technology [318] [317] [319].

The operating principle of magnetic resonant inductive charging is largely identical to that of magnetic inductive charging (defined previously) however incorporates the beneficial phenomenon of strong coupling of resonant coils to achieve greater effective power transfer distances. Such phenomenon is achievable where the point of power transfer operation (read: electromagnetic field frequency) for transmitter & receiver coils is at identical "resonant" frequencies, a property dictated by coil physical properties. Primarily capacitance, resistance and inductance. Such a coupling methodology can be thought of in the same sense as tuning a radio to receive a specific frequency or station & has the advantage in that only devices coupled to the resonant frequency shall be charged. Whilst the physical behavior for such a system is more complex than inductive power transfer, the primary advantage is that the power transmission is no longer omni-directional from primary coil to secondary coil(s) enabling extended transmission distances for equivalent transmitter power ratings. Also, whilst energy attenuation does increase with distance between transmitter & receiver, the primary source of attenuation is the gain bandwidth, which is controllable through sufficient compromise in design for differing applications.

At present, although high gains are required to achieve extended effective charging separation distances, it is claimed that efficiencies upwards of 90% have been achieved at 3.7-11kW power ratings through breakthrough resonant induction-based EV chargers with an airgap of 20cm (8"). As will be discussed, such a claim is supported in that a pilot scheme utilizing wireless charging for electric buses achieved system efficiency of above 80% with 20cm clearance and 75kW power rating. However, such claims directly conflict other sources which indicate that at distances of 2cm and 75cm, only 30% & 15% respective efficiency is achievable. With regards to coupling coefficient, it is estimated that for stationary medium distance resonant induction, values of 0.1 are estimated to be achievable, which would again hinder achievability of claimed efficiency figures in the region of 90%. As with non-resonant inductive charging, separation distance & physical dimension sensitivities are influences on coupling coefficient however alignment is not as significant for resonant applications [317] [318] [320] [319] [321] [322].

4.8.3. STATIC VS. DYNAMIC INDUCTION CHARGING

Of importance to the discussion pertaining to the short-medium term feasibility of inductive charging infrastructure roll-out within the context of the UK is the distinction of static systems and dynamic systems. As presented briefly within the section introduction, the distinction can be made as follows;

1) Static systems require both the transmitter and receiver to remain stationary for effective transmission of power through inductive charging methodologies. A typical system could comprise a ground mounted, fixed position transmitter pad connected directly to either the grid or local energy storage platform (e.g. battery bank) and a vehicle mounted receiver connected to an on-vehicle energy storage unit. The advantages offered in comparison to conventional charging infrastructure are perceived to include a lack of a requirement for a physical "plug-in" connections between transmitter and receiver.

2) Dynamic systems theoretically enable stationary transmitters, which are either connected directly to the grid or to local energy storage infrastructure, to be embedded within revised road infrastructure, such as A-roads and motorways, to effectively transfer power through wireless inductive charging to mobile receivers. Receivers could include transducer equipment mounted to the undercarriage of a moving vehicle. Perceived benefits of dynamic charging include reduced battery degradation due to minimization of depth of discharge, shown to negatively affect battery longevity, and extension of uninterrupted range.

Though both systems offer distinct combinations of advantages & disadvantages, with current technology levels it is estimated that stationary charging systems can achieve overall greater system efficiencies due to the improved controllability with regards to transmitter & receiver alignment [323].

4.8.4. INDUCTION CHARGING INFRASTRUCTURE DEVELOPMENT

At present, there are numerous pilot schemes devoted to demonstrating the feasibility and economics of both stationary and dynamics induction charging systems for automotive applications. Within this section, the most prominent examples of these systems to demonstrate current technology readiness.

The first system which shall be discussed is the Korean Advanced Institute of Science and Technology (KAIST) commercially available Online Electric Vehicle (OLEV) system. Since inception in 2008, three generations of prototype dynamically-charged EV buses have been developed with correspondingly varied “track” layouts. Reports indicate that the OLEV system developed by KAIST was first introduced in late-2009 to act primarily as a shuttle system for Seoul Grand Park, with a second-generation design successfully implemented in 2012 as a shuttle bus for the KAIST campus [324]. Two third-generation OLEV buses began operations in Gumi City, a major industrial city, in 2013 on the South Korean city’s popular metro bus line. Following success of the scheme on a small demonstration scale, there are plans for the expansion of the OLEV network to include additional bus lines in Gumi City [323] [325]. Furthermore, deployment of OLEV network buses is scheduled to expand to exclude Sejong City, where it is proposed that existing bus routes shall be services by OLEV systems. Studies prepared by KAIST have indicated that efficiencies greater than 70% have been observed on existing routes [323] [325] [326]. A common conclusion achieved from numerous studies of OLEV prototypes performed by KAIST demonstrates that significant reductions of depth of discharge can be achieved for equivalent distances. Dynamically charged vehicles state of charge was monitored and found to vary between 40-60% of capacity throughout operation where-as non-dynamically charged equivalent counterparts discharged between 20-90% on equivalent journeys; indicating that reduced energy storage capacities are required for and that storage unit longevity can be improved through dynamic charging infrastructure [322] [327] [328].

Closer to home, there have been demonstration studies performed for stationary, or static, charging measures introduced within bus routes within the bounds of the UK city Milton Keynes [324] [329]. A fleet of 8 electric buses have been in operation alongside conventionally powered diesel buses for a 15mi route connecting 3 major rail stations and which is estimated to carry upwards of 800,000 passengers per annum – a first for UK infrastructure at introduction [194] [329]. At inception, the demonstration scheme was intended to form the basis a 5-yr feasibility study was to be performed jointly by Arup & Japanese firm Mitsui. Unlike the KAIST scheme where OLEVs were charged dynamically whilst in operation, the recharging on the Milton Keynes routes is performed through static resonance induction charging infrastructure at fixed positions on the route; specifically the beginning and end of each route cycle there-in enabling charging to be performed whilst drivers are resting [194] [193]. The induction charging system operates through a receiver plate mounted to the undercarriage of the bus, which is physically lowered towards a transmitter plate embedded in the road surface [329] [324]. It is claimed by ARUP that a charge of roughly 2/3's of the capacity employed to complete the 15mi route can be recovered through a 10-minute induction charging process. Night-time charging through, rather more conventional, physical plug-in charging is currently employed to supplement vehicle energy capacity to enable a continuous 17 hour, 7-days a week operation in line with equivalent diesel buses [324] [193]. The batteries employed are Lithium-ion type and, though their exact chemistry is unknown, the dominant mass fractions indicate an $LiNiMnCoO_2$ formulation [194]. Further details of the architecture of the buses is available from [194], including battery capacity, positioning and state-of-charge monitoring system architecture. Figure 62, below, depicts an overview of the employed architecture & displays an in-use induction charging plate.

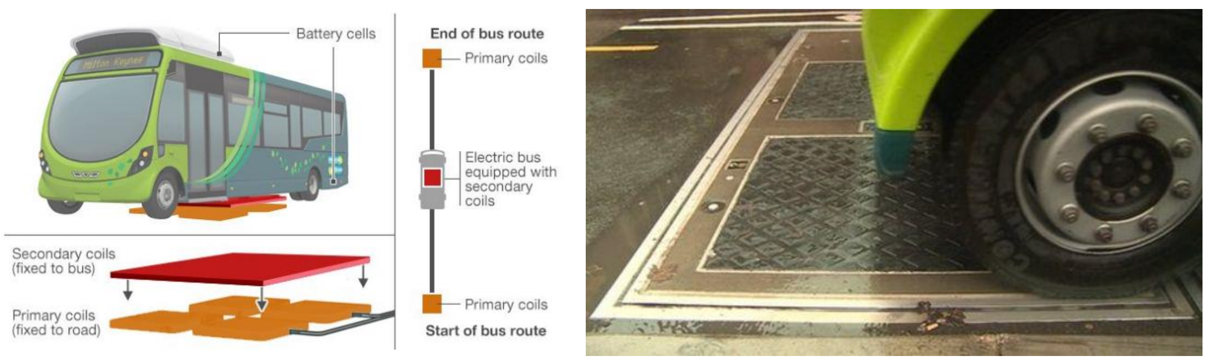


Figure 62 *An overview of the Milton Keynes EV bus charging infrastructure* [196].

The development of the demonstration scheme estimated that the 8 electrically operated buses would reduce street-level tailpipe particulate emissions by approximately 5 tonnes per annum [194] [193]. Furthermore, estimations of total carbon emission reduction were estimated to be more than 260 tonnes per annum, with potential to grow to over 680 tonnes per annum as the UK's grid infrastructure adapts to greener technologies through divestment from carbon-heavy generation such as coal & natural gas [194] [195]. Further benefits were anticipated with regards to noise pollution in comparisons to equivalent conventional diesel bus operation along the route. In regards to effectiveness, thus far the buses have proven to be a success, with studies of real-world data indicating that significant emissions savings, in-line with simulated predictions, have been accomplished & system efficiencies of between 65-86% have been accomplished [194]. However, it is noteworthy that data has suggested agreement with previously presented literature that the identified principal cause of efficiency variance in overall system performance may largely be attributed to alignment variance between transmitter and receiver at the induction charging station [194]. However, as this development is viewed by those involved as a preliminary demonstration of the technology designed to assess the feasibility of UK-wide roll-out of induction charged buses, it is believed that such issues may be circumvented through further study & maturation of the technology. To provide indication of the perceived success and strength of the program, it was recently announced that a £1.75m investment is to be made to bring 11 new electric buses to Milton Keynes, which would see penetration of up to 25% of the commercial fleet [196]. In addition, following success of a similar feasibility scheme in Turin, Italy, £10m investment has been awarded for development of a 19-bus strong fleet of electric buses to operate along Turin's major bus routes [330] [331].

The final case study of infrastructure development which shall be briefly presented is that of the Highways England agency's intentions to perform "off-road" (read: private) assessments of inductive power transfer technologies for dynamic charging of HEV, EV and alternatively fueled vehicles [324] [332] [333]. A strategic component of Highways England's 2010-2015 Strategic Plan for road network investment, the trials result from a 2-yr, £200k feasibility study performed from September 2013 through September 2015 [334]. At most recent update, the Highways Agency was requesting tendered bids from contractors aiming to secure participation in the scheme, with representatives of the agency indicating that formal, 18-month long trials will begin in either 2016 or 2017, date to-be-confirmed upon contractor appointment [332].

Though little information has been published since initial announcement & feasibility study, it is known that the off-road assessments shall aim to replicate motorway conditions through use of underground cabling infrastructure. Focus of the study is anticipated to be in line with key metrics explored within the feasibility study; namely operating speed (vehicle velocity relative to stationary inductive charging infrastructure), power transfer level and suitability for differing vehicle types, including HGVs [333] [335]. The trials shall be the first of their kind with regards to the UK and if successful could drive significant investment towards dynamic charging infrastructure, particularly through links to manufacturers as stated within the published feasibility study [335]. However, there have been some outspoken skeptics of the scheme; including Dr Paul Nieuwenhuis, director of Cardiff Business School's Electric Vehicle Centre of Excellence [332] [324]. Most skeptics, including Dr Nieuwenhuis, believe that developments in battery manufacturing improving battery density and cost per kWh & the proliferation of fast charging networks significantly reducing battery recharge durations, may limit the requirement for dynamic charging infrastructure. However, most critics at this stage do remain open-minded with economic assessments of dynamic charging suggesting that the value of such systems may lie in improving battery longevity, which can be accomplished through reducing depth of discharge throughout journeys (Refer to KAIST study) & through enabling up-take of low capacity, rapid discharge technologies such as ultra-capacitors [323]. One such study performed indicates that 1% of road network dynamic charging infrastructure coverage may enable a typical 8kWh rated, 38mi ranged HEV to obtain 300mi of continuous range under the US Urban Dynamometer Driving Schedule (UDDS) [318]. However, the study does also conclude that under highway conditions (US HWFET driving cycle), which better represent the conditions proposed for Highways England's off-road trial scheme, up to 17% road coverage would be required to achieve 300mi range [318].

In addition to the above demonstration projects, the group explored at great length several operational dynamic induction schemes led by engineering & transport firm Bombardier under the commercial name "PRIMOVE". Such schemes included a tram system in Augsburg; an e-bus scheme in Berlin and a further e-bus scheme in the city Bruges. It was found that all projects had experienced similar success to those described previously, with comparable conclusions to those above drawn with regards to the transferability of such systems to private and fleet HEV & EV automobiles [336] [337] [338] [339] [340] [341].

4.8.5. INDUCTION CHARGING INDUSTRY INVESTMENT

It has been estimated by some research groups that global sales of wireless automotive charging devices will reach 302,000 units by 2020, however the technology of inductive wireless charging is at an infantile stage of development in regards to commercialization [342] [343]. Though investment has been pioneered by companies with backgrounds in electronic devices and battery technologies for several years, such as Samsung and Qualcomm, there are several key barriers to proliferation of the technology within automotive markets, with leading manufacturers announcing projects only within recent years. Within this brief section, a summary of key on-going developments and investments by leading automotive manufacturers shall be presented to give indication of the direction of the industry and reference shall be made to the development of competing standards for technology implementation.

At present, there are numerous competing standards of inductive charging, with manufacturers developing unique solutions through investment and partnerships with technology firms. For example, in 2014 it was announced that both BMW & Daimler would collaborate to develop a means of stationary (read: fixed) position induction charging for deployment in garages and parking bays. Employing resonant inductive charging technology, the system has been claimed to deliver power at a charging rate of 3.6kW, with potentially for scaling to 7kW in preparation for the next generation of production HEV & EVs. The efficiency of the system is claimed to be in excess of 90%, aided greatly through the use of a guided parking system which enables the driver to achieved near-optimum positioning & alignment, boosting the coupling factor which may be achieved. It is also claimed through use of example that the BMW i8 model, with a 7.1kWh lithium-ion based battery can be fully charged in less than 2-hours through the system [344] [345]. However, in contrast to this BMW-Daimler partnership & providing exemplification of the on-going competitive development of automotive charging technology, Daimler announced that a partnership with computer chip & electronics firm Qualcomm had been formed with intentions of developing jointly both in-car charge for electronic devices and inductive charging capabilities for HEV & EV vehicles [346]. Few details of the system have been announced however it is believed to be similar in architecture to BMW's.

Other manufactures are also developing competitor systems; including leading Japan-based automotive manufacturers Toyota and Honda. Toyota's proposed system is similar to that of both BMW & Daimler where-in there is a requirement for stationary parking, aided by on-board navigation systems, to accomplish inductive charging of vehicular batteries. Developed in partnership with the firm WiTricity, demonstrations have been performed however at present there are no available specifications for the system in regards to either power delivery or efficiency; though a significant reason for this may be that neither Toyota nor WiTricity intended to manufacture induction charging transmitters themselves, opting instead to fit only receivers to their vehicles awaiting 3rd party development of transmitters [347] [348] [349]. Mitsubishi, again a Japanese-based automotive & electrical power systems manufacturer is developing a similar system to that of Toyota independently [350]. By contrast, Honda is currently developing dynamic charging systems for future HEV & EV charging. Proposing to demonstrate its technology at WCX 17 SAE World Congress Experience in March of 2017, Honda claims to have developed a system capable of 180kW charging rates at vehicle speeds of 96 mph [351] [352]. Audi too are investing in 'wireless' induction-based charging systems, with anticipated near-term investment towards a 3.6kW to 7kW stationary system [342] [353]. Bosch, a German-based powered electronics firm has also developed an induction-driven stationary system which it currently offers for both the Nissan Leaf & GM Chevrolet Bolt for a cost of £2,500 [354].

As demonstrated through the above highlighted technology & investment summary, there are several emerging methodologies & architectures which are experiencing limited penetration of a niche market. This is presenting a major barrier to the up-take of induction charging technology due to interoperability & compatibility problems with competing transmitter and receiver platforms. At present, there are two leading standards emerging, each of which was developed independently through various organizations and manufacturer partnerships; previously there had been three [317] [342]. These competing standards have been pioneered by Wireless Power Consortium (WPC) and the Alliance for Wireless Power (A4WP) respectively, who are each backed by various OEM manufacturers and automotive leaders [317]. Similar in concept to the various propriety mobile device charging systems which limit charging options for consumers (e.g. Apple's Thunderbolt vs. USB-based charging employed by the Android group), presence of two incompatible directly competing induction charging standards is inhibiting up-take & investment; inherent OEM risk of investing in eventually superseded technology is increased and the perceived benefits of more convenient charging in comparison to existing 'plug-in' architectures is diminished through requirements for compatible proprietary hardware.

To resolve this, the Society of Automotive Engineers (SAE) is currently undergoing development of a standard for induction-based charging technology. Consolidating efforts of industry partners and with aims of stabilizing the market and encouraging further reduced-risk investment, SAE is targeting to publication of their standard by 2018. SAE are confident of capability for up to 7kW systems, however indicate that trials are on-going for 11kW and above [355]. Already this is impacting the direction of innovation for induction-based chargers with leading OEM manufacturers such as WiTricity specifically targeting the development of systems compatible with preliminary publications of the SAE standard [356]. However, not due for publication for a number of years still and with a period of time required for the adaption of manufacturer hardware, it is thought that inductive charging shall not be at a product maturation level capable of thorough commercialization until at least the year 2020 [355].

Considering all the above, the overall conclusion that can be drawn for induction-based wireless charging systems for HEV & EVs within the scope of a short-medium term outlook is that such infrastructural developments are unlikely to significantly influence the volume of HEV & EVs sales. The fundamental barrier of a distinct lack of current standardization, particularly within high-gain, high power automotive applications, inhibits market penetration of such charging systems at present. However, this major barrier is due to be overcome with the release of a pending draft standard generated by SAE, due for publication in 2018 & which is proposed to enable interoperability across both leading standards. Standardization in conjunction with increased market penetration of inductive charging for small devices such as mobile phones and with sustained investment for automotive applications, inductive charging may yet play a significant role in the medium-long term outlook of HEV & EVs; principally through alleviating much of the behavioral change requirements for transition from conventional ICEs through improving convenience. Thus, consensus is that any proposed HEV concept should facilitate accommodation of induction charging.

5. ELECTRIC BATTERIES IN VEHICLES

A battery electric vehicle is a vehicle of alternative propulsion that is driven by an electric motor. This one is powered by electrical energy which comes from a battery. The battery is one of the main and most used Electrical Energy Storage technologies in the daily life and in industry. The Battery Energy Storage system is formed by a number of electrochemical cells that are set up in series or parallel and they produce electricity thanks to an electro-chemical reaction. [357] A cell is a device that is composed of two electrodes (the anode and the cathode) and an electrolyte (it can be solid, liquid or viscous). At the time of discharging, there are electrochemical reactions at the cathode and the anode. During this action, the electrons go from the anode to the cathode, so that there can be electric current on an external grid. In the case of charging in which an external voltage is applied to both electrodes the reverse reactions are shown. Figure 63 illustrates how BES works [358].

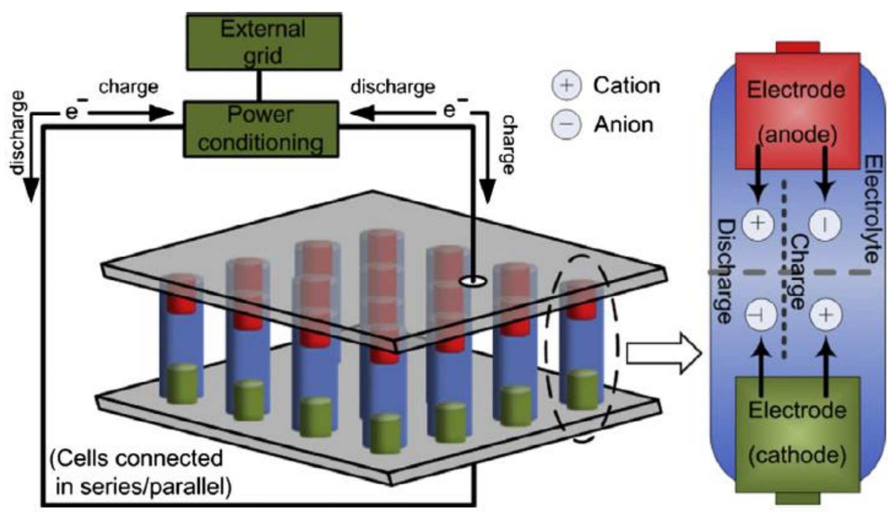


Figure 63. Schematic diagram of a battery energy storage system operation

Giving a brief presentation about the earlier electric cars of the 19th century, it can be said that during that period the researches about electromagnetism were developed fast and one of their first applications was motorizing the vehicle. At that time, the vapour was not able to substitute horse-drawn carriage, a new competitor was established. After the first experiments of Jedlik in 1828 and Thomas Davenport in 1835, the first electric vehicle could be developed when Robert Davidson was able to drive a locomotive at 6 km/h without using vapour and coal in 1838 [359] [360] [361]. Between 1832 and 1839, Robert Anderson made up the first carriage of electric traction. It had a battery of energy not rechargeable [361]. The first rechargeable batteries appeared before 1880. What it is more, the technology of the batteries progressed in a really good direction. Thomas Alva Edison set up a nickel battery in an electric car before 1890 and in that way more autonomy and features were reached. However, IC cars won the battle in the market as

Henry Ford used mass production, oil's price was dropped and their autonomy was much bigger. Nevertheless, batteries started to be completely necessary in cars in 1920 when crank was replaced by automatic start. The electric motor that was in charge of setting the car in motion needed to be powered by energy whose source was an electric storage battery [359]. Since that time it has been used lead-acid batteries (there are some punctual exception) to this purpose because of its good amperage, price and cold response. However, it does not offer a good specific energy (stored watts per hour in each kilogram) due to its weight.

In an ordinary internal combustion car, the power requirements to make the engine starts up are minimum and the battery just need a few watts per hour (600-1000). A voltage of 12 V and an amperage that provides 70 A/h. While in the case of electric cars, the role of the battery is different. If a comparison is made, it can be said that the purpose of the battery is substituting the oil of a conventional car.

Nowadays there are many types of batteries, but it is sure that one of them is going to lead the market in the near future: lithium. [362] Setting some of the most important current batteries from the smallest to the greatest specific energy:

1. Lead-acid: as it has been said before, this is a kind of battery that can be found in any ordinary car along the road. It has been used for many years because of its price (50–600 $/kW h) and ease of fabrication. Unfortunately lead is a heavy material and it can just reach 25-50 Wh/Kg. What is more, it does not last many cycles of charge and discharge (200-1800). An autonomy of 100 Km can be reach with them. In addition, and the interesting point of this battery is that it has been used as power resources for hybrid and electric cars as some versions of the Reva. Lead-acid batteries are also a good option because they are recycled more than any other major consumer product (Figure 64) [363].

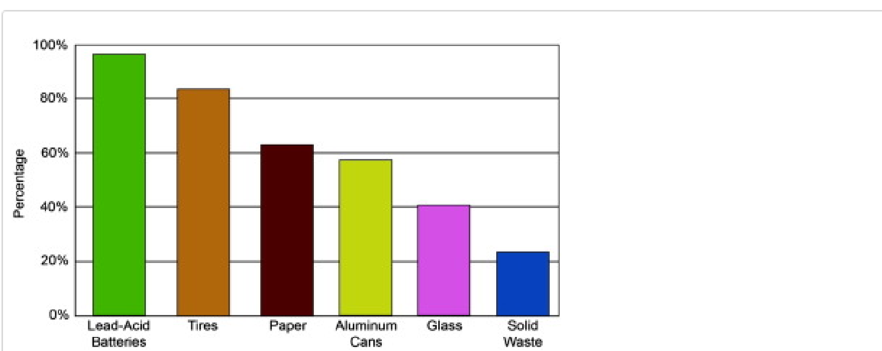


Figure 64. It shows the percentage of recycled of each material.

Some additional technical data is that its cathode is composed of PbO_2, the anode of Pb and sulphuric acid works as electrolyte. It has fast response times, small daily self-discharge rates (less than 0.3%) and it works badly at low temperatures, so it needs a thermal management system, but this increases the final price.

Now, researches are focused on trying to innovate materials to improve features like number of cycles and the deep discharge capability. [362] [358]

Its chemical reaction is:

Lead–acid	$Pb + SO_4^{2-} \Longleftrightarrow PbSO_4 + 2e^-$ $PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \Longleftrightarrow PbSO_4 + 2H_2O$	2.0 V

2. Nickel-cadmium (Ni-Cd): it is a kind of technology that was mostly used for rechargeable batteries in 90's. This battery uses nickel hydroxide and metallic cadmium as electrodes and for the electrolyte an aqueous alkali solution. It has to be reflected that cadmium and nickel are toxic heavy metals that are dangerous for the environment. It has got a big defect, since it has got really high memory effect. This means that it cannot be load again until the battery is completely discharge, because the maximum capacity can be decreased. In addition, its low load cycles (2000-2500) do not help to consider a good argument about it. With this data it can be concluded that this battery is not interesting for electric vehicles. However, it can reach more specific energy than the previous battery (50-75 Wh/kg). There is no information collected of any electric car that used this battery before. It is difficult to think that NiCd battery can have any presence in the future. [362] [358]

   Its chemical reaction is:

Nickel–cadmium	$Cd + 2OH^- \Longleftrightarrow Cd(OH)_2 + 2e^-$ $2NiOOH + 2H_2O + 2e^- \Longleftrightarrow 2Ni(OH)_2 + 2OH^-$	1.0– 1.3 V

3. Nickel-metal hydride (Ni-Mh): this battery is similar to the previous one, but a hydrogen-absorbing alloy is used for the electrode instead of Cd.

   In 2011 most of the hybrid cars that were on the market used this type of battery due to its wealth of applications. It has been selected by HSD Toyota's system, LHD of Lexus and Honda's IMA. It shows advantages as a good specific energy (70–100 W h/kg), it is considerate cheap if the price is compared with its characteristics. Ni-Mh batteries show less memory effect and they are less toxic than Ni-Cd.

   Nevertheless, it has high self-discharge (5-20% of its capacity just the first day after having a full charge) and after a few hundreds of full cycles the performance decreases. [362] [358]

   Its chemical reaction is:

Nickel–metal hydride	$H_2O + e^- \Longleftrightarrow 1/2H_2 + OH^-$ $Ni(OH)_2 + OH^- \Longleftrightarrow NiOOH + H_2O + e^-$	1.0–1.3 V

4. Lithium: nowadays it is the battery selected by most of the manufacturers to be settled up in their hybrid and full electric vehicles. The Li-ion battery has got a cathode formed by lithium metal oxide as $LiCoO_2$ and $LiMO_2$ and in the case of the anode by graphitic carbon. In addition, a non-aqueous organic liquid with dissolved lithium salts like $LiClO_4$ works as the electrolyte. It uses large format cells and packs with capacities of 75-200 W h/kg. It has got a high number of load cycles (1000-10000) and very low self-discharge. In this way, it can be achieved more autonomy with less weight. The Li-ion battery is considered good candidate in the cases that small dimensions, response time and/or equipment´s weight are important. However, there are also some disadvantages as the fact that with the pass of time it loses capacity and it is expensive due to the relative lack of lithium. What is more, in the case of a hypothetical accident, it is the most dangerous battery.
   Now, researchers are focusing on increasing the power capability of the battery with nanoscale materials and improving its specific energy with the use of advanced electrode and electrolyte materials. [362] [358] [364]
   Its chemical reaction is:

Lithium-ion	$C + nLi^+ + ne^- \Longleftrightarrow Li_nC$ $LiXXO_2 \Longleftrightarrow Li_{1-n}XXO_2 + nLi^+ + ne^-$	3.7 V

The next two graphs are going to be used in this section in order to show the huge rise in the demand in the li-ion batteries along recent years and an expectetion for the next year and to exhibit the main sources of lithium around the world. The first graph claims the succed of this battery, increasing its demand exponentially [365]. The second one advices where this metal can be founded and if there is any development project related with this material in that place [366].

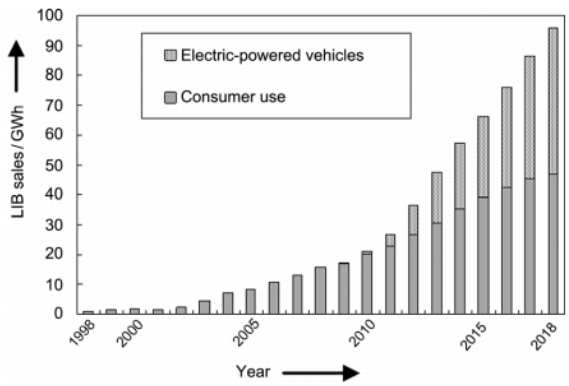


Figure 65. Forecasted expansion in demand for lithium-ion batteries. GWh=gigawatts hours.

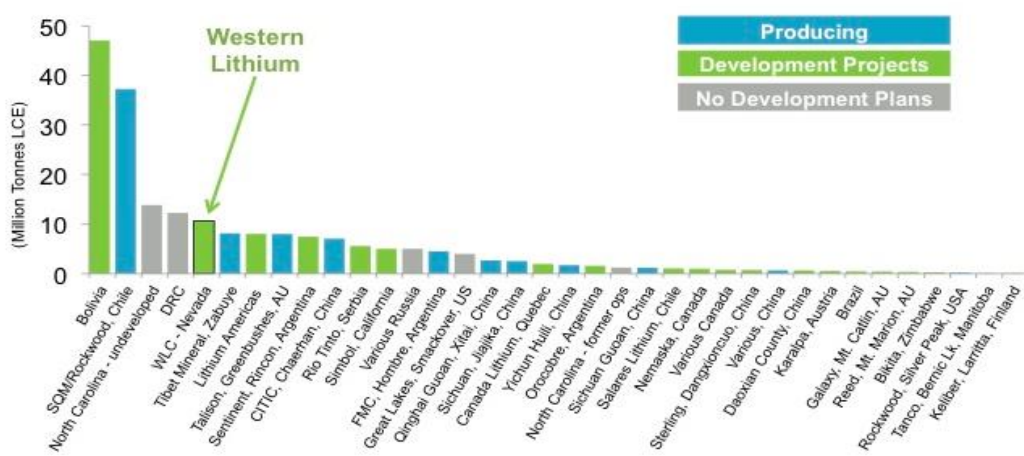


Figure 66. World lithium resources.

Another fact that can be important is that as it has been said Li-ion batteries use cobalt. In figure 67, it can be seen how the demand of cobalt is increasing along the years [367]. This material is mostly mined in Congo, producing half of the total extraction in the world. The problem is that the inhabitants of the country do this extraction in really bad labour conditions: some of them sleep in the mine (lack of oxygen and high probability of mudslides and floods) and they have to descend hundreds of meters with a flashlight that just works for very short distances, hand tools to break up rocks and the intuition as a guide, so it can be said that there is no labour security for the workers and the most shocking thing is that nobody does anything in case of accident. Their salary is just of 3 dollars per day and some children are forced to work in these places. At the end, the rocks are cleaned in the river, so the water arrives with toxic metals to the villages. All these facts are an enough reason to think that the possibility of a revolution or a war can happen and this could directly affect to the production of Li-ion batteries.

For example, Congo DongFang International Mining is a company that collects most of the extracted rocks in the country and it belongs to one of the major producers of cobalt in the world, Zhejiang Huayou Cobalt, that sells Apple 20% of the cobalt this company uses for their batteries, so if there is any revolution, the production of Apples´s devices can be drastically decreased [368].

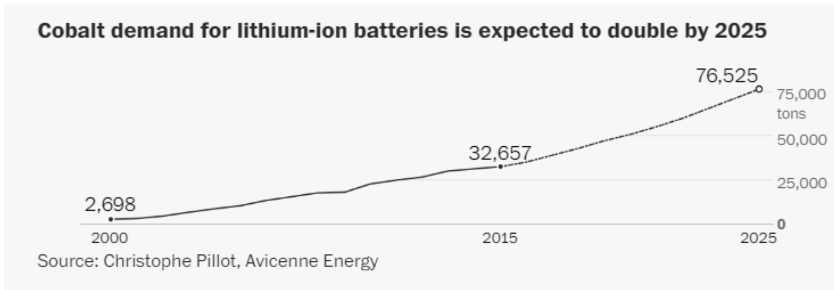


Figure 67. Demand of cobalt for li-ion.

TABLE OF COMPARISON

Table 20 *Summary of technical data of each battery.*

Technology	Specific energy (Wh/kg)	Specific power (W/kg)	Rated energy capacity (MWh)	Daily self-discharge (%)	Cycling times (cycles)	Response time
Lead-acid	25-50	75-300	0.001-40	0.1-0.3	200-1800	milliseconds
Ni-Cd	50-75	150-300	6.75	0.2-0.6	2000-2500	milliseconds
Ni-Mh	70-100	-	-	5-20	-	-
Li-ion	75-200	150-315	0.004-10	0.1-0.3	1000-10000	milliseconds

In this table there are some data that can seem to be too high, as for example the 10000 cycles of the li-ion. This can be explained since it is also taken into account recent results that have been found in laboratories while researching.

5.1. LITHIUM BATTERIES OF VARIOUS MANUFACTURERS

5.1.1. RENAULT AND NISSAN

Electric vehicles of Renault-Nissan´s partnership are working with the innovative and compact lithium-ion batteries that are supplied by the joint venture Nissan-NEC, AESC (Automotive Energy Supply Corporation), which was found in 2007. The production of their batteries started in 2009 in a production facility of Nissan that is placed in Zama, Japan. This battery is composed of elementary units that are called modules. They are stacked following capacity requirements and architecture restrictions. The modules contain cells of 3.7 v (figure 68).

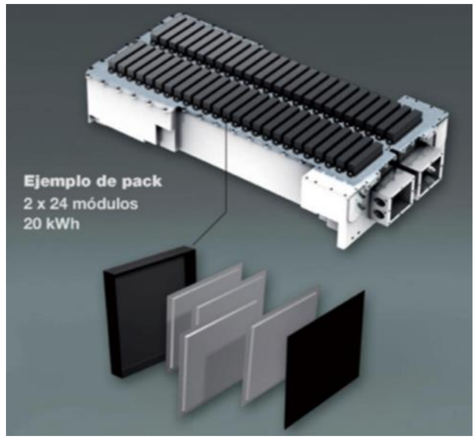


Figure 68. Batteries NEC-Nissan

The ions of lithium move from the anode to the cathode. This reaction creates electron flow (electric current) in the supply circuit. While charging the battery, the opposite reaction takes place (figure 69) [369].

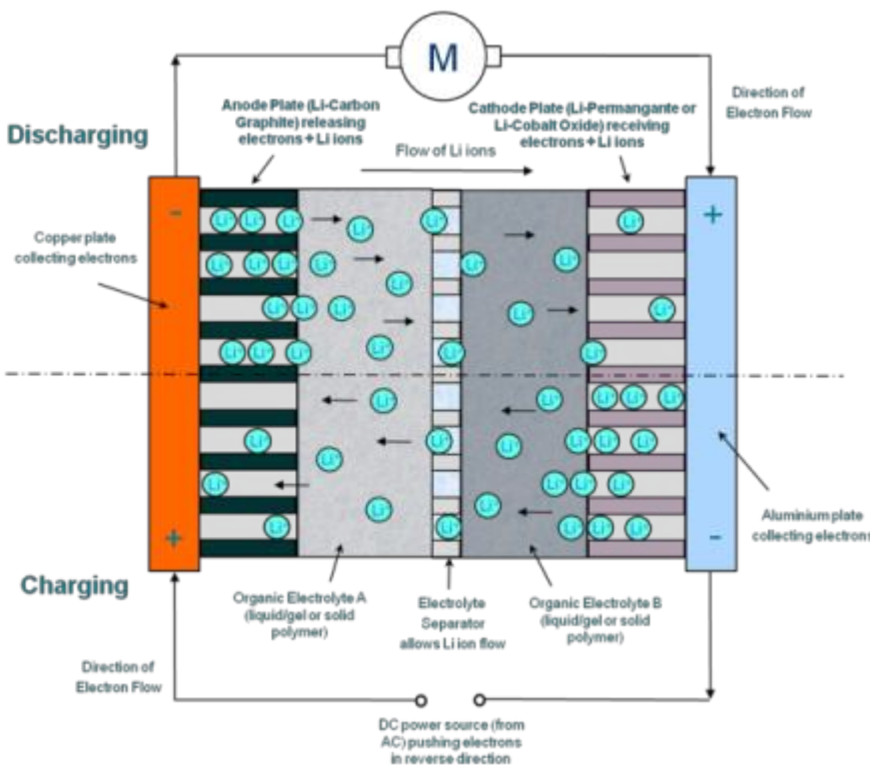


Figure 69. Behaviour of ions of lithium while charging or discharging.

Renault and Nissan decided to do the "zero emission" project together, but instead of working in a parallel way, they determined to distribute the different functions. Renault develops the electric motors and Nissan the batteries. As it was said before, the Japanese constructor has made an alliance with NEC (also Japanese), that leads electronics and informatics around the world. This superiority allows the alliance to have a great competitive advantage, in terms of technical solutions and industrialization, because it involves a complex and expensive process. This sharing of functions does not mean that each manufacturer cannot develop and sell its own vehicles [362]. In figure 71 it is shown how these two manufacturers are spread around the world and if there are any cross production activities between them.

RENAULT NISSAN

Figure 70. Logo of the joint-venture between Nissan and Renault.

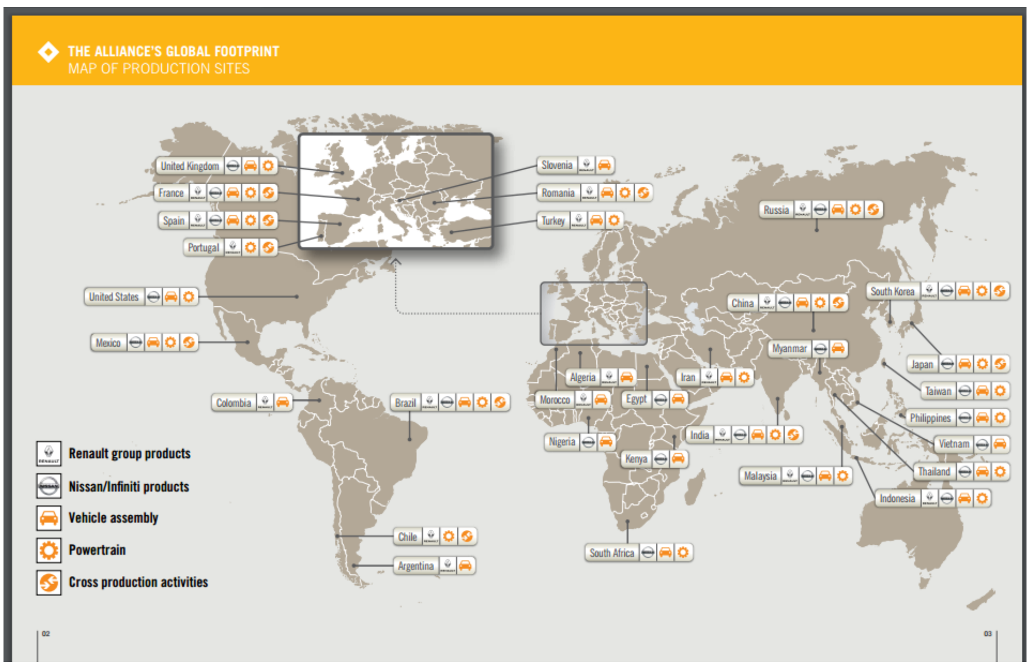


Figure 71. Production sites of Renault and Nissan.

5.1.2. RENAULT

Renault Z.E. range of cars can charge in 3 different ways (it depends on the model):

- The standard charge:
  In a common domestic plug (230V-16A or 10 A) for Twizy or with an intelligent and protected recharge box for the rest of the vehicles. Twizy charges in 3 hours and 30 minutes and the other cars spends between 6 to 8 hours to get a full charge.

- The quick charge:
  In a specific charge point with high power (400V-36A). 10 minutes will be enough to reach 50 km of autonomy. These charge points will be placed close to homes, central offices and shops, so that they can be near users as much as possible.

- Change of battery with the system Quickdrop:
  This works by a change battery system with which only 3 minutes will be needed to replace the discharged battery to other one that is full charged. This will take place in battery exchange stations. At this point the station will automatically recognize the car. A robot will open the battery compartment and will replace the battery in a secure way.

5.1.3. NISSAN

In relation with the ”zero emission” project and the launch of Nissan Leaf, Nissan has also started to build the necessary infrastructures to charge electric vehicles. Nissan’s data show that the battery of the LEAF is developed for being able to be fully or partially charged. In other to charge it, there are two electrical outlets that are placed in the front part of the car. The one that has got bigger dimensions is used for quick charges and the smaller one is used in domestic charges (figure73). The electric part of the Nissan Leaf has got a warranty of 5 years and its battery is estimated to last 10 years [362].

Figure 73. Nissan leaf and its two electrical plugs (quick and slow charge).

As it was said above, their batteries are developed by the joint venture Nissan and NEC (specialised in this kind of batteries, particularly in mobile phones) in Japan, but countries like USA, UK and Portugal are also suitable places to have in mind to develop this technology [362].

5.1.4. BATTERY IN HOUSES

Is it possible that an electric car can supply energy to a house? Nissan proves that with Leaf model. Nowadays, electric cars have more quality. They are less noisy and more environmental. In addition, they are able to supply the stored energy of the battery to a house in the case of emergency. This system is called “Kan-kan-kyo” and it was shown by the constructor Sekisui House Ltd in a house that was placed close to the headquarters of Nissan in Yokohama. This system is incorporated in the programme Nissan “Zero Emissions”. It works by connecting the car to the electrical distribution board of the house, using a special connector that is linked to the fast loading port of the Leaf. This system can help in case of power failure thanks to the 24 KW/h that its battery can store. This amount is enough to supply a Japanese house during two full days [362].

5.1.5.CITROËN

C-Zero´s battery is manufactured in Japan by Lithium Energy Japan. This company was composed by Mitsubishi Corporation, Mitsubishi Motor Corporation and GS Yuasa (battery specialist) in 2007. In 2011, GS Yuasa was the only manufacturer that turns out mass production of high density lithium-ion batteries in Japan. This series production started in 2009. The Japanese company Lithium Energy will manufacture 200000 lithium-ion cells for electric vehicle’s battery annually. C-zero´s battery is composed by packages of 4 or 8 cells. In total, there are 88 (with 10 of 8 cells and 2 of 4 cells). Its shape allows it to be fixed in a vertical or transversal way. It weighs 230 kg. The company assures that the battery will have 80% of its initial capacity after 10 years of function. It can be charged in two different ways. The first one is connecting the car to a conventional plug (230V) and it will last 6 hours. The second one is a quick three phase load that is called CHAMEDO. With this one the battery will be 80% charged in 30 minutes [362].

5.1.6. MERCEDES-BENZ

If its lithium-ion battery has enough charge, Class B E-CELL PLUS will be driven exclusively by the work of its electric motor. If it is below an established limit, there will be two operating modes: at lower velocities than 60 Km/h the combustion motor is used to charge the battery through a generator. At velocities above 60 Km/h, wheels are driven by both motors [362].

5.2. OTHER ELECTRIC BATTERIES

There are also electric batteries that are used for other devices like A123 LIFEPO and LI-PO [370].

1. LI-PO

   This kind of battery is used by radio-controlled planes.
   The appearance of LIPO has revolutionized electronic flights. This battery has got an energy density between 5 and 12 times NI-Cd´s or Ni-MH´s one (with same weight). With this electronic model the time of flight has increased between 20 and 30 min. A LIPO battery is four times lighter than NI-Cd battery with the same capacity. However, its main disadvantage is that it requires a delicate treatment, since it can cause a great damage as it can burn. It must never be as discharged as Ni-Cd or Ni-MH, because this can deteriorate its charge capacity forever. This is why special LIPO speed controllers should be used in electric models. They will switch off the current if the critical voltage is reached. Another disadvantage is its price that can be the double of Ni-MH´s one with the same capacity. However, its price is dropping quickly with its introduction in the market and the appearance of new branches with high quality.

2. A123 LIFEPO

   It is used for electric remote controlled cars.
   This new kind of rechargeable lithium battery is becoming popular because of two reasons with respect to LIPO batteries: it allows a quicker charge (15 min versus 1 hour in LIPO) and it is less delicate while working. It is common to have an overload or over-discharge in a LIPO battery. It can be concluded that A123 LIFEPO are more secure. What is more, LIPO tends to burn or explode while an extreme charge or discharge. This fact can be explained since it uses a different chemistry that is based on lithium and iron phosphate (LIFEPO) as a cathode. Nevertheless, in the case of LIPO, $LiCoO_2$ is used.

5.3. FUTURE POSSIBILITIES

5.3.1. SUPERCAPACITORS

The future seems to be related with supercapacitors. A capacitors is a device that stores a minuscule amount of energy. It consists of two plane electrodes which are separated by an insulating layer (sometimes an electrolyte in solution is used). The more surface the better for the capacitor to store more energy [371] [362].

Supercapacitors are electrical components that are able to store a huge electric charge amount for long periods and return it lightly and in a constant way (ordinary capacitors do it sharply). This device would be able to be loaded quickly, to have a great amount of charge and discharged cycles and to be operational in a larger range of temperatures (-60 to 70 ºC). They are endowed with an unloading rate, so they can give and receive energy in short time. In this way cars could be charged really fast. In addition, although supercapacitors would have an "infinite" number of charge and discharge cycles, it would never affect their capacity. However, it has got a main disadvantage that consists on the requirement of a huge surface, hence the mass it would have. Some researchers think that this problem could be fixed by using carbon nanotubes, so that the final product could be light and reliable [372]. There are also other disadvantages as its high price (50-150 Euros/Wh) and self-discharge (50%/ month).

5.3.2. BATTERIES VS SUPERCAPACITORS

Table 21 *Summary of a comparison between technical of current batteries and supercapacitors.*

Features	**Batteries**	**Supercapacitors**
Discharge rate	Minutes/hours	Seconds
Discharge voltage	Relatively plane	Decreases linearly
Specific energy	25-200 Wh/kg	2.5-15 Wh/kg
Specific power	100-500 W/kg	500-5000 W/kg
Rechargeability	Moderate	Very high
Cycles	200-10000	10000-100000

5.3.3. GRAPHENE

It is one of the most attractive materials in electronics and it can revolutionize the concept of future batteries. It basically consists on one sheet of pure carbon´s rims. It has got a thickness of just one atom. It can be said that its structure looks like a chicken wire-fence. This structure has captured the attention in the most advanced research laboratories of the world, from London to Texas, and from Solar Tech to IBM. Now, these laboratories are studying the different applications that the graphene can achieve: batteries for electric vehicles, computer chips, communication devices, touch screens or energy accumulators (it could also be implemented in high voltage electrical wiring). The existente of graphene has been raised for decades, but it was thought that a two-dimensonal cristal with a thickness of an atom would shed, until a group from the University of Manchester directed by Andre Geim proved that it was viable. Now, a great number of scientific teams are trying to made enough amount of this material for its use in electronics or the development of other materials. The graphene consists of just a graphite layer (allotrope in chemistry terms). Allotropy implies any shape in which electrons of one element can be organised and this element remains the same. This provides it the capacity of taking different properties. The graphene has got several attractive characteristics. Its electrons confront a resistente of 100 times less with respect to silicon components. This is possible due to its thickness. It can be considered as two-dimensional. Manufacturing smaller devices and managing the flow of electricity is going to be easier than in the case of three-dimensional alternatives as silicon transistors [373].

In conclusion, the graphene could revolutionize the industry of cars, and solar and wind energy. Nowadays they are affected by store problems, but researches think that this can be solved by using supercapacitors of graphene. As it has been explained before, a supercapacitor is a device works by separating electric charges instead of storing them chemically. Supercapacitors of graphene could have three or two times the storage of current ones [374].

5.3.4. MOLTEN SALT BATTERIES

An other option for the future is the molten salt battery. It uses sodium as electrolyte. On the one hand, it has great energy density that could duplicate lithium´s one and good voltage per cell. On the other hand, this battery needs a working temperature of 600 °C, that is almost the melting point of sodium. This seems to be a clear disadvantage as if it does not work, it will cool down, so it will not be usable. Heating it is the solution just to make it give electricity again. What is more, with this battery, some parts of the car would be at 600 °C and this could be a problem with the fire.

Nowadays it can be found some of these batteries working. What is more, some prototypes use them with cooler temperatures (around 300 °C). This kind of battery can be viable in urban buses and vehicles that are working continuously during long periods, since this would avoid the cooling of the battery [362].

5.3.5. LIQUID FUEL FOR ELECTRIC VEHICLES

Electric batteries have been used since a long time ago, but customers want them to have more quality. They demand more autonomy for the devices and at the same time they want them to work with more power that requires more consumption. Something similar is happening in the car market. The problem is that electric vehicles have got less autonomy than IC cars. In addition, other issue that can be found is the time needed to charge a battery (15 min in the best case and 8/9 hours if the car is connected to an ordinary plug). Nevertheless, researchers from Massachusetts Institute of Technology (MIT) have developed a new kind of battery that is charged with a liquid fuel. The fuel is called Cambridge Crude and it is able to load the battery since it is powered by charged particles in an electrolyte. This battery consists of two compartments where the particles are stored, one is for ones that store the charge of energy and the other one is for the ones that discharge this energy. The main advantage of this system is that it takes less time to charge the battery, as it would be like filling the tank of an IC car because of the use of the liquid fuel. In addition, MIT´s report shows that this new concept would reduce the size and the price of the battery by half of their present values. In this way electric cars can compete better with IC cars in the market and this is going to make the car to be lighter, so that they can improve their features and driving [362]. If researches achieve introducing this battery in the car market, it will be an important step. However, the problem with the autonomy would not be solved as reaching 200 km would be hard [362].

5.3.6. ALUMINIUM BATTERIES

5.3.6.1. ALUMINIUM-ION

Some researchers think that the era of lithium-ion batteries will be finished with this new kind one. A research team from the University of Stanford has developed Al-ion batteries (ions of aluminium). Its main characteristic is that the battery can be charged in just one minute. In addition, it has got other important features as the fact that they are flexible, enduring, very cheap to produce (there are no complex elements to be manufactured and the aluminium is one of the metals with more presence in the earth crust, 7.5%) and safer as they do not flame or explode like in the case of lithium-ion.

Over the last three decades the science has been trying to achieve an aluminium battery, but all the attempts have been ruled out. The reasons were related with cathode material disintegration (at that moment, a proper material for the cathode had not been found), low cycle life (less than 100 cycles with a capacity of 26-85%) and low cell discharge voltage (0.55 volts). In Stanford the suitable material for the cathode has been found. The solution is the graphite. The current data supports an aluminium battery with great capability which uses aluminium for the anode and a three-dimensional graphitic foam in the cathode. The battery works by the electrochemical deposition and dissolution of aluminium at the anode, and intercalation and de-intercalation of chloroaluminate anions in the graphite. Using a non-flammable ionic electrolyte, the cell shows a discharged voltage of almost 2 volts. Its charges lasts just 1 min due to the cathode that enables quick anion diffusion with a current density of 4000 mA/g. The new composition of the battery makes the battery reach more cycles of charge and discharge. Researches in Stanford calculated 7500 cycles without decay of its original capacity. On the other hand, ordinary lithium-ion batteries can withstand around 5000 cycles. With all these advantages it is difficult to think why manufacturers do not use these kind of batteries, so there is obviously one important disadvantage. The problem is that the aluminium-ion just reaches half of the voltage that is shown in a lithium-ion battery. In other to solve this, researches are calculating the correct density for the cathode [375].

5.3.6.2. LIGHT ALUMINIUM-AIR BATTERY

Nowadays, there are three companies in the world (Spanish, Japanese and Israeli) that are working on developing and studying this alternative battery that is supposed to have an autonomy of 1100 mile range on a single charge. This would mean an incredible progress, since the 300 miles autonomy of Tesla Model S are considered as high quality.

It works using oxygen from the air in its cathode, so that the car can be lighter than other one that uses lithium-ion batteries. The problem is that it drains, so aluminium hydroxide is obtained, but fortunately it can be recycled, so that more batteries can be made. In this way, swapping batteries would take place once in a period of few months, but as it is cheaper and lighter it should not be a huge problem. In the case of Tesla, they have a battery swap-out service that can change it in 90 seconds, so it spends less time than fuelling your IC car with petrol. In addition, another important thing that drivers should do is adding water to the system each month (or two months), so that the reaction can occur [376].

5.3.7. INFINITE CYCLES BATTERY

One of the main objectives that manufacturers want to achieve while building a battery is creating one that can withstand infinite cycles. Researches from the University of California (Irvine, USA) have found a way to make it possible. They were studying how liquid lithium of batteries could be substituted as it is too sensible to temperatures which can be dangerous, when they accidentally got a battery 400 times more efficient than current ones. These researches started their investigation with nanotubes of gold that were covered with a gel of electrolytes. Scientists found out that they were incredible durable. The battery could work perfectly after 200000 cycles of charge (it would just lost 5% of its capacity). For a long time, researchers have experienced with nanotubes for batteries, since they are thin, high conductive and they have got a huge surface for storing and transferring the electrons. Nevertheless, they are too fragile and they cannot withstand the phases of charge and discharge. Specialists think that the batteries made in Irvine have got a great effectiveness because the gel plasticises the metal oxide in the battery, living it more flexibility, so that crashes are avoided. The electrode maintains its form and this means being more reliable.
However, the use of gold is expensive, it does not matter that it is just used for thin filaments, so it is impossible to produce them in volume. The proposed solution is replacing the gold with a common metal like nickel [377].

These are the most suitable batteries for the future, but there are obviously more alternatives that can be considerate as good options. For example, researchers are studying a new battery technology called Ryden dual carbon, an organic battery that is 97% cheaper to make and an alternative lithium-ion battery that uses sand to achieve three times better performance than current ones. In the case of being interested on the different studies of future batteries, it would be great to take a look to this page: http://www.pocket-lint.com/news/130380-future-batteries-coming-soon-charge-in-seconds-last-months-and-power-over-the-air.

5.4. BATTERY PERFORMANCE

A 2011 report showed that at that time one kilogram of battery accumulates approximately the same energy as 50 g of petrol. Consequently, 50 kg of petrol would be the same as 10000 kg of batteries. Notwithstanding, it has to be taken into account the high efficiency of an electric car. [362]

Before keeping on talking about energy efficiencies, it has to be known that there are three evolving cases in the case of an electric motor: IE1- standard efficiency, IE2-high efficiency and IE3- premium efficiency.

Now, the efficiency of an electric car is going to be analysed:

- Generator mixed system: ɳg
- Distribution and transport: ɳt
- Electronic converter and battery: ɳc* ɳb
- Electric motor: ɳm
- Mechanical system: ɳmec

Finally, the overall performance is represented by:

$$\eta = \eta_g \cdot \eta_t \cdot \eta_c \cdot \eta_b \cdot \eta_m \cdot \eta_{mec}$$

The performance of the total generated primary energy for a standard European country can be rated as ɳg=36.7%. [378]

The losses related with transport and distribution are 6.32% [379], so the performance is ɳt=93.7% in this case.

The electronic converter's efficiency is ɳc=97% [380].

The Ion-Lithium battery with a resistance of 0.175 mΩ shows an electric efficiency of 99.14% [381] and if it is multiply by 99.63% that is the performance of the thermal conductivity, the battery's efficiency will be ɳb=98.8%.

In the case of the electric motor, the average yield is established by powers between 4 and 45 kW, with the set 2p=4 poles [382]. Working in conditions that are not the optimal makes losses that are not taken into account. This can happen due to vehicle's auxiliary services like lights, comfort and others. With all these data, it can be made an estimation shown in table 22.

Table 22 *Summary of the ηm depending on the type of motor.*

Type of motor efficiency	**Efficiency ηm (%)**
Standard efficiency	86.0
High efficiency	88.7
Premium efficiency	90.2

Finally, the mechanical system that is form by the transmission of efforts and the security system is going to have an efficiency of ηmec=80.0%.

Now, a table with the overall performances can be made for the three evolving cases of electric motors.

$$\eta = 0{,}367 \cdot 0{,}937 \cdot 0{,}970 \cdot 0{,}988 \cdot \eta_m \cdot 0{,}800$$

Table 23 *Summary of the total η depending on the type of motor.*

Type of motor efficiency	**Efficiency η (%)**
Standard efficiency	22.7
High efficiency	23.4
Premium efficiency	23.8

On the other hand, in the case IC vehicles it is needed to take into account the extraction process, the refinement, the storage and transport, the combustion in the motor and the mechanical system. In this way a global efficiency of 10-15% is reached [383].

An electric car needs less power to work and to be driven than an ordinary IC car. However, batteries of 15-20 kWh that weight many kilograms are needed to provide an acceptable autonomy.

5.5. COOLING SYSTEM

In terms of efficiency and battery it is important to mention the cooling system. For example, Kreisel is a company that has developed active thermal management for their electric batteries. Their cells are set up with a special casing that is regularly flushed with liquid. What is more, if this system is combined with a heat pump, the battery can increase or decrease its temperature efficiently. The result of this is a battery with more autonomy and service life [384].

5.6. TESLA STARTS BATTERY MASS PRODUCTION

Tesla has started the lithium-ion mass production in its plant that is placed in Reno (Nevada). This new facility called Gigafactory will help to produce the Powerwall and the recent electric vehicle Model 3. The beginning of volume production is a great milestone for Tesla and its desire of electrifying the transport. In this way USA is going to be involved in an industry which has been monopolised by China, Japan and South Korea (88% of the total production in 2015). Nowadays, more than 2900 people are working in a space of 455000 m^2 in the Gigafactory and this year 4000 more employees are going to be incorporated thanks to the joint venture between Tesla and Panasonic. The construction of the Gigafactory is still uncompleted (just 1/3 is built), but it is expected that for 2018 it will reach full operation capability with 65000 employees. The aim is to duplicate the production of lithium-ion batteries. The setting up of the Gigafactory is really important for Tesla, a company that is known for complying “unattainable” deadlines and that has to demonstrate its clients and investors that the company is able to have its first series-produced car for the estimated time.

In order to success in the 500000 sales of the new Model 3 in 2020 (figure 74), it is necessary that Tesla produces its own batteries, since there is no place where there are such amount of lithium-ion batteries that can help Tesla to reach its goal. One of the main objectives of Tesla is make USA one of the top countries in the industry of batteries and not just vehicles. As it has been said before the batteries they made are also used for the Powerwall, which is a device that supplies energy to the houses. Now, they are producing Powerwall2 at prices 30% cheaper than their main competitors. It seems that Elon musk wants to transform his electric vehicle company into a clean energy company.

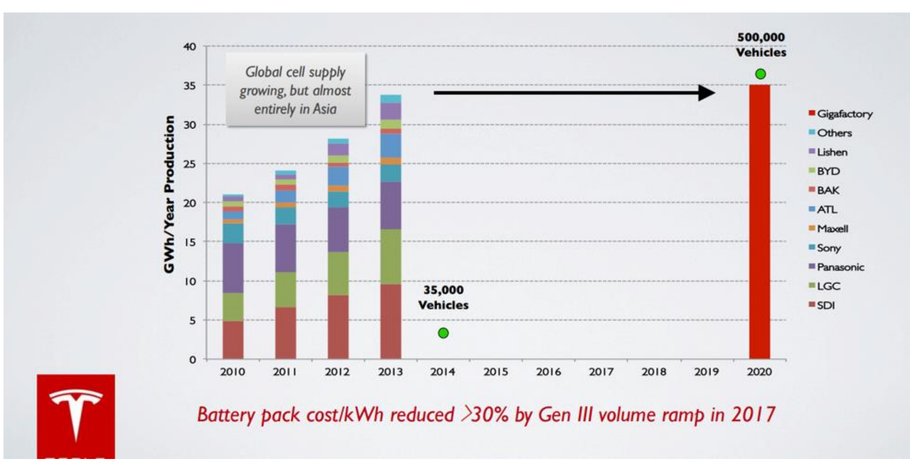


Figure 74. Planned 2020 Gigafactory Production Exceeds 2013 Global Production.

In conclusion, ideas like the Gigafactory of Tesla are helping on the development and production of more batteries making them cheaper and affordable for the clients. Prices dropped 22% in 2016 and Bloomerang new Energy Finance expects a new reduction of 15-20% in this year [385].

5.7. TOXICITY

A study made by the Norwegian University of Science and Technology provides information about electric cars and their real impact in the atmosphere. They are expected to substitute IC cars because they are supposed to be a “clean” alternative, but they could contaminate much more. This study concluded that the emissions related with the greenhouse effect are increased in a shocking way if coal is used to produce the electricity. In addition, electric car factories also emit more toxic waste than conventional factories. Moreover, the production of batteries and electric motors requires the use of a huge amount of toxic materials as nickel, aluminium and cooper. Even so, researchers believe that electric vehicles can be favourable in my cases considering an environmental point of view. The aim of the study is not trying to stop the manufacture of electric cars, but to work harder in the phase of production and to produce clean electric energy. As it has been said the production of electrical cars causes a bad impact to the environment, so they have contaminated considerably before driving the car in the road. In contrast with IC cars, almost half of the Global Warming Potential of an EV life cycle is related with its production [386]. It has been calculated that the GWP from EV´s production is about 87-95 grams carbon dioxide equivalent per kilometre (g CO_2-eq/km), this is twice the value of the IC car production (43 g CO_2-eq/km). In the case of the EV cars, the production of their battery is 35-45% of the total production phase GWP. At the same time, the production of the electric engine is 7-8% and other components like inverters and the passive battery cooling system are 16-18%. In addition, if the electricity is produced with coal, lignite or combustion with oil the damage will increase due to more amounts of greenhouse effect gasses. This means that it would be a nonsense pushing this kind of alternative vehicle in places where the electricity is produced with those materials. However, in places like Norway, the produced energy is clean as most of it is generated in hydroelectric plants. In this way electric vehicles have got considerable advantages. In figure 75 it is shown the evolution of percentages of energy supply in Norway [387].

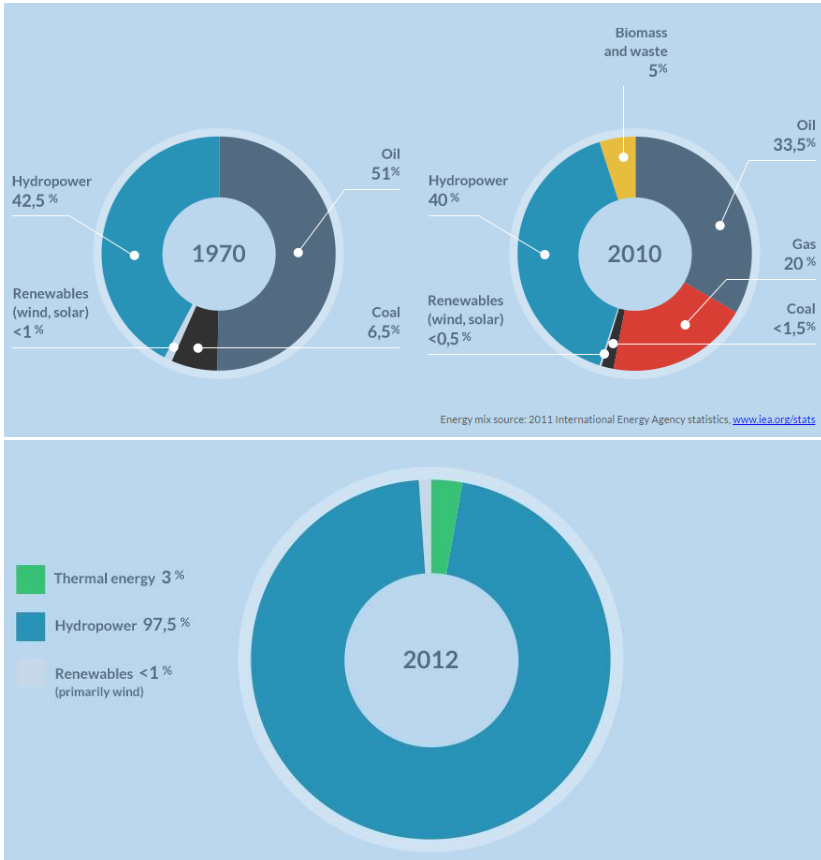


Figure 75. Percentages of different energies.

In Europe, where electricity is produced in many different ways, electric vehicles show environmental advantages if they are compared with conventional cars. Electric cars that are charged with clean electricity deliver a reduction of 10-24% in the contribution of the global warning with respect to IC cars. The Norwegian's study notes that the more an electric car keeps on working the better will be its environmental advantage over diesel and petrol engines. At 200000 km it is between 27-29% cleaner than a petrol engine and 17-20% than a diesel. However, at 100000 km it is just between 9-14% cleaner than a petrol or diesel engine. The usable life of an electric vehicle depends in the quality and durability of its battery. Nowadays, batteries are improving and reaching a great efficiency, so this means longer useful life. Another point that should be added is that petrol and diesel engines are also improving, but not at the same rate as electric ones. However, this is an important interim step that can help to the environment in these years of change.

In conclusion, the numerous potential advantages of electric vehicles should be a good reason to concentrate on improving the production of electrical energy [386] [388].

5.8. REASONS WHY LI-ION IS THE BEST BATTERY FOR HEV/EV

In the case of manufacturing a car, it would be extremely recommended using a li-ion battery. In 1991, Sony commercialized the first li-ion, and today this technology has become the most promising and fastest growing battery on the market. Many researches around the world are trying to develop improvements in this technology, as it has not been yet reached its maximum potential. Lithium is the lightest metal and has the greatest electrochemical potential. In addition, Li-ion owns the largest number of cycles of charge in current electric batteries (1,000-10,000). This amount of cycles are far away to the ones that can be reached by other battery options like lead-acid with a range of 200-1800 cycles and in the case of Ni-Cd with a range of 2000-2500 cycles. It also stands out because of a specific energy between 75-200 W h/kg, while lead-acid can just deliver 25-50 W h/kg, 50-75 W h/kg in the case of Ni-Cd and 70-100 W h/kg in Ni-Mh. In this way, it can be achieved more autonomy with less weight. The key to the superior specific energy is the high cell voltage of 3.60V. These facts combined with the cost reduction thanks to efforts from manufacturers to produce this battery in volume as it has been faced with the Tesla's Gigafactory make li-ion universally accepted for portable applications, satellites and electric powertrains. Furthermore, li-ion is a low-maintenance battery while the rest ones face the reverse situation. Moreover, this battery has not got memory problems like Ni-Mh, so full discharge is not compulsory to keep its capabilities. In addition, its daily self-discharge is very low (0.1%-0.3%), exactly the same amount as in the case of lead acid, but thankfully half of the one that can be faced in Ni-Cd (0.2%-0.6%) and far away from the 5-20% of Ni-Mh [389].

All the data that has been shown above claims that this kind of battery is the best for EV and HEV. The Li-ion battery is considered good candidate in the cases that small dimensions, response time (milliseconds) and/or equipment´s weight are important. That is why branches like Toyota have set up all their HEV cars with this technology.

Table 24 *Summary of the advantages and limitations of the li-ion battery.*

Advantages	-High load capabilities and specific energy (75-200 W h/kg). -Extend shelf-life and high amount of cycles (1000-10000). -Maintenance free. -Reasonably short charge times. -Low self-discharge (0.1%-0.3% per day).
Limitations	-Requires protection circuit to prevent thermal runaway if stressed. -Degrades at high temperature and when stored at high voltage. -No fast charges at cold temperatures (<0°C). -Transportation regulations required when shipping in larger quantities.

A table with the current advances and limitations of this battery is shown above. Although there are a few disadvantages, the positive features are good enough to keep on developing and studying this type of battery in order to succeed in the automotive industry.

6. ARCHITECTURE SELECTION

Please refer to Table 25, below, for a summary of the proposed vehicle concept properties. The following text shall briefly outline the justifications for such choice, and will be supported by both website & oral.

***Table 25** Summary of the identified properties of the vehicle concept.*

PROPERTY	SELECTION
Chassis Classification	Compact / Small SUV
Architecture Classification	Parallel Hybrid (HEV) Architecture
Estimated On-the-Road (OTR) Price (£)	£25k-£32k (non-inclusive of grants)
Targeted Cost per MPG Estimate (£/MPG)	≤ £200
Estimated CO_2 Emissions (g/km)	≤ 75 (g/km)
ICE & EV Drivetrain Structure	Front-Wheel Drive (FWD)
ICE Power Unit Peak Power (kW)	75-100 kW (small classification)
ICE Power Unit Classification	In-line 4-cyl, 1.4-1.6L petrol-fuelled ICE
Grid-Dependence / Independence	Grid-Dependent (PHEV)
EV Power Unit Peak Power (kW)	60-130 kW (Small-Medium)
EV Energy Storage Unit Chemistry	Li-ion classification of battery chemistry
EV Energy Storage Unit Capacity (kWh)	10-15 (kWh)
All-Electric Range (mi)	30-40 (mi)
Maximum Top Speed (MPH)	95-115 (MPH)
Achievable 0-62 (MPH) (Sec)	9-12 (sec)
Curb Mass Estimation (kg)	1550-1750 (kg)

In regards to the chassis classification, an analysis of the current status of the automotive markets & identification of trends there-in, resulted in identification of the Compact/Small SUV classification as that which is most viable in a short-medium term outlook. In addition to growing, strong historic sales, the SUV classification has inherent properties which synergise with the proposed concept requirements; namely the raised ride height in comparison to a sedan or hatchback facilitates sufficient volume of underfloor space for the addition of an automotive energy storage system, without inducing ground clearance issues. In addition, the general pricing of such vehicles, namely the Audi Q2 & Q3 Ranges and the Mercedes GLA is such that the group are confident that it would be achievable to implement a HEV architecture that is within the bounds of the above specified estimated on the road price range of £25k-£32k. With respect to chassis design & materials, the group has concluded that a predominantly Steel Unibody chassis should be employed for purposes of reductions to both cost of manufacture & materials procurement. Though comparatively heavier than both Al & CFRP, & comparably less strong, the high cost of such exotic materials was deemed to be prohibitive to their use by the group. This decision is also vindicated in that at present up to two-thirds of all Steel employed in an automobile can be recycled, which, although less in comparison to Al, is significantly greater than CFRP & adds to the sustainability of the selected concept.

Considering the architecture selected, it was quickly identified that due to lack of existing infrastructure, prohibitively expensive investment requirements required to sustain growth, expensive total cost of ownership and lack of consumer familiarity with the technology, H_2-fuelled FCEVs would not be viable in a short-medium term outlook such as that investigated within the scope of this project. With regards to fully-electric EVs, it was determined that the perceptive barriers of the consumer were prohibitive to the mass-market potential of such vehicles within the scope of the timeframe considered; namely perceived range anxiety was a significantly identified barrier

N.B. No directly comparable vehicles exist, however comparisons to ICE SUVs are visible on the website.

7. CONFERENCE ATTENDENCE & JUSTIFICATION ASSESSMENTS

7.1. INTERNATIONAL EV BATTERIES 2016: COST-EFFECTIVE ENGINEERING FOR HEV & EV

7.1.1. CONFERENCE BACKGROUND

Organized by the Institute of Mechanical Engineers (IMechE), the International EV Batteries 2016 was intended to address numerous critical challenges currently posing an issue for original equipment manufacturers (OEM) & prohibiting proliferation of alternatively-fueled HEV and EV vehicle architectures. Principally, those who attended were stated to have had the opportunities to discover numerous, automotive application-relevant innovations in battery technology; including battery management & control systems, improvements for packing & modularity, development of range extension, such as that employed within the BMW i3 Rex model, integration improvements & standardized testing processes.

IMechE states directly that they aim to aide in alleviation of limitations of current battery technology through providing a platform for & promoting dialogue between OEM's and research representatives. Specifically targeted through the conference was improvements to both cost & battery performance.

7.1.2. CONFERENCE LOCATION

The conference was to be held in London, UK between 6th-December & 7th-December, 2016. The building elected to host the 2016 conference was the IMechE's Westminster-based home, One Birdcage Walk. Situated in central London, within short walking distance of Westminster Abbey & the heartland of London's tourist region, research showed the location proved suitably serviced by hotels & was accessible.

7.1.3. ASSOCIATED KEY DATES

EV Batteries Conference Start	–	Tuesday 6th December, 2016
EV Batteries Conference End	–	Thursday 8th December, 2016

7.1.4. CONFERENCE PRESTIGE & SPONSORS

Figure 76 provides indication of the level of industry, academic & regulatory support for this conference.

Figure 76 *Summary of regulatory bodies and industry partners of the EV Batteries conference.*

7.1.5. TECHNICAL PROGRAMME OVERVIEW

Detailed overview of the EV Batteries 2016 Technical Programme are visible here.

A full outline of the Technical Programme is available for reference here.

A brochure for the conference can be downloaded in .pdf format here.

Details of prominent speakers at the conference are available here.

7.1.6. PERCIEVED VALUE FOR ME519 PROJECT & STUDENTS

Through Project Group K's proposed attendance at the EV Batteries 2016 conference in London, the following benefits were expected to be realized for the on-going '16-'17 Project & subsequent projects.

- ✓ Knowledge exchange; awareness of battery industry challenges, solutions & sector direction
- ✓ Development of technical expertise with battery management & control systems; critical for EVs
- ✓ Potential creation of future industry & academic partnerships &/or funding through networking
- ✓ Raise the profile of the University of Strathclyde within the battery systems & supplier industries
- ✓ Personal growth & development, supporting achievement of the learning outcomes of ME519

Highlighted Technical Sessions of relevance to ME519 & future projects include;

"The Chevrolet Bolt EV Battery System"

"Reducing the Size and Weight of Battery Packs Without Impacting Performance"

"Advanced Battery Management Systems"

7.1.7. FEASIBILITY ASSESSMENT & CONCLUSIONS

To attend the conference, disregarding travel expenses, would cost each group member a £299+VAT fee. Notable was that unlike the EuroBrake Conference (Section 7.1.), no funding would be provided to support travel. Thus, considering also travel & accommodation, to send one member would exceed the full budget. Furthermore, upon publication of the December exam timetable, conference dates were unsuitable for all of the '16/'17 group members; notably clashing directly with the Pressurized Systems examination.

For these reasons, the group concluded to not attend the conference. However, the group utilized the Technical Program as a source of inspiration for research tasks conducted throughout the project.

7.2. EUROBRAKE 2017 – INTERNATIONAL BRAKE CONFERENCE (FISITA)

7.2.1. CONFERENCE BACKGROUND

By their own statement; EuroBrake was founded in 2012 to address increasingly profound changes in the demands made by the braking industry's OEM customers (read: recognizable manufacturers such as BMW or Fiat) and end-users (read: vehicle owners), and to provide a discussion forum for companies and engineers engaged with progressing & refining brake technology within the scope of the full range of relevant industries to come together participate in knowledge sharing. Since its inception, EuroBrake has grown to be the leading dedicated braking technology conference on a global scale & its attendance numbers are rising. For example, over 1,100 delegates attended the EuroBrake 2016 conference held in Milan, Italy. It is stated that of these 1,100 delegates, representatives of the following list of industries & sectors were in attendance that year; passenger car, commercial vehicle, aerospace, rail, wind energy, materials science, quality & process and testing & measurement. Noteworthy is that this list is non-exhaustive with namely the commercial & passenger vehicle industries of most relevance to the Project.

EuroBrake 2017 is scheduled to feature 120+ technical presentations & host over 100 exhibitors, which shall include academia, industry manufacturers and material suppliers. In addition, several technical tutorial sessions shall be performed, led by leading academics (refer to Section 7.2.5).

7.2.2 CONFERENCE LOCATION

The conference shall be held in the International Congress Centre of Dresden, Germany. The Congress Centre is situated within Dresden's city center, on the southern bank of the river Elbe. Dresden International Airport is a short 18-minute drive from the Centre and, as is visible in Figure 77, below, there are numerous traditional hotels in the nearby vicinity capable of servicing the conference. The Centre's location & prominence should ensure ease of access in the event of attendance through means of either public transportation or private hire firms.

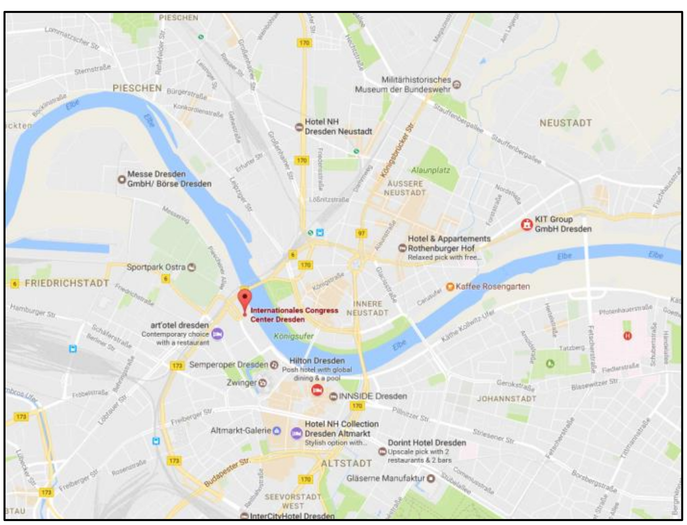


***Figure 77** The location of Dresden's International Congress Centre & contemporary hotels.*

7.2.3. ASSOCIATED KEY DATES

Sponsorship Application Deadline	–	Monday 6th March, 2017
ME519 Final Report Deadline	–	Friday 17th March, 2017
ME519 Oral Assessment Date	–	Monday 27th March, 2017
EuroBrake Conference Start	–	Tuesday 2nd May, 2017
EuroBrake Conference End	–	Thursday 4th May, 2017
Preliminary Feedback Deadline	–	Monday 29th May, 2017 (End of Exam Period)

7.2.4. CONFERENCE PRESTIGE & SPONSORS

Organizer: FISITA

Fédération Internationale des Sociétés d'Ingénieurs des Techniques de l'Automobile (FISITA) is an umbrella organization for national automotive societies. FISITA is controlled by the engineering profession & is supported by the global automotive & supplier industries. According to statistics published on the corporate website, FISITA's Member Socialites represent over 210,000 automotive engineers globally. Amongst other responsibilities, FISITA organize events including the biennial World Automotive Congress, annual World Automotive Summit & EuroBrake.

"Diamond" Sponsor: ITT Corporation

ITT is a corporation comprised of numerous leading manufacturers who develop solutions for the energy, transportation & industrial markets. Globally recognized brands include Gould's & Bornemann Pumps, KONI Shock Absorbers, Motion Technologies (Refer here) and Enidine Energy Absorption devices. As a multinational corporation, ITT Corp. employs over 9,400 persons in more than 35 countries, with a customer base located in over 100 countries globally. Of most relevance to the ME519 Project, & those most likely to be represented at EuroBrake would be Motion Technologies who develop brake pads for transport sectors amongst other components.

EuroBrake Dinner Sponsor: Brembo

Globally-recognizable, Brembo is the global leader of braking system design, development & production. In addition to over 40 years of racing heritage, Brembo has manufacturing facilities in 16 countries on 3 continents and employees over 7,700 persons. They are the world leader & recognized innovator of disk brake technologies. Industrial sectors for which Brembo manufactures products include, cars & commercial vehicles, motorcycles and racing applications, extending as far as Formula One. Although out with the scope of the EuroBrake conference, Brembo also design & manufacture high performance clutches for racing applications.

7.2.5 TECHNICAL PROGRAMME OVERVIEW

Details of the EuroBrake 2017 Technical Programme are visible here.

A preliminary Programme of lectures is available in .pdf format here.

Details of Technical Sessions are available here.

Details of the Exhibition halls are visible here.

7.2.6. PERCIEVED VALUE FOR ME519 PROJECTS & STUDENTS

Through Project Group K's attendance at the EuroBrake 2017 conference in Dresden, the following benefits are expected for the on-going ME519 Project & subsequent Projects;

- ✓ Knowledge exchange; awareness of current industry challenges, solutions & sector direction
- ✓ Development of technical expertise with a performance & safety critical component; brakes
- ✓ Potential creation of future industry & academic partnerships &/or funding through networking
- ✓ Raise the profile of the University of Strathclyde within the brake systems & supplier industries
- ✓ Personal growth & development, supporting achievement of the learning outcomes of ME519

Highlighted Technical Sessions of relevance to ME519 & future projects include;

"Advanced Stability Control System for Battery Electric Vehicles" – Abstract available here

"Expert Panel – Brake Emissions, a Worldwide Challenge" – Details available here.

7.2.7. EUROBRAKE STUDENT OPPORTUNITIES PROGRAMME: GENERAL INFORMATION

EuroBrake are offering a student sponsorship package for the 2017 conference, held between 2nd & 4th May in Dresden, Germany. Details of the sponsorship program are as shown on the official EuroBrake flyer presented within Figure 78 of Section 7.2.11, overleaf; Included in the package are;

- ✓ Financial Assistance with travel & accommodation expenses
- ✓ Full access to the Technical Programme (Refer to Section 7.2.5.)
- ✓ Full access to the Exhibition Halls & associated opportunities for networking & discussion
- ✓ Access to discussions with persons including "Top experts from Industry & Academia"
- ✓ invitation to attend "Strategy Panel Session" focusing on key challenges in brake development
- ✓ Invitation to the EuroBrake, Brembo sponsored dinner

7.2.8. EUROBRAKE STUDENT OPPORTUNITIES PROGRAMME: APPLICATION PROCESS

The application process for the Student Opportunities Programme was as follows; first submission of personal information; names, addresses, course studied etc. Following this, a technical, 2-page CV outlining previous experiences such as academic involvement & industrial placements is required to be submitted. Following attachment of a CV, applicants are required to construct a Personal Statement of maximum length 250 words, outlining "*why you would like a sponsored student place at EuroBrake 2017*". The final aspect of the application, which was required to be submitted by 6th March, is a brief series of questions relating to the EuroBrake conference history, braking systems architecture and their behavior, including identification of the causes of brake "squeal". Finally, students are required to state through which method they learnt of the EuroBrake student sponsorship scheme.

It was confirmed through contact with Ms. Hayley Millar, acting Education Manager at FISITA that the Group should apply individually but state that we hold intentions of attending as a group within our personal statement, as appropriate. Communications can be made visible if requested. Although it is not known when decisions shall be made nor the extent of invitations, it is known that 50 students will be selected by a panel of "international industry and academic experts" on behalf of FISITA.

7.2.9. EUROBRAKE STUDENT OPPORTUNITIES PROGRAMME: ESTIMATED COSTS INCURRED

Though unable to attain explicit confirmation as to the extent to which EuroBrake shall fund selected students, general language on their website indicates that students shall be able to attend the conference at no personal expense, which implies full assistance with travel costs. Regardless, the Project Group have assessed the financial implications associated with attendance at the conference.

Assumptions made are that the Group must fund 50% travel & accommodation costs incurred for a group member to attend the EuroBrake conference in Dresden, Germany and that full price is required to be paid for all costs (i.e. no time-specific discounts on hotels & travel etc.). As is visible in Table 25, assuming financial assistance provided as stated, the Group has finance available to provide full travel & accommodation costs for *at least* one Group Member to attend EuroBrake 2017.

Table 25 Summary of estimated travel costs found through comparison websites (18/02/17)

PURCHASE	DESCRIPTION	COST INCURRED (£)
Student Entrant Pass	Access pass to EuroBrake.	£0.00 (FREE)
Hotel Accommodation	1st May (Check-in) – 4th May (Check-out)	£60.00 pp.
Flights & Short Travel	1st May (GLA-DRS) & 4th May (DRS-GLA)	£180.00 pp.
	TOTAL COSTS INCURRED (£)	£240.00 pp.

7.2.10. EUROBRAKE STUDENT OPPORTUNITIES PROGRAMME: STATUS OF APPLICATION

The group are awaiting a response form EuroBrake with respective to success or failure of applications.

7.2.11. EUROBRAKE 2017 – OFFICIAL FLYER

Please see the EuroBrake 2017 official flyer; detailing conference background & student program.

Figure 78 *Students at EuroBrake 2017 Official Flyer circulated via email.*

8. PROGRESS TOWARDS HIGH-LEVEL CONCEPTUAL DESIGN

As stated within the agreed contract & within the objectives discussion of this report (Section 0.), there was a task subsequent to long-term research & sustainability conclusions pertaining to the high-level development of a conceptual HEV or EV architecture; whichever emerged as most promising. Within this section of the report, an overview of the stated task requirements, scope & contract revision and the group structuring, tool procurement & resource investment made by the group shall be presented.

8.1. OVERVIEW OF CONCEPTUAL DEVELOPMENT TASK REQUIREMENTS

As outlined within both the contract (Refer to website) and within the introduction to the project (Section 0.), a task pertaining to development of a conceptual vehicle, utilising the long-term research task as a foundation, was within the original work scope of this ME519 Project. The task explicitly required that, for the given architecture of HEV & EV employed, design should be performed such that performance, range capabilities and architecture longevity should be maximised, with cost minimised.

With respect to performance; it was determined by the group that acceleration capabilities, handling behaviour, both with respect to manoeuvrability & safety, and supporting aspects such as chassis stiffness, body mass distribution and un-sprung mass were of most significance and would require optimisation. Additionally, considerations of control systems at both a system & component level (e.g. transmission controls, if applicable, and electrical component controllers) were identified as of significance. Features such as rise-time and overshoot percentage would be of most significance here. Compromise would also feature, most prominently with regards to sizing of ICE & EV drivetrains. Optimisation of the response of systems such as the suspension were also of importance. Notable is that performance is of lower priority to consumers than both cost & range (Section 3.).

With respect to range capabilities, compromise of all-electric range capabilities and both cost & mass of on-board energy storage & EV drivetrain components were identified to be of most significance. In addition, the group identified that factors such as charging capabilities, with both current & future infrastructure standards & proliferation in mind, would be of significance to commercial viability. Furthermore, it would be important to optimise combined ICE & EV range for any HEV architecture.

With respect to longevity, the group identified several areas of significance. Sustainability & availability of materials employed, namely in chassis design & battery chemistry, was one. In addition, longevity of the technology & architecture proposed was also of great importance; for example, though unpredictable, there are potential future changes to fiscal incentives for HEV & EV ownership and there are looming phased changes to emissions regulations at both a national & international level which could potentially affect the viability & legality of any proposed concept vehicle. Compatibility with existing & future infrastructure, mostly charging-related, was important also. The group also identified longevity may consider maintainability & serviceable life of components, such as the maximum number of charge cycles a battery chemistry can sustain before losing charge capability.

With respect to cost, demonstrated as a significant factor within Section 3., the group rapidly identified that total cost of ownership was of most significance, followed by operating costs and initial purchase costs respectively. Cost would feature prominently throughout all work design undertaken. Significant investment of time was made by the group towards identifying these task requirements.

8.2. TARGETED CONCEPTUAL DESIGN TASK DELIVERABLES

Following the group's initial assessment of the task requirements, time was invested & progress was made with respect to generating a formal series of deliverables that would be targeted to be achieved. To this extent, the group reached a stage where-in the following were proposed to the Client;

- ✓ Production of a specification sheet pertaining to sizing of components, materials & masses
- ✓ Generation of a high-level model which enables estimation of HEV or EV performance capability
- ✓ If possible, performance of optimisation of system-level operations e.g. ICE & EV drivetrain control
- ✓ If possible, generation of schematics for system-level controllers & high-level component drawings
- ✓ If possible & suitable, production of high-level concept drawings of a proposed vehicle

Though with discussions on-going pertaining to identification of fixed deliverables, the group had, thus far, succeeded in their efforts of proposing deliverables which would satisfy the criteria of the Client.

Though, noteworthy & as shall be discussed within Section 12.14, the project work scope was revised.

8.3. PROPOSED GROUP STRUCTURING, METHODOLOGY & PROCUREMENT

In-line with a revised semester two schedule developed, group members invested time in preparations for performance of the conceptual design task whilst simultaneously performing the stated long-term research task; this facilitated, in theory, readiness for conceptual design development initiation upon immediate satisfactory completion of the long-term research task, or in the very least, a smoother transition. With regards to this, the group performed several principle tasks, which are as follows;

- ✓ Identification of likely significant sub-systems and subsequent allocation of design responsibility
- ✓ Identification of an appropriate design methodology to facilitate structure conceptual design
- ✓ Identification & procurement of required utilities & resources; e.g. CAD, user guides & support

Table 26, below, presents a summary of the proposed allocations of design responsibilities.

Table 26 *Summary of proposed sub-system design responsibility allocation.*

INDIVIDUAL	PRIMARY SUB-SYSTEM	SECONDARY SUB-SYSTEM
R. ANDERSON	Motor(s) & EV Drivetrain	Control System Development
P. LIZZERI	ICE & Associated Drivetrain	Chassis & Weight Distribution
A. G. PORAS	Electrical Storage Unit	Wheel Assembly

Whilst there is typically a large degree of commonality amongst hybrid & pure electric architectures, there are fundamental differences in required sub-systems & sub-assemblies. As such, allocation of Sub-System Lead Design Roles was scheduled to be performed only upon finalized agreement of the proposed to-be-utilised vehicle architecture; hybrid electric (HEV) or pure electric (EV).

With respect to the identification of a suitable design methodology, the group elected to employ the "Total Design" methodology of conceptual design developed by S. Pugh; though adapted somewhat to suit the situational requires & context of the previously performed long-term research task & identification of leading architecture. This methodology was selected for a number of reasons, though principally as the group had prior experience implementing the full workflow associated through the degree syllabus. Such a decision is in-line with the risk-aversion policy as declared within the Project's contract (refer to Section 0.). Notable is that several other methodologies, including M. J. French's "Conceptual Design for Engineers", were considered. Figure 79 presents comparisons of each [390].

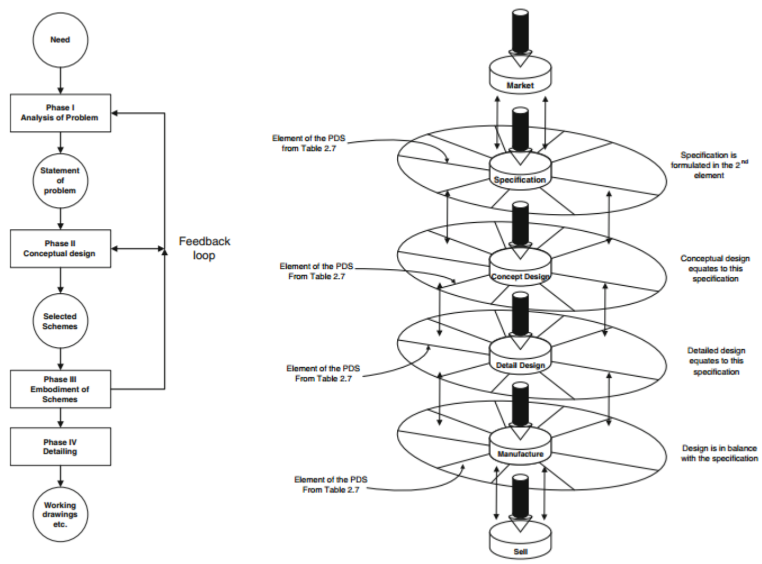


***Figure 79 LHS** M. J. French's design methodology **RHS** Total Design core developed by Pugh* [390].

With respect to the identification of a suitable CAD platform through which to develop a conceptual vehicle, early within semester two the group identified & explored possibility of utilising the Matlab suite of utilities. Specifically, the Simscape & Simscape Driveline, a sub-utility within Matlab's software suite and the controller development & modelling package Simulink. Justifications were as follows;

- ✓ Though minimal; prior experiences held with Matlab, thus selection is in-line with risk mitigation
- ✓ Matlab suite is industry recognised & employed, hence availability of support tools & literature
- ✓ Simscape Driveline tailor-built to fulfil the purposes for which we aimed to utilise the software
- ✓ Simscape's assumptions, equations & theory applied to generic models are prominently declared
- ✓ Simscape suite graphical user interface; in theory supporting smoother growth of familiarity
- ✓ Modular construction of Simscape models facilitates work scope flexibility as necessary
- ✓ Simulink environment known & utilised by Client within academic research; support network
- ✓ Capabilities within Simulink for control system modelling are viewed as industry leading
- ✓ Availability of numerous introductory level tutorial schemes offered by Matlab suite
- ✓ Availability of one-time-fee student package schemes at heavily discounted rates

To this extent, the group identified that to best facilitate meaningful design of a conceptual vehicle, access to the industry-utilized software suite Matlab would be required to be procured. Whilst availability of the generic Matlab suite was available at no cost through on-site university computer labs, access to the specific sub-suite Simscape, which was required for the bulk of proposed conceptual design, was not possible through this scheme. Therefore the group took measures to ensure access.

Initially the group approached the university's IT Support Helpdesk to request whether the sub-suite Simscape was be available within on-site university computer laboratory(s) unknown to the group; this proved unsuccessful in that no student-available labs supported the software. The group therefore then re-approached the university's IT Support Helpdesk to enquire whether it was known if small, one-off licenses were within the university's license pool; servicing a closed-group of PhD or post-doctorate researchers within one of the university's many engineering & non-engineering related departments, and if not, could a process be initiated to enable university-funded access. However, again, this proved unsuccessful where-in university-funded access proven unobtainable.

8.4. RESOURCE INVESTMENTS – FISCAL & TIME-MANAGEMENT

Therefore the group took measures to obtain access through utilisation of the project budget. Below, Table 27 provides explicit confirmation of the packages offered; notable is that through the student scheme, numerous add-ons were available at a reduced price of £6.00 (a saving in excess of 60%).

Table 27 *Summary of the purchased Matlab suite of software, including justifications.*

SOFTWARE SUB-SET	JUSTIFICATION FOR PURCHASE	COST (£)
Matlab & Simulink Student	Combined single-license student suite package. Noteworthy is that the selection of this package at £59.00 permits savings of greater that 60% on add-ons which are required for the procurement of Simscape. Where the add-ons cost £6.00 below, had a non-combined package been purchased, these would have otherwise cost £17.00 per add-on required. The group has therefore saved significantly through smart buying.	59.00
Matlab Student		0.00 (incl)
Symbolic Math Toolbox		0.00 (incl)
Statistics And Machine Learning		0.00 (incl)
Optimisation Toolbox		0.00 (incl)
Control System Toolbox		0.00 (incl)
Signal Processing Toolbox		0.00 (incl)
DSP System Toolbox		0.00 (incl)
Image Processing Toolbox		0.00 (incl)
Data Acquisition Toolbox		0.00 (incl)
Instrument Control Toolbox		0.00 (incl)
Simulink		0.00 (incl)
Simulink Control Design		0.00 (incl)
Stateflow	Modelling system-level control schemes	6.00
Simscape Driveline	Modelling of vehicle dynamics & powertrains	6.00
Simscape Multibody	Suspension & chassis system modelling	6.00
Simscape Power Systems	Three-phase electrical machine capabilities	6.00
Simscape Fluids	Cooling & heat transfer; fuel supply systems	6.00
Simscape Electronics	Electronics, mechatronics & motors	6.00
Simscape	Environment supporting drivetrain modelling	6.00
Simulink Design Optimisation	Optimisation & reverse parameter estimation	6.00
	∑ SUB (£)	107.00
	VAT (£)	21.48
	∑ TOTAL (£)	128.40

With respect to time investment, group members spent a not insignificant amount of time preparing for the conceptual development processes whilst simultaneously performing the long-term research task throughout the early to late period of semester two. This time investment included both developing familiarity with the resources to be utilised, including referencing online support tools & lecture tutorials, developing deeper familiarity with the capabilities & processing requirements of the CAD software suites to be used and researching background analytical methodologies of system dynamic & component-level design; including longitudinal body dynamics & suspension systems.

Within the following section, a brief overview of some key developments made through this time investment shall be presented for purposes of evidencing group resource commitments to this aim; Preliminary investigation towards the implementation of component & sub-system modelling was a significant investment made by several group members. For instance, R. Anderson returned to previous course syllabus notes to revise analytical modelling & characteristics of high-level control systems, including closed-loops control systems containing disturbances, noise. This includes determination of estimations for rise time, settling time and overshoot in motor speed controllers excited by the actions of the driver. Several tutorial lecture series, located online & with some pertaining to DC & some pertaining to AC motors, were consulted with numerous cases explicitly utilising the same platform that the group intended to use to perform this aspect of design; Simulink. In addition, group members researched characteristics and performance-critical parameters of potential components with a viewing to informing development of successful conceptual design work. In addition to the above design, great investment of resources was spent in consulting literature and online tutorial lectures pertaining to development of longitudinal vehicle dynamics; a critical aspect of the proposed conceptual development within the Simscape environment & within the scope of the project due to a requirement to maximise performance. Quarter-body models for vehicle suspension systems and analytical systems of equations governing situations such as vehicles traveling at fixed speed through an inclined gradient were derived from first principles through consultation of said literature & review of historic course syllabus notes. Furthermore, and demonstrating the extent of project group efforts is that studies pertaining to road surfaces across the UK were consulted, in preparation for development of meaningful input into longitudinal dynamic models within Simscape. Whilst no other investment shall be discussed in detail, a further example of preparations is that of sourcing real-time measurements, including velocity, emissions & instantaneous fuel burn, of existing vehicles with a view to validating high-level system or low-level component models.

8.5. PROJECT WORK SCOPE & CONTRACT REVISION

As will be discussed in more detail within Section 12.14 of this document, the work scope of the project was negotiated during semester two to remove the mandating of performance of this task. Such a decision was made largely due to an initially ambitious proposal by the project group to perform a full work scope intended for four persons with just three members and an executive decision which was made to enable maximising of meaningful project output following a series of minor delays; including significantly greater research-oriented investment than was initially anticipated. At present, although significant preparations were made, the group has not engaged with this task to meaningful extent beyond preliminary preparations. It was determined partially through semester-two that meaningful deliverables would not be achievable with respect to this task. Instead, additional time was invested in the long-term research task, which is evident in the expansion upon the original scope; particularly within the infrastructure section where-in additional disruptive technologies were explored.

9. WEBSITE DEVELOPMENT

9.1. OVERVIEW OF WEBSITE DEVELOPMENT

The group was required to develop a website as part of the project undertaking. Acting as a key deliverable, this website would be employed to portray the project background, accomplishments & working structure of the project group to external parties, including the assessors. In addition to the above specified objectives, the group elected to construct a website that would act as externally facing tool for outreach to parties in view of requesting sponsorship &/or support; predominantly this was intended to be performed at the conference, if attendance was possible. Therefore there became additional aims to maximize the professionalism of the website; accomplished through purchasing of a premium account (removing advertisements & improving bandwidth) with hosting supplier & selection of a formalised URL; www.HEVTechStrath.com.

Considering what was at the time only partial exploitation of the group's budget, it was decided that the investment towards both the domain & premium website hosting would be made under a proposed two-year subscription; facilitating the use of the group's budget to cover costs incurred upon subsequently performed group investigations. This enabled significant cost savings to be achieved; with over 35% saved in the premium website hosting subscription alone vs. subscription for the period required for the '16/'17 Project Group K's requirements in isolation.

With regards to website content, the group identified a series of "minimum" requirements and combined list of "potential" additions which it was felt would significantly improve website value. The following outlines the minimum requirements identified by the group;

- ✓ **HOMEPAGE** – Landing page promoting notable sections within the website.
- ✓ **PROJECT OVERVIEW** – Segment depicting the project background, objectives & deliverables
- ✓ **MEET THE TEAM** – Section where-in profiles of the group members are client are visible
- ✓ **PROJECT MANAGEMENT** – Discussion pertaining to group management & summarized reflection
- ✓ **PROJECT HANDOVER –** Sections presenting reflection of group members & recommendations
- ✓ **AKNOWLEDGEMENTS –** Presentation & thanks to relevant parties, e.g. ERASMUS
- ✓ **FURTHER READING –** Provision of a selection of useful links & info pertaining to HEV & EVs
- ✓ **CONTACT US –** A page providing means of contact HEVTech@Strath

As per the agreed contract, the website is required to be delivered by 26th March; however as the group's oral assessment is to be held on 27th March, the group is targeting delivery of the website for the evening of Wednesday 23rd March, thus facilitating access to information prior to assessment.

9.2. REFLECTION PERTAINING TO WEBSITE DEVELOPMENT

Although the website is partially constructed at the time of this report's submission, the group near-fully confident that the proposed earlier date of completion of construction (23rd vs. 26th) is viable. In addition, the above minimum features list, which the group intends to expand upon, is felt to be more than sufficient to satisfy the requirements of the website component of the assessment.

In regards to the professionalism of the websites appearance, the combined use of a premium account, dedicated formalized domain and structured theming is felt to have accomplished this goal. In fact it has been raised by the Client that the website be linked directly to the Client's research group, which we believe reflects in the quality of the presentation, thus supporting the group's assessment.

With regards to the choice of host & construction site, the group believes that a critical decision to switch developments tools following the revelation of new information demonstrates successful management & decision making skills. Initially the hosting tool Weebly was selected for development of the site. This decision was made through research pertaining to the capabilities and features of a number of hosting suppliers. However, following the initial phases of construction of the website, it was identified that a new development tool had been launched for WiX which was superior to that of Weebly. Therefore following a discussion, the group elected to transfer the website & utilise WiX as the hosting platform for the foreseeable. This of course had implications for time investment as time had essentially been inefficiently used through development on two platforms. However, ultimately through switching to the WiX platform the group were able to achieve a greater quality output with significantly less requirement for investment in familiarity with development tools; that WiX had superior tutorials & worked examples was a significant benefit to the group with regards to time. This decision also reflects the risk mitigation depicted within the risk assessment section of this report.

10. GROUP COMPOSITION & PRELIMINARY ASSESSMENTS

10.1. GROUP COMPOSITION INTRODUCTION

All Project Group members comprising Project Group K held no pre-existing experience in engaging together throughout previous academic sessions prior to the initiation of the ME519 Master's Thesis Project. This statement is accurate from a professional & academic respect, pertaining to previous group-based undertakings, but is also true from a social perspective. Emphasizing this initial barrier to group synergy is that group member A. Porras was, at the time of project initiation, embarking upon his first academic session within the University of Strathclyde Mechanical & Aerospace Engineering Department, given that he is currently participating in the ERASMUS Exchange program. As a result of this severe lack of pre-existing relationships, group members were wholly unaware each other's professional characteristics, preferential work style, social traits & competencies, technical interests and general academic strengths & weaknesses at project initiation. Therefore, to mitigate potential issues which may arise from this as the project progresses and adhering to recommendations provided throughout the numerous project management seminars attended, the project group elected to extensively utilise personality assessments to inform both up-coming role allocation and group structuring processes, in conjunction with thorough examination & reflection of previous, relevant experiences and backgrounds. Furthermore, forecasted threats to availability were considered.

10.2. GROUP PERSONALITY ASSESSMENTS

Presented within Figure 80 and Table 28 are the outcomes of the first assessment which was performed; the "Belbin Self Perception Inventory" (SPI). Figure 80 denotes the cumulative percentage composition of each group member, highlighting at a glance, the principle dominating characteristics & team roles on an individual person to person basis. Table 28 provides a breakdown of results obtained in terms of a metric ranging from low, through medium, to high, where-in high indicates a dominant trait. Computed group means are presented for both references. As is clearly visible, the group had a considerable potential for synergy where-in the results for all group members are consider; most evident in that the group average is exactly that - "average". Further evidence of synergy can be seen in that where R. Anderson scores low in the "Plant" metric, for example, P. Lizzeri & A. Porras compensate and bring the group's overall rating to a medium-high rating. In support of the Belbin test assessment, self-reflection upon personal outcomes was performed; validating conclusions drawn. This stage proved highly critical to risk mitigation as identification of principle personal weaknesses, obtained through performance of Belbin's test process, was a crucial metric informing group structure.

In support of Belbin assessments, additional assessment tools were consulted. The first was that of Hummanetrics Jung Typology Test, the results of which are depicted within Figure 81. This assessment collaborated the outcomes of Belbin's, indicating that the group held potential to achieve strong levels of synergy; though adequate direction & management would of course be necessary to achieve this. With an exception of extraversion vs. introversion the group average tended to marginal preferences which was hoped would lead to idealised best-of-both-worlds; again if adequate management is performed. A further, less scientific tool was also considered. Presented overleaf, it again, corroborated results of both Belbin's and Hummanetric's assessments. The group perceived this strong agreement as a sign of validity and thus employed results extensively in group structuring.

Table 28 *Tabulated breakdown of rated Belbin compositions of project group members.*

		INDIVIDUAL BELBIN SELF PERCEPTION INVENTORY RESULTS			
		R. Anderson	*P. Lizzeri*	*A. Porras*	*Group Avg.*
TEAM ROLES	CW	Average	Average	Average	Average
	CH	Average	Low	Low	Low
	SH	Average	Low	Low	Average
	PL	Low	Average	Very High	High
	RI	Average	Very High	Very High	Very High
	ME	Average	Low	Low	Low
	TW	Low	Very High	High	Average
	CF	Very High	Low	Average	High

Table 29 *A summary of the group's outcomes from the online resource employed.*

		PERSONALITY TEST RESULTS			
		R. Anderson	*P. Lizzeri*	*A. Porras*	*Group Avg.*
TRAITS (0-5)	OPENNESS	3	2.5	3	2.8
	CONSCIENTIOUSNESS	3.5	2.5	3.5	3.2
	EXTRAVERSION	3	5	3	3.7
	AGREEABLENESS	3	4	3	3.3
	NEUROTICISM	4.5	1.5	4.5	3.5

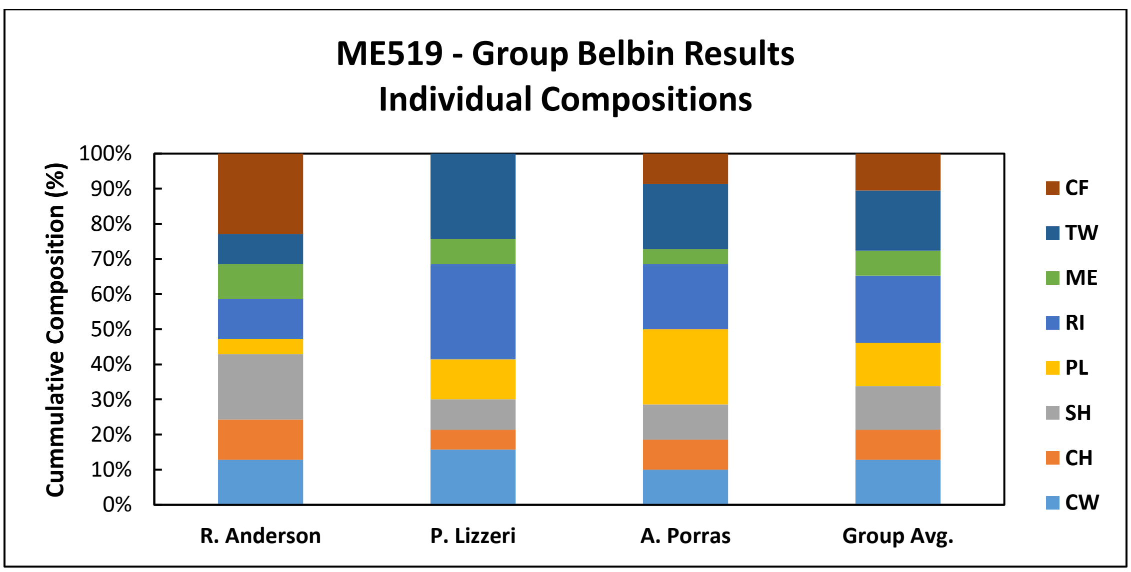


Figure 80 *Cumulative Belbin compositions for the project group's members.*

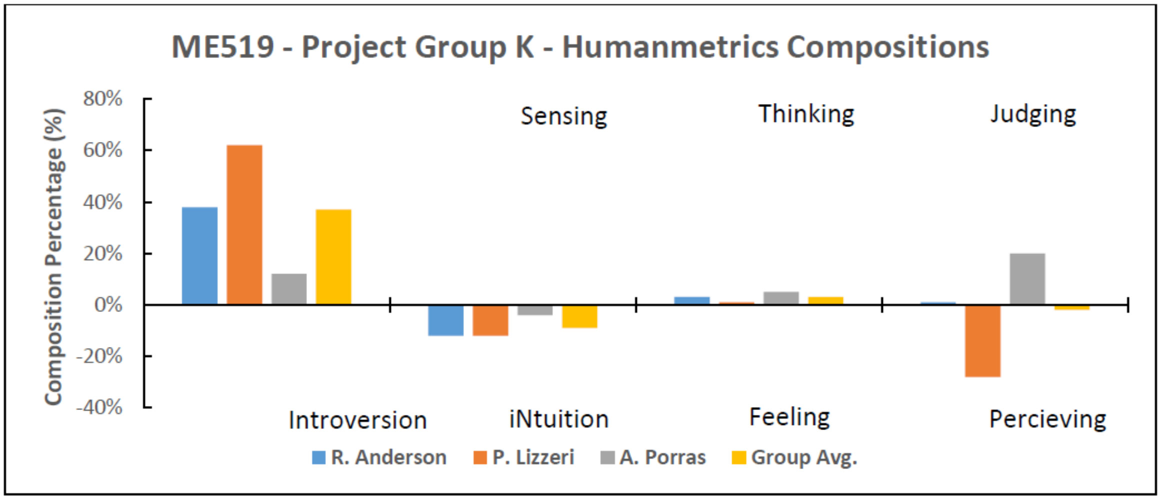


***Figure 81** A graphical summary of the Group's Hummanetrics Jung Typology results.*

10.3. BACKGROUND EXPERIENCES REFLECTION

As alluded to previously, the group considered previously held positions & experiences in addition to the aforementioned personality assessments; where-in industrial experiences & university-based historic project experience was most strongly considered. In the case of R. Anderson, significant previous project management experience, computer-aided engineering design and technical literature review experience had been achieved through a strong academic experience thus far, numerous summer placements and through industrial visits. Notable strengths identified for R. Anderson were those of experience in development & implementation of industrial-level processes, familiarity with extensive industry-based communications & management methodologies and a high degree of proficiency with the MS Office & SharePoint suites. In the case of P. Lizzeri, a previous, successful internship with medical device engineering firm Vascutek provided a pre-existing in-sight into intra-personal operation of large organisations, strengths in the use of finite element analysis software & technical design and key skills regarding teamwork & collaboration towards achieving a shared goal. Similarly, an innate passion for vehicles acts as a motivator towards the development of concepts pertaining to vehicle design & manufacture. In the case of A. Porras, whilst no industrial placements had been undertaken, notable strengths from prior experiences gained within university included significant CAED experience, including utilisation of automotive CAED software, extensive familiarity with industrial manufacturing techniques through a course syllabus and an ability to offer in-sight & perspective, with regards to structuring & design, through a significantly differing culture.

10.4. IDENTIFICATION OF POTENTIAL LIMITATIONS TO PERFORMANCE OF DUTIES

Of great importance to eventual role allocation was potential individual availability & there-in forecasted barriers to performance of duties. Beginning with university commitments, it was found to be significantly challenging to estimate course demands in the cases of P. Lizzeri & R. Anderson due to having no prior experience of 'Tier 5' credits & due to the significantly varied expectations of lecturers with regards to commitment to coursework & independent study. The shortening of the teaching semesters to 11-weeks also limited the effectiveness with regards to contacting now graduated Department alumni. Regardless, thorough assessments were made by both parties. In the case of A. Porras, although he personally had no experience of the course syllabus, this was not such a significant issue as all classes comprising A. Porras' curriculum had previously been undertaken by the other Group Members. However, the anecdotal reflection of P. Lizzeri & R. Anderson indicated that the mix of second through fourth year credits undertaken by A. Porras were the 'worst case scenario' in terms of workload for the respective academic sessions within which they were undertaken, & therefore there existed significant potential threat to A. Porras' abilities to perform time-demanding roles, e.g. Project Manager. Also considered was that A. Porras is entirely new to the Department this academic session and so was unfamiliar with most common university practices, procedures, available resources and assessment formats employed. Noteworthy was that R. Anderson had under-taken the Advanced Research elective module and therefore would have more flexibility in terms of workload than could be expected of traditional lecture-based modules. With respect to non-academic commitments, a potential limitation to performance of duties applied to P. Lizzeri only; who throughout a commitment, outside of typical university hours (9am-5pm, mon-Fri), in the form of part-time employment.

10.5. INDIVIDUAL PREFERENCES & SELF-ASSESSMENT

The final consideration prior to role allocation was that of individual preferences and suitability based on honest self-assessment. For example, one group member admitted to a tendency to leave the bulk of heavy lifting for coursework till close to deadlines & thus did not pursue roles heavily responsible for planning. Conversely, a group member stated desire to improve upon personal weakness identified in personality assessments & self-reflectance; that of an often-lacking willingness to delegate & put reliance upon others to perform tasks to high quality. Notable is that preferences were given precedence over other considerations due to the significant impact(s) upon individual & group moral.

10.6. POST-PROJECT REFLECTION ON GROUP COMPOSITION & ASSESSMENTS

To aide in reflection upon whether these identified personalities were truly representative of actual behaviours & traits exhibited throughout the project and whether the identification of commitment limitations was successful, the group dedicated a full meeting to this issue late in semester two. The general conclusion of this meeting was that the processes employed were both of high success.

It was unanimously thought that a strong group synergy had been achieved to such an extent that meaningful personal & professional relationships had been built; facilitating open & honest discussion. This was achieved through consideration of perceived traits & behaviours identified in the personality assessments. With regards to the performance of pre-project reflection upon personal backgrounds & experiences was worthwhile with respect to, to be discussed, role allocation in both group structure & design task. Namely identification of A. Porras CAED strengths & P. Lizzeri's FEA-specific skill set and R. Anderson's previous experiences with project management & industry process development.

Considering specifically the outcomes of the personality assessments, prior to the reflection meeting each group member revisited the Belbin Self-Perception Inventory & identified from the list of traits three which they felt best defined their behaviours exhibited throughout the two semesters of the project's duration. These were then presented, along with justification & subsequently discussed.

Beginning with R. Anderson, it was identified that the three defining traits suggested through performance of Belbin's perception test were accurate; especially that of the most strongly identified characteristic of Completer Finisher (CF). R. Anderson was found to be demonstrate key traits of CFs where-in orderly processes, influenced by perfectionism, were demonstrated to significant extent with a view to improving general quality of deliverables & project outputs. In addition, shaper (SH) traits were regularly demonstrated through the regular provision of new leads to be explored within the scope of other group member's task assignment. Traits of company workers (CW) were also evidenced; where-in self-discipline & organisational skills were routinely demonstrated. However, notable is that group members agreed that some negative aspects of the above traits were exhibited; including the CF's tendency to "not let go", although this was somewhat resolved by semester two. In addition, R. Anderson did display the negative SH trait of being highly anxious on numerous occasions.

With respect to P. Lizzeri, the group agreed that both the Belbin identified team worker (TW) and resource investigator (RI) traits were identified. Examples include the TW's ability to influence others and the RI's extroverted & enthusiastic nature. Where P. Lizzeri's post-project reflection differs from the identified dominant Belbin self-perception process is in the post-project allocation of Plant (PL). Throughout P. Lizzeri demonstrated the positive & impactful trait of general intellect, however at times attention span did drift in-line with PL traits; most notably during semester one meetings.

Considering A. Porras, again the group agreed that for the most part the initial assessments were a reasonable reflection of eventual performance throughout the project, though company worker (CW) replaced resource investigator (RI). Through the duration, Alex regularly demonstrated the behaviours of his strongest Belbin-derived traits; plant (PL) and team worker (TW). For example, A. Porras proved self-motivated and organised with respect to performance of his assigned duties; though did require input upon where best to direct his effort at times from the project manager.

In addition to this, the decision to incorporate potential limitations to performance of duties proved to be a successful & significantly beneficial practice. For example, P. Lizzeri had external commitments in the form of part-time employment, which whilst mostly managed well, at times did impede short-term availability for performance of assigned tasks. In the case of A. Porras, assessment of the to-be-expected workload by other group members, unfortunately, proved to be accurate, where-in on occasion A. Porras experienced a short-term spike in intensive coursework & assessment requirements. Thankfully, this was reasonably manageable with support of colleagues & through effective planning through application of a group-wide availability tracker. The benefit observed here was noticeable in the vindication of the decision to provide A. Porras & P. Lizzeri less time demanding principle roles of Financial Manager & Chief Engineer, as opposed to Project Manager (Section 11.).

11. GROUP ORGANISATIONAL STRUCTURE

This section outlines the organisation structure, role allocation & authority hierarchy which was informed by Section 10. & implemented to maximise Project Group effectiveness. Comparisons across both semesters will be presented within a conclusive summary.

11.1. ROLE ALLOCATION PROCESS INTRODUCTION & IMPORTANCE

Critical to the success & potential failures of the project group was the delegation of roles & responsibilities. Therefore, prior to the allocation of permanent roles and to facilitate effective, informed decision-making, accurate assessment of individual suitability & inclusion of individual preferences, the following process was both developed & adhered to;

- ✓ Generation of a shortlist of prospective roles, derived through assessment of the objectives
- ✓ Identification of “idealised” traits, proficiencies & capabilities on a role-role basis, where relevant
- ✓ Assessment & self-reflection upon personal strengths & weaknesses in comparison to the above
- ✓ Engagement in open & honest discussion, where-in unanimous decision(s) were required

For summaries of the “idealised” traits & proficiencies identified for the roles, see Figure 82 overleaf.

Worthwhile to discuss is that initially it was proposed that a rota would be scheduled which would facilitate all Group Members dabbling with all primary roles which were shortlisted. Applied within Semester One only, the proposed benefit was that short-term experiences could inform decisions regarding permanent positions at the beginning of Semester Two. However, this rota-based system was neglected in favour of assigning ‘permanent’ roles with immediate effect through application of the process defined above. It was felt there may be possible disruption, delaying project progression, due to role changes through the adoption of a rota system. Inconsistent project direction was also thought to be a potential negative symptom of a rota system where-in differing leads were chosen.

11.2. ALLOCATED ROLES & RESPECTIVE DESCRIPTIONS

Through adequate performance of the process discussed within Section 11.1., the following shortlist of required roles was both generated and subsequently fulfilled. Considerations were given to project deliverables, objectives (both project-oriented & personal), advice garnered through attendance of project management seminars, experiences of industry best practices and management structures. Again, refer to Figure 82 for details of both roles & idealised traits. Table 30, overleaf, presents the eventual delegation of ‘permanent’ project roles. As is clearly visible, the group achieved a theoretical even distribution of responsibilities amongst members, where-in close to a near-even workload was theoretically implemented, which was perceived to be beneficial for project efficiency & deliverables.

It was identified that a key benefit of the proposed, yet neglected, rota-based system was that there was flexibility for changes to be made if managerial failures occurred or if group members desired to experience specific aspect of management, otherwise out with their allocation. Therefore, all group members agreed within the contract that at any time, discussion could be opened regarding amendments to role allocation, if formal requests for change are lodged with the PM.

Table 30 *Summary of the identified roles & respective individual allocations for performance.*

PROJECT ROLE	GROUP MEMBER ALLOCATION
Project Manager (PM)	R. Anderson
Financial Manager (FM)	A. Porras
Communications Manager (CM)	A. Porras
Storage System Administrator (Sys. Admin)	R. Anderson
Website Development Lead (Web Dev.)	P. Lizzeri
Chief Design Engineer (CDE)	P. Lizzeri

PROJECT MANAGER (PM);

Primary Responsibilities **-** Scheduling & delegation of task(s), mediation of Group conflict & discussion, performance of critical decision-making & general motivation of Project Group.

Idealised Traits **–** Decisiveness, tact, consummate, prudent & holding prior experience(s).

FINANCIAL MANAGER (FM);

Primary Responsibilities **–** Management, planning and logging of expenditure records.

Idealised Traits **–** Resolute, thorough & holding prior experience (or willingness to learn).

COMMUNICATIONS MANAGER (CM);

Primary Responsibilities **–** Meeting arrangement & agenda consolidation, maintenance of logs pertaining to discussion, outcomes & actions to be performed and update circulation.

Idealised Traits **–** Extraverted, reliable, empathetic, consummate and communicative.

STORAGE SYSTEM ADMINISTRATOR (Sys. Admin);

Primary Responsibilities **–** Development & maintenance of centralised storage system, including hierarchy & document structure, maintenance of document ownership & amendment logs and development of document back-up policy.

Idealised Traits **–** Organised, logical & holding prior experience in hierarchy development.

WEBSITE DEVELOPMENT LEAD (Web Dev.);

Primary Responsibilities **–** Identification of appropriate domain hosting packages utilising desirable features, planning of website content and implementation of website creation.

Idealised Traits **–** Creative, unorthodox & holding prior experience (or willingness to learn).

CHIEF DESIGN ENGINEER (CDE)[3];

Primary Responsibilities **–** Advisor on technical areas of interest, performance of quality control in terms of technical output(s) and supervision of any manufacturing undertaken.

Idealised Traits **–** Practical, analytical, virtuous, knowledgeable (or willing to learn).

Figure 82 Group-identified roles and their respective idealised traits & pre-requisites.

11.3. GROUP AUTHORITY HEIRARCHY DEFINITION

To improve Project Group synergy and to aid in methodology for resolution of potential internal conflict (read: disagreement), a hierarchy was generated which would explicitly outline authority structure. Figure 83 presents the tiered hierarchy which was created & which was, *flexibly*, applied.

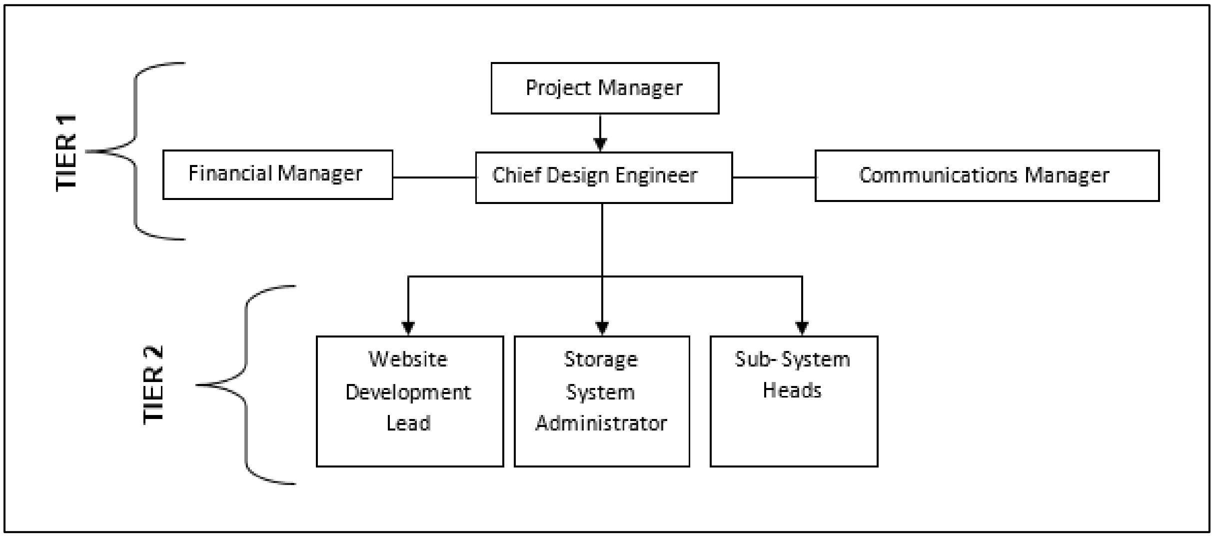


Figure 83 *Group structural hierarchy indicating waterfall of authority pertaining to decision making.*

11.4. DETAILED SUB-SYSTEM DESIGN LEAD ROLES

Combined the Project Group had little prior competencies in automotive vehicle sub-system design beyond general engineering principles & transferable competencies. Therefore, to maximise Group efficiency and ultimately maximise meaningful Project deliverables, it was felt that specialism through allocation of distinct Sub-Systems Lead Design roles would be beneficial in Semester Two prior to the initiation of the detailed design phase of the Project. The purpose of these roles was to allocate responsibility for individual sub-system and research-informed, detailed design of sub-assemblies.

It was intended that for a sub-system to be deemed completed satisfactorily, the Client, PM, CDE and relevant Sub-System Lead Designer must all sign off. Such a role may be Chassis Lead Designer and responsibilities may include structural & aerodynamic considerations of vehicle body & shape, for example. Further details of the preparations made towards conceptual design, refer to Section 8..

11.5. POST-PROJECT REFLECTION ON GROUP ORGANISATIONAL STRUCTURE

Upon reflection, the group were in unanimous agreement that the methodology employed to determine suitable role allocation was both justified & vindicated, with respect to the principle aims of identifying the best-fit roles to be fulfilled, and the distribution of responsibilities. Within the scope of the role allocation process, efforts for which the group believed to be particularly impactful upon the success of the utilized process was, principally, the detailed assessment of the idealised traits & pre-requisites; which synergized with the thorough assessment of individuals (Section 10.). For direct example, R. Anderson's prior experiences with respect to development & implementation of industry & communications processes, in conjunction with a high-level proficiency across the MS Office suite and compatible, management-oriented Belbin traits, such as self-disciple & level-headedness, were identified to be suited for a high-level management position; hence selection for project manager. Similar arguments were prepared for tole allocations for P. Lizzeri & A. Porras also.

With regards to the hierarchy, again, unanimously the group agreed that tiered system where-in, although all perspectives were valued, critical decisions lay with an individual proved effective. This opinion was formed as it was determined that whilst the tiered system enabled flexibility for relative autonomy for minor, role-specific issues a significant benefit was felt in instances of urgency & criticality use of a single-point-of-decision system, informed through group discussion, was beneficial.

12. GENERAL GROUP MANAGEMENT & ORGANISATION

12.1. GROUP CONTACT LISTS

At project initiation, group contact details were exchanged & documented within a centralised storage location. Tableted contact details for the group are presented within Figure 84 below for reference.

GROUP MEMBER	EMAIL ADDRESS	TEL. // MOBILE	PRIMARY ROLE
R. Anderson	jrb12179@uni.strath.ac.uk	+447921542407	Project Manager
P. Lizzeri	lyb12180@uni.strath.ac.uk	+447983727564	Chief Design Eng.
A. Porras	alexqporras@gmail.com	+346360336	Comm. Manager
Prof. M. Cartmell	matthew.cartmell@strath.ac.uk	+441415483753	Client & Supervisor

Figure 84 *Contact details for the project group members, stored prominently for visibility.*

Though the benefits are rather obvious, the decision to centrally store contact details proved useful on numerous occasions, particularly when group members were lacking data for instant message or email communications. In addition, the decision to include a statement of primary role was something which the group felt, though minor, reinforced the tiered hierarchy system developed.

12.2. GROUP AVAILABILITY TRACKING

12.2.1. INTENDED PURPOSE & SEMESTER ONE TRACKER

Due to the nature of the 5th year & ERAMUS student curriculums, it became evident in the project's initial phases that group availability varied greatly. To aide in minimisation of the impacts of these curriculum disparities, and indeed, to minimise impacts unforeseen circumstances and external commitments, a group availability tracker was created. This tracker comprehensively covered all known commitments of all group members throughout both semester, including mid-term deadlines such as coursework for additional syllabus classes. An example of the tracker employed within semester one is presented within Appendix Sheet G.1 of this report.

12.2.2. MODIFICATIONS & SEMESTER TWO'S AVAILABILITY TRACKER

It became apparent that whilst the semester one availability tracker was of value in forecasting build-up of commitments, both with regards to the project and with respect to the external commitments such us the course syllabus and part-time employment, there was significant room for improvement. As identified within the improvements discussion of the Interim Report, the group identified that through revision of both the format and the frequency of revision, the return on investment for maintaining the tracker would be improved greatly. Visible in Appendix Sheet G.2. is the revised format of the tracker, for reference purposes. With respect to the frequency of maintenance, previously this had been reserved for during group sessions; however, within semester two this was adapted to an "update as and when information becomes available" policy. The group had previously thought that performing updates at group sessions only would ensure a consistency of expectations, however, the group later identified that a simple circulation of the tracker following ad-hoc updates would be sufficient as it would adequately ensure all group members were aware of circumstance changes.

12.2.3. REFLECTIONS UPON GROUP AVAILABILITY TRACKER

Group reflection indicated belief that regular up-keep of the availability tracker & its prominent availability with the centralised storage space enabled time management from both personal & intra-group member perspectives than would have otherwise have been possible. Though difficult to present evidence of this, notable periods of high external commitments on the part of group members which were identified long in advance of deadlines included a brief period of mid-November through to early-December for both P. Lizzeri & R. Anderson and late-January through to early-February for A. Porras. The group reflected that through generation of a warning system for personal periods of limited availability, or spikes in external commitments, better group planning could be accomplished. Noteworthy too was that the identification of key dates for the commitments & deadlines within the scope of the project were also thought very beneficial since it made such events prominently visible. Noteworthy is that whilst beneficial, the tracker didn't alleviate all issues, nor could it be expected to.

12.3. GROUP HOURLY CONTRIBUTIONS TRACKER

12.3.1. HOURLY CONTRIBUTIONS METRIC & METHODOLOGY

A critical metric of the Group's successes within the scope of this Project was the investment of time required to satisfy, or partially satisfy where applicable, the agreed upon objectives & stated deliverables. In the case of Project Group K, 1,200 usable hours are allocated to the Project; 400 hours per member. Noteworthy is that, as will be presented within Section 8., the group had initially negotiated access to the original 4th member's additional hours, as stated with in the original contract. However, following work scope renegotiations to be discussed within Section 12.14, the originally intended four-person work scope was revised to more adequately reflect that only three group members were undertaking the project and as such the allocated hours was reduced to 1,200. To enable analysis of this metric an hourly contribution tracker was generated in October. As stated within the Statement of Purpose, it was required that all Group Members submitted a summary of their estimated personal committed hours to the project on a weekly-basis to the project manager for review. Table 31, overleaf, defines the total hours committed the project by all three group members.

Table 31 *Estimated individual hours contributions to ME519 project, inclusive of meetings.*

INDIVIDUAL		HOURS EST.	AVERAGE PER WEEK (20 Wks)
A. Porras		385[2]	19.25
P. Lizzeri		355	17.75
R. Anderson		520	26
	Σ	1260	63

12.3.2. REFLECTION UPON HOURLY CONTRIBUTIONS

The overall conclusion is that when combined the group's hour contributions slightly exceeded the allocated 1,200 hours as stated within the contract; however, the degree to which the allocation is exceeded is both marginal and justifiable. Principally the allocation of resources towards expansion upon the original scope of research (refer to infrastructure's disruptive technologies; Section 4.4. through to Section 4.8.), the investment of time towards preparations for conceptual design undertakings (Section 8.) and the investment of time in assessing the feasibility & justification for numerous conference visits which were initially not within the scope of the project (Section 0.) account for all additional resource investment. With just a total 5% resource overinvestment in terms of overall commitment of hours vs. the stated allocated hours, the group feels that in general time resource investment was well-managed throughout the duration of the two-semester project.

12.4. MEETING STRUCTURE & FREQUENCY

12.4.1. FIRST SEMESTER MEETING SCHEDULING

To aid the project group with regards to efficiency and to maximise both potential meeting attendance & value, a preliminary schedule was developed outlining the various meeting purposes, frequencies, required attendances and stating any required prerequisites. Table 32, overleaf, outlines the structure that was developed and employed for first semester meeting arrangements. It was stated within the responsibilities that the comms. manager would hold responsibility for arrangement of meetings.

12.4.2. SECOND SEMESTER MEETING SCHEDULING

Through reflection performed prior to the conclusion of semester one, the group determined that there should be adaptations made to the developed meeting schedule as defined above; namely changes were to be made to the frequency of Supervisory meetings. Throughout semester one, such meetings were held only when deemed necessary; typically, once every 1.5-3 Wks & depending upon availabilities of all relevant parties. The group's reflection indicated that, availability permitting, meetings should be held on a weekly basis, ideally with use of a regular time-slot. The use of a regular timeslot perceived beneficial since it would facilitate greater likelihood of attendance & availability; improving overall group synergy, clarity & communications and thus deliverables achieved.

[2] **N.B.** for initial submission it was stated A. Porras committed 285hrs; this was a mistype & is corrected above.

In addition to meeting frequency, it was determined through reflection at semester one's conclusion that often group member-only meetings were slow to begin, overran and under-delivered in terms of discussion effectiveness and agenda coverage. Therefore, throughout semester two, the project manager was assigned the informal role of meeting chairperson; where-in responsibility was held for maintaining schedule & minimising distractions as meetings progressed. It was believed the allocation of such a role would yield efficiency benefits with regards to group communications and would improve synergy; thus, adding to the value of meeting attendances & discussions. In addition to the above, the group implemented changes to task assignment through identification of possible improvements following semester one. Principally, this change was that following discussion of project-specific topics, the group will identify critical questions which require to be addressed by individuals over the coming period. It was believed this would aid in improving clarity and in minimizing the risk of misunderstanding of task assignment. A final change which was identified through post-semester one reflection & implemented throughout semester two was the formalisation of meeting locations. Previously a small lab within the JW building, on campus, had been employed by the group for all non-Supervisory meetings. However, the group identified that a change of location would be beneficial; opting for computer labs within Livingstone Tower building, where-in large shared screens and increased computer availability were present.

Table 32 *An overview of the meeting structure employed by 'Project Group K'.*

MEETING TYPE	REQ. ATTENDEE(S)	PREREQUISITES	FREQUENCY
Supervisory	Client Group Members Relevant Academic Staff	N/A	As required
Scheduled Group	Group Members	Agenda preparation Minutes allocation	Once weekly
Impromptu Group	As required	N/A	As required
Milestone Review	Client Group Members Relevant Academic Staff	Performance of tasks Presentation prep.	As required

12.4.3. MEETING STRUCTURE & FREQUENCY REFLECTION

With respect to the decision to utilise a regular time slot for weekly Supervisory meetings throughout semester two proved very beneficial from group's perspective following performance of post-project reflection. The change meant that the group could achieve not only greater contact time with the Client, which improved general project clarity, but there also was a requirement to spend significantly less time arranging subsequent meetings; an approach of "same time, same place" was applied on a majority of occasions. Given that the Client had a significantly varied & busy schedule due to his standing in the university, the decision to allocate a provisional weekly time-slot was beneficial as it enabled the Client to schedule external arrangements such that there would be no clash with the group's 10.10-11.00am Monday sessions. In addition, when on occasion there were requirements to cancel scheduled meetings at short-notice, both the project group & client acted swiftly to rearrange suitably; the group would like to thank the Client for promptly flagging any cancellations. In regards to the decision to elect a meeting chair for group-sessions, all group members found agreement in that the decision was both effective & accomplished the stated goals. It was noted that whilst most group sessions were scheduled for around

1.5-2hrs, most could be fully performed in as little as 1hr; critically without losing any value or context. In addition, it was found that group discussion did not deviate as regularly. The decision to formalise group sessions through utilisation of a differing lab space throughout semester two was viewed as a worthwhile endeavour by the group following post-project reflection. Principally, through moving to a space where-in a screen was more prominently visible to all project group members and where-in there was increased availability of computers for multi-screen purposes was viewed as hugely beneficial; improving the general efficiency of all group sessions undertaken and ensuring all could following the discussion.

Considering the changes to task assignment performed at semester two group sessions, again, the group unanimously determined that the changes made were highly beneficial to the groups effectiveness & efficiency. Though difficult to provide evidence, anecdotally we found it less likely for follow up questions to be asked, either through an instant message chat, informal in person discussion or otherwise. However, the group did identify one further action which potentially could have been undertaken to improve the effectiveness & value of group sessions; that of identifying high-level priorities & generating a prominently visible document. Though generally performed rather well throughout, the group feels prioritisation of task could have been slightly improved through adoption of such a strategy; though this addition was only identified very late in the project.

12.5. COMMUNICATIONS ORGANISATION

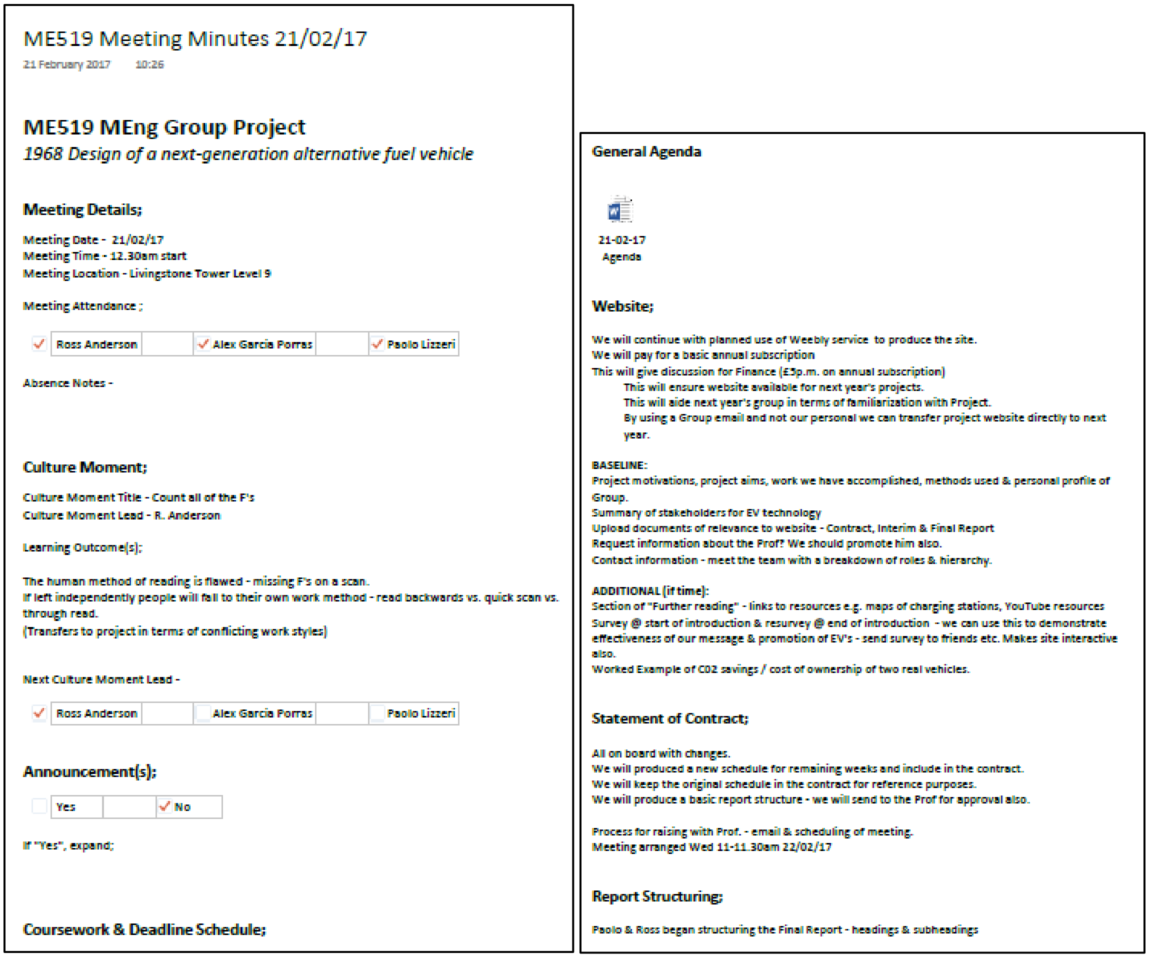
12.5.1. CORE ORGANISATION OF COMMUNICATIONS

The group developed a communications structure to aid individuals in the identification of the appropriate means of presenting, circulating and delivering knowledge, thoughts & project-relevant updates. It was believed that such a system would facilitate efficient and effective project progression through improving prominence of available communications channels. In addition to supporting intra-group communications, the developed structure was utilised to support external communications, such as those with members of academic staff, when relevant & representatives of the conferences.

Table 33, overleaf, provides the summary of the group's developed communications structure.

12.5.2. MEETING MINUTES ORGANISATION

Maintenance of records of outcomes from Group discussions were deemed a potentially significant contributor to Project success. Through assessment it was identified that the primary benefits would be those of enhanced Group Member awareness & understanding of context and facilitation of records of Project progression. The responsibility for generation & circulation of meeting minutes was delegated to the Communication Manager (CM) upon performance of role allocation. Figure 85, overleaf, presents exemplary minutes using the standard which was generated and employed throughout. Minutes were taken at all Scheduled Group Meetings. Proficiency with MS OneNote & its flexibility resulted in its selection as the tool through which minutes would be recorded and as shown, consideration was given to meeting arrangement details, attendances, 'Culture Moments' (refer to Section 12.6), announcements such as the release of the Interim Assessment Schedule and provision of a platform to present individual progress & to generally address project progression. Additionally, it was felt important that a platform was offered for raising of ad-hoc queries or discussion points to facilitate continuous improvement. It was felt that formalisation of such discussions would be more encouraging than simply leaving it to self-motivated communications.



ME519 Meeting Minutes 21/02/17
21 February 2017 10:26

ME519 MEng Group Project
1968 Design of a next-generation alternative fuel vehicle

Meeting Details;
Meeting Date - 21/02/17
Meeting Time - 12.30am start
Meeting Location - Livingstone Tower Level 9

Meeting Attendance ;

✓ Ross Anderson	✓ Alex Garcia Porras	✓ Paolo Lizzeri

Absence Notes -

Culture Moment;
Culture Moment Title - Count all of the F's
Culture Moment Lead - R. Anderson

Learning Outcome(s);

The human method of reading is flawed - missing F's on a scan.
If left independently people will fall to their own work method - read backwards vs. quick scan vs. through read.
(Transfers to project in terms of conflicting work styles)

Next Culture Moment Lead -

✓ Ross Anderson	Alex Garcia Porras	Paolo Lizzeri

Announcement(s);

Yes	✓ No

If "Yes", expand;

Coursework & Deadline Schedule;

General Agenda

21-02-17 Agenda

Website;
We will continue with planned use of Weebly service to produce the site.
We will pay for a basic annual subscription
This will give discussion for Finance (£5p.m. on annual subscription)
This will ensure website available for next year's projects.
This will aide next year's group in terms of familiarization with Project.
By using a Group email and not our personal we can transfer project website directly to next year.

BASELINE:
Project motivations, project aims, work we have accomplished, methods used & personal profile of Group.
Summary of stakeholders for EV technology
Upload documents of relevance to website - Contract, Interim & Final Report
Request information about the Prof? We should promote him also.
Contact information - meet the team with a breakdown of roles & hierarchy.

ADDITIONAL (if time):
Section of "Further reading" - links to resources e.g. maps of charging stations, YouTube resources
Survey @ start of introduction & resurvey @ end of introduction - we can use this to demonstrate effectiveness of our message & promotion of EV's - send survey to friends etc. Makes site interactive also.
Worked Example of C02 savings / cost of ownership of two real vehicles.

Statement of Contract;
All on board with changes.
We will produced a new schedule for remaining weeks and include in the contract.
We will keep the original schedule in the contract for reference purposes.
We will produce a basic report structure - we will send to the Prof for approval also.

Process for raising with Prof. - email & scheduling of meeting.
Meeting arranged Wed 11-11.30am 22/02/17

Report Structuring;
Paolo & Ross began structuring the Final Report - headings & subheadings

Figure 85 LHS *Excerpt from 21-02-17 Minutes (1/2).* ***RHS*** *Excerpt from 21-02-17 (2/2).*

12.5.3. REVISIONS TO ORGANISATION OF COMMUNICAITONS

The principle change that was implemented was that of introducing meeting minutes for Supervisory meetings, following identification of this requirement from reflection performed upon the conclusion of semester one in December. This change was implemented to bring Supervisory meetings in-line with the standards of meetings & processes performed for group-only sessions. Measures were also taken to introduce agendas to Supervisory meetings for similar purposes, during the second semester.

12.5.4. REFLECTION ON ORGANISATION OF COMMUNICAITONS

In a similar outcome to previous conclusion outlined, again the group largely decided that the changes implemented were vindicated and ultimately worthwhile. In retrospect, the group recognised that these changes should have been implemented sooner than they were, however we feel it noteworthy that action was taken to address minor shortcomings in our approach to a successful outcome. Also noteworthy is that although the addition of agendas and minutes were beneficial, the process employed within semester one with no minutes nor agendas had proven to be sufficiently robust.

Table 33 *An overview of the communication guidance circulated to the Group.*

COMMUNICATION METHOD	GENERAL PURPOSE(S)	FREQUENCY
Supervisory Meeting	Formally discuss important updates Discuss changes to Project scope Clarification of task requirements	Refer to Table 32
Scheduled Group Meeting	Discuss internal updates Review performance & output(s) Discuss problems Assignment of tasks	Refer to Table 32
Impromptu Group Meeting	Discuss ad-hoc issues Raise suggestions &/or queries	Refer to Table 32
Milestone Review	Review of task performance Sign off task completion OR Reassignment of action(s) to be taken	Refer to Table 32
Email Communication	Circulation of significant updates Contact platform for external parties Contact platform with academic staff	As required
Document Storage Platform	Secure sharing of Project documents	As required
Group Facebook Page	Rapid sharing of information	As required
Group Facebook Chat	Immediate, ad-hoc discussion	As required
Text Message / Phone Call	Immediate, ad-hoc discussion	As required
In-person Discussion (unnoted)	Clarification & minor issue flagging	As required

12.6. CULTURE MOMENTS

12.6.1. PURPOSE & UTILISATION OF CULTURE MOMENTS

Culture Moments were a main-stay within the Project Group’s meeting minutes & discussion sessions. Inclusion of such discussion periods stemmed from prior experiences within industry held by R. Anderson, where-in the often dubbed “High Performance Culture (HPC)” served to promote effective discussion across working groups & colleagues – often regarding controversial or ambiguous topics. An example of one such Culture Moment is presented below; where-in the participants are asked to read the text in 10 seconds & count all instances of the letter “F”. Following performance of the task discussion pertains to the differing approaches undertaken (scanning just for Fs, reading full text etc.) highlighting potential for differing work styles within a group and to, when applicable, highlighting requirement to ensure thorough checks are performed & potentially obtaining a second opinion.

> “Feature films are the result of years of scientific study combined with the experiences of years”.

Figure 86 *An exemplary excerpt from a Culture Moment employed by the group.*

12.6.2. REFLECTION ON CULTURE MOMENT SUCCESS

It is firmly believed by all group members that the performance of regular culture moments and their inclusion in the group session schedules was of benefit to the group; namely from a perspective of development of strong group synergy & intra-personal relationships. Though learning outcomes, such as those defined for the “count all the Fs” example were also beneficial, the group felt that the most influential topics of discussion were those of a controversial standing. For example, discussions pertaining to both opinions regarding Scottish independence and upon the suitability of Donald Trump produced rather quite divisive conversation. However, through performance of an honest, open-mind and friendly debate regarding these topics, the group developed intra-personal confidence to enable willingness to speak out in disagreement where-in it was believed that a differing approach or conclusion to that suggested by a majority was necessary to be taken by the group.

12.7. DOCUMENT OWNERSHIP & REVISION HISTORY

12.7.1. PURPOSE & UTILISATION OF DOCUMENT OWNERSHIP & REVISION HISTORY

Taking inspiration from industrial placements, early in the Project’s initiation it was decided that document ownership & revision history would be implemented. A working example of the system is visible within Section A. of this report. Ultimately, the tangible benefits of these measures are such that amendment to documentation can be tracked therefore reference to documents can be clear in terms of applicable version &/or draft, reducing potential confusion. Furthermore, delegation of ownership demands active responsibility to be taken by Group Members to ensure that documents under their control are produced to adequate quality standards. Table 34 outlines the naming convention which was defined and implemented with respect to document revision history. As defined within the Statement of Purpose, responsibilities of Document Owners are that of ensuing document accessibility and prominence within the employed storage system. Furthermore, Owners are responsible for individual document back-up & enforcement of the document revision policy for any documents which fall under their control; including maintenance of document front cover sheets & providing brief indication of amendments.

Table 34 *The naming convention employed during revision history.*

REVISION TYPE	CONVENTION	EXAMPLE
Publication / Release	Generation of release level	A1
Minor (non-transformative)	Addition of +1 to vers. number	A1 → A2
Major (transforms intent)	Transfer to subsequent letter	A2 → B1

12.7.2. REFLECTION ON DOCUMENT OWNERSHIP & REVISION HISTORY

It is of firm belief that the use of both revision history and allocation of document owners was a great benefit to the group’s effectiveness; primarily with regards to the principle purpose of alleviating issues of confusion as to both changes made between revisions. In addition, since the process was supported by the maintenance of a centralised table of up-keep, confusion as to whether documents accessed were of the most recent version in existence were fully alleviate; with no occurrences of misinformation or misunderstanding arising from such a mistake taking place. To this extent, the group therefore concluded that the revision history was of significant success.

12.8. DOCUMENT STORAGE & BACK-UP POLICY

12.8.1. OVERVIEW OF STORAGE POLICY EMPLOYED

To enable effective, efficient storage of important Project documentation and to minimise the potential for data loss, significant time was invested in both identifying an appropriate storage platform and implementing a sound back-up schedule. Initially, due to existing competencies and in the desire to produce a storage platform which would be capable of hassle-free inheritance by subsequent Project Groups, viability of SharePoint was assessed. However, upon beginning dialogue with the Department & Supervisor, it became apparent that the platform would not be suitable due to potential liabilities. Ultimately, Dropbox was employed as the storage platform of choice, primarily due to advantages such as a perceived, initial non-existent cost, up to 2GB of online storage capacity, ease of accessibility from internet accessible computers and existence of prior degree of familiarity. A structured folder hierarchy was implemented to aid in identification of storage locations (Figure 87). In addition to the development of a centralized storage location, the group utilized Dropbox-stored "Working Drives"; where-in on-going work was uploaded at conclusion of daily efforts to ensure that, whenever access was required, both the original author & others could access the most recent copy of an in-work file so long as they could obtain suitable internet access, namely Edu Roam or LAN.

With respect to back-up policy, Table 35, below, outlines the differential back-up schedule employed. Notable is that Dropbox shall be used as a working directory and so the in-built 'continuous' back-up function, identical to MS Word's ctrl+s, can be utilised also.

***Table 35** Back-up schedule overview.*

BACK-UP TYPE	RESPONSIBLE	BACK-UP LOCATION	FREQUENCY
Continuous (Dropbox in-built)	User editing document	Currently in-use folder	Continuous (i.e. "ctrl+s")
Unscheduled	Sys. Admin	Dedicated Dropbox folder	Upon user request
Scheduled Weekly	Sys. Admin	Dedicated Dropbox folder & dedicated offline folder	Once weekly

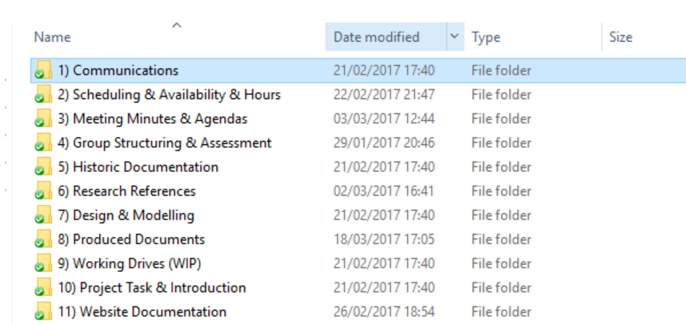


***Figure 57** A screen capture of the high-level document storage structure employed.*

12.8.2. REFLECTION UPON STORAGE & BACK-UP POLICY

The group's utilisation of a structured back-up policy ensured that no significant data loss occurred throughout the duration of the project, there-in vindicating the decision to develop such a process & demonstrating its relative success. On several occasions, minor data loss occurred due to computer crashes, however thanks to the use of online Dropbox-based working drives and adequate use of the ctrl+s functionality, no significant loss of data occurred; a prime example of this was the loss of a 4-5-line sentence when R. Anderson swivelled his university computer monitor to better show A. Porras a figure and inadvertently pulled the main power cable from the computer's casing.

It must be noted however that a significant issue occurred on the 17-Mar where-in between 1-4pm, Dropbox fluttered in and out of availability due to a server issue. Though this coincided with the official hand-in date, & did not help the situation, this issue was not responsible for the group's quality of submission. Figure 88 presents evidence of this having occurred. Notable however that at no other time did the group encounter such issues with the use of an online-storage drive and thankfully through use of offline back-ups, no significant problems occurred on the day of hand-in beyond minor delays.

The group also concluded that the developed structure for document storage was both adequate & clear. On few occasions was it required for group members to clarify storage locations of required documentation or spreadsheets; indicating the success of the layout developed and implemented.

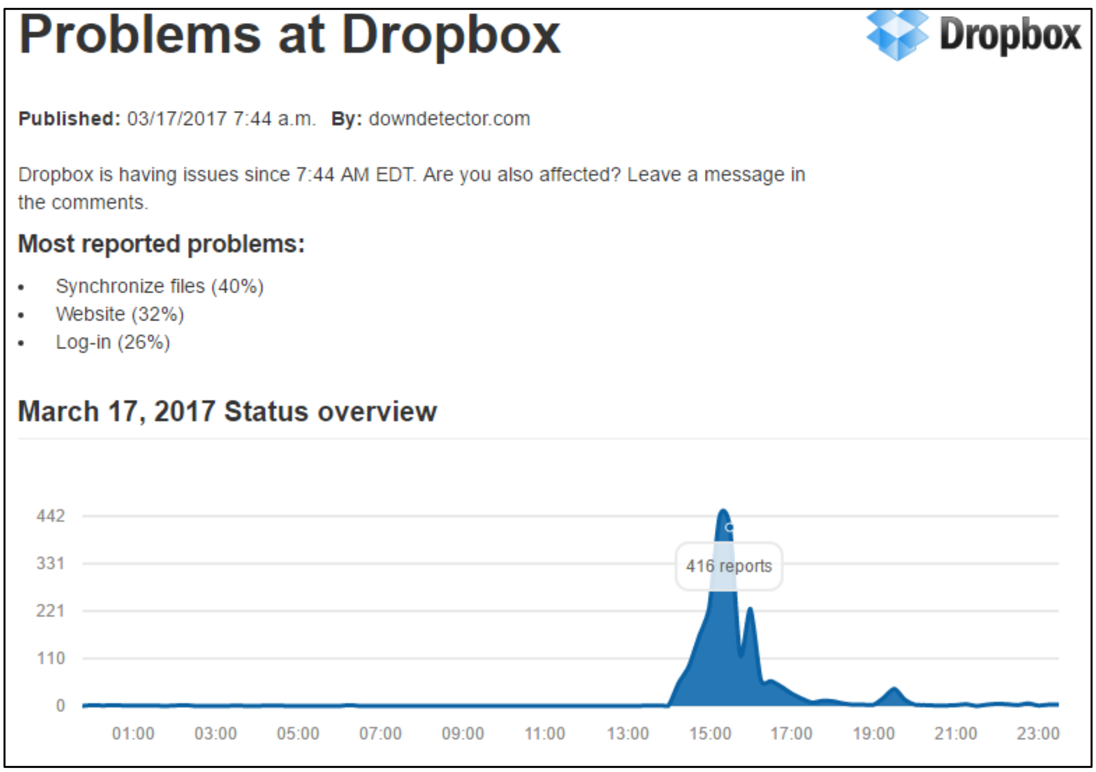


Figure 88 *Depiction of influx of reports indicating server issues with Dropbox on 17-Mar* [391].

12.9. TRAINING & CONSISTENCY MATERIALS

Throughout the project, the project manager developed and deployed several training exercises with a view to addressing quality issues identified within semester one and to aid in the efficiency with which the group developed the write-up. Whilst participation was not always fully ensured on the part of all group members, the decision by the PM to ensure that a full recap of the training was performed ensured that all group members were indeed able to benefit from the processes employed. An example of tone such exercise is presented below, however in addition the group also held training for formatting of figures, captions and general structuring of the individually written report sections.

A significant learning experience of the first semester was that of identification of the issues of referencing within a group-produced, lengthy document. Therefore, the project manager developed and implemented a training exercise where-in the group members were required to individually implement referencing to a journal, a report & a publicly viewable website, with a requirement to utilise the same referencing format and to implement a prominent visible, consistent bibliography. Figure 89, overleaf, presents the task which was assigned and performed.

Notable outcomes of this project were that it was identified that in the case of A. Porras & P. Lizzeri, there was a requirement to utilise university-based PCs for reference purposes as personally owned Apple-OS based laptops required a significantly different referencing approach to be taken. As such, arrangements were made and the avoidance of issues was realised. This we feel is evidenced in that, even within the original submission where-in most formatting was incorrectly presented for the final report, all 380+ references were suitably inserted within the submitted document & bibliography.

REFERENCES SUBTASK

Dear both,

To make sure that the references compilation goes smoothly, we all are required to be on the same page in terms of how we're approaching it. I've put this together such that, in the space of 5-10 mins, we should all be capable of citing references for journals, governmental reports, webpages and books.

I propose that we all give this a bash independently prior to this coming Friday's session. We will then compare & discuss. I also advise that, once we complete this task successfully, we all save a copy to a prominent &/or visible location on our personal computers, USB's etc. for later reference if required.

All the best,

Ross

TASK – REFERENCE THE FOLLOWING & CREATE A BIBLIOGRAPHY

Using agreed style (21/02/17 minutes if forgotten), within word, create a reference for the following;

A Journal Article – Visible here.

[Insert the reference here & delete this text]

A Governmental Report – Visible here. *Ignore the "City" & publisher section if no clear indication given.*

[Insert the reference here & delete this text]

A website – Visible here.

[Insert reference here & delete this text]

[Insert bibliography here]

Figure 89 *Extract of the referencing training task developed & utilised by the group.*

12.10. FINANCIAL EXPENDITURE & MANAGEMENT

12.10.1. FINANCIAL MANAGEMENT OVERVIEW

Significant aspect of the group's project management was that of financial expenditure planning & tracking. Such was of great importance to the achievability of the stated agreed objectives & project deliverables but was also employed as a valuable metric with regards to the assessment of the ME519 MEng Group Project's general successes from a learning outcomes perspective. Table 36 below presents a summary of all significant expenditure incurred whilst undertaking the project. As presented within the contract, responsibility for financial management lay with A. Porras, the acting Financial Manager (FM). The FM held responsibility for the maintenance of expenditure records & for documenting prospective cost incurred during fulfilment of the objectives.

A format for maintenance of financial costs was agreed between FM & PM. total funding of £400 has been supplied by the Department of Mechanical & Aerospace Engineering, which includes a successfully negotiated additional £100 of funding supplementary to the £100 per Group Member due to the project scope initially being set for 4 persons. Finalised expenditure is depicted within Table 36. Minor costs have also been incurred; specifically, document printing & binding. These are depicted under "Other" within Table 36. As per Statement of Purpose, records of PM & FM sign-off have been maintained. Notable is that due to the available funding's adequacy, no discussions were undertaken with respect to increasing available funds throughout the Project's lifespan, beyond the initial £400.

Table 36 *An overview of financial expenditure incurred, incl. forecast conference costs.*

COMPONENT	QUANTITY	SUPPLIER	PPU (£) (EXC. VAT)	PPU (£) (INC. VAT)	TOTAL (£)
Current Expenditure					
Domain Name	1x	GoDaddy	11.98	11.98	11.98
WiX Premium	1x	WiX	114.00	136.80	136.80
Matlab License	1x	Mathworks	107.00	128.40	128.40
Other	1x	Various	34.80	34.80	34.80
				Sub-Total	311.98
Sponsorship and Capital Increases					
-	-	-	-	-	-
				Sub-Total	NIL
Potential Further Expenditure					
Conference	1x	Various	88.02	88.02	88.02
				Sub-Total	88.02
				Total Cost	400.00

12.10.2. FINANCIAL MANAGEMENT REFLECTION

As is presented within Table 36, the group were able to deliver the project outcomes well within budget. This we feel is particularly notable given that much of our expenditure was incurred procuring tolls & resources which would be employed for several years to come; for example, both the domain & WiX premium subscriptions are purchased as 2-yr recurring payments since through doing so, significant cost saving could be achieved. Thus, Project Group K's budget has not only been able to meet our requirements but in addition will also serve to reduce financial costs of subsequent project groups.

12.11. MILESTONE REVIEWS

12.11.1. MILESTONE IDENTIFICATION & REVIEW PROCESS

Prior to the submission of the contract, it was suggested that identification of numerous, key project milestones would be beneficial to the assessment(s) of the group progression and functionality throughout the project's duration. In conjunction with generation of milestones, a process through which they were both performed and subsequently reviewed was developed. This process was outlined within the contract and is also summarized as follows below;

- Arrangements for mandatory review attendance circulated to all relevant parties
- Presentation & discuss of works undertaken with regards to the appropriate milestone
- Discussion regarding satisfactory achievement of relevant objectives & deliverables
- Unanimous conclusion as to whether satisfactory performance achieved
- Whenever appropriate; reassignment & scheduling of further action(s) required

The milestones identified are as depicted within the bounds of the signed & agreed contract, which is visible on the group's dedicated website.

12.11.2. MILESTONE REVIEW REFLECTION

The project group feels that upon reflection the utilisation of milestone reviews was rather mixed in terms of the extent of the benefits felt. With regards to group-exclusive milestone reviews, such as completion of the fifteen vehicle MPG assessment, were found to be rather successful; serving to consolidate works undertaken and to perhaps identifying weaknesses in information presented. In addition, these reviews facilitated meaningful conclusions of significant portions of the project.

In the case of the formal design reviews where-in the client was present, the outcomes varied from review to review. In the case of the formal review following completion of the long-term research task, there was significant benefit to the project outcomes from performance of the design review. It was made clear that though some additional efforts should be made to address additional technical variances of the identified vehicles (performed subsequently by the group), in general satisfactory performance of the objectives were agreed to have been achieved. However, in the case of the final major client-targeted review subsequent to the completion of the long-term research task, due to an insufficient allocation of time for the session had been made by the project group and thus a minor amount of the presentation prepared required to be skipped. This prevented the group from fully demonstrating what was felt to be satisfactory performance of the requirements. However, through realisation that insufficient time was allocated and through cutting short of the presentation, time was available from which the group could receive valuable critical feedback from the Client. So, whilst the group recognises that more time should have been allocated, significant benefit was still achieved.

12.12. RISK MANAGEMENT

12.12.1. RISK ASSESSMENT PERFORMANCE

As thoroughly detailed within the Project's Statement of Purpose, a preliminary risk assessment was performed to aid in potential identification & mitigation of failure(s) or disruption(s). This extract is visible in Figure 90, overleaf, for reference purposes. Table 37 provides details of the metric system used. Here, the identified risks have been scored on both "Probability" of occurring and potential "Severity" of the impact which may be felt by the Project Group, with "1" being lowest and "5" being the highest. An Overall Rating has been determined through the product of Probability & Severity and the categorisation detailed in Table 37 below applied to more clearly express the level of risk. Viable steps for the potential mitigation of extended delays & significant failure have also been considered.

Table 37 *Details of the categorisation set used to assess the potential of risks.*

RISK CATEGORY	"Low"	"Medium"	"High"
OVERALL RATING (Probability x Severity)	1-9	10-18	19-25

12.12.2. RISK ASSESSMENT REFLECTION & GENERAL CONCLUSIONS

The group dedicated a segment of a session to reflecting upon the value of the risk assessment process performed upon the conclusion of the project. In general, it was determined that the risk assessment had been worthwhile to perform and had successfully aided in the mitigation of issues with respect to the project. Most notably this could be seen in the group's repeat decisions to utilize resources for which previous experiences, where possible, were present in-line with the mitigation identified in the risk assessment table, shown within Figure 90. This is evidenced in the use of Dropbox as an online data storage utility and in the decision to pursue the procurement & use of Simulink & the Matlab-based environment suite Simscape in preparation for conceptual design. In the case of Simulink, it was known that the Client & acting supervisor has significant previous experience with the resource and as such could provide a support network & high-level. Low input guidance if required. With regards to Simscape, though no prior experiences were available to drawn on, this was true for all such software. In a similar vein to the decision to utilise the WiX platform for website development, the group elected to utilize Simscape as there was a significant array of literature & supporting guides available.

Again, evidence of the success of the risk assessment is visible with regards to the point pertaining to the loss of data. Without prior identification, the group may potentially have found themselves in a position where-in no centralised storage system was present and, if one was employed, may not have implemented a robust back-up strategy to minimize the risk of severe data loss. As discussed previously, this proved to be a particularly successful aspect of the group's management since no major data losses occurred throughout the two-semester duration; surprising the group to an extent.

Noteworthy is that all points covered by the risk assessment can be evidenced as successful by the group upon receipt of request, and indeed exemplars & evidence can also be provided as necessary.

RISK	DESCRIPTION	PROBABILITY (1,2,3,4,5)	SEVERITY (1,2,3,4,5)	OVERALL RATING (PROBABILITY X SEVERITY)	MITIGATION
Group Member commitments to university &/or external activities hinder ability to fulfil project work scope	Group Member availability requires to be redirected towards external commitments such as part-time employment or university commitments such as courseworks & class exams	4	5	20	Maintenance of a Group Availability schedule, proactively tackling tasks, communication of short-notice up-coming commitments & a willingness to pool Group responsibilities
Group Member absences due to illness of otherwise	Group Member ability to perform stated roles hindered by extenuating circumstances	3	5	10	Continuous knowledge sharing & recording of outcomes. Centralised storage & use of resources. No smoking. No partaking in extreme sports.
Mismanagement of finances and/or over-spending	Ability to perform work scope hindered due to insufficient &/or scare finance availability	2	5	10	Maintenance of financial expenditure records. Authorised spending only (by PM & FM). Other financial management techniques employed.
Loss of data &/or data inaccessibility	Members unable to retrieve data when required & delays caused redeveloping work produced	2	5	10	Maintenance of a secured centralised storage system. Management of access rights. Local back-ups when necessary.
Resource availability issues encountered	Resources required to perform stated work scope inaccessible	1	5	5	Continuous discussion with dependants, such as lab technicians or IT, regarding accessibility & down time. Long-term planning of activities, with stakeholder parties. Provision of contingency periods.
Insufficient resource familiarity / proficiency for Group Members to perform required tasks.	Group Members unable to perform work scope due to a lack of knowledge in either application or knowledge within resource, e.g. Word	2	3	6	Utilisation, on a majority level, of resources for which the Group have serious experiences. If no such resource exists, selection of alternates for which adequate reference material &/or guidance is available
Project work scope slips to a position where-in agreed work scope is realistically unachievable.	Work scope grows too large due to identification of additional areas &/or failures due to scheduling, contribution, unidentified challenges or otherwise.	4	5	20	Maintenance of regular discussion channels with Client & in event of occurrence, adherence to stated process of raising issue(s) with Client & requesting amendments to work scope as is necessary.

Figure 90 *Risk assessment performed by group, extracted from the statement of contract.*

The group also reflected on the balance of risk & reward throughout the project; particularly with regards to the decision making on behalf of the project manager. The most prominent example would be the decision pertaining to pursuit of attendance of the EuroBrake conference. Requiring a non-insignificant time investment for feasibility study & for application, this was performed at a time where-in the group were slightly behind their proposed running schedule; thus, imposing risk-reward. Upon reflection, the group has identified that regardless of the outcome of applications, the correct decision was made by the PM to pursue attendance. The group, and in particular the PM, had an opportunity to exercise skills both in regards to risk-reward and in terms of performance of feasibility studies regarding the cost-benefits of attendance at an event out with the stated scope. In addition, there is the potential value that attendance will bring (Section 7.). The final comments made in this regard pertain to the fact that due to effective time management, the PM's responsibilities did not actually suffer due to investment of additional time towards the feasibility study nor application for attendance of the conference.

12.13 TASK ASSIGNMENT & SCHEDULING

With respect to task assignment, following conclusion of the project the group performed reflection pertaining to how it was felt both task assignment was handled an the effectiveness of scheduling. The details of this are presented below for assessment purposes; though in general both were thought to have been performed both to a satisfactory level, with minor potential improvements noted. With respect to task assignment, the principle evidence of effective task assignment was that it was only on rare occasion that clarifications of what had been requested to be performed by the PM during group sessions was required; with any requests typically rapidly accomplished through informal instant messaging services or through informal face-face discussions, arranged ad-hoc. It must be noted however that on numerous occasions due to the revelation of new information observed during long-term research, the PM did inform others of additional areas of interest; with examples of this most prominently visible in the decision to assess chassis design & to investigate specific battery types. Though it was felt that task assignment was performed to a satisfactory level, the group did identify towards the end of the project that it could have been beneficial to have concluded each group session with formal identification of top level priorities; this was generally performed through discussion however generation of a brief summary would have enabled more prominent visibility of priorities. With respect to scheduling of the project, although group feels that this was performed adequately to ensure that the objectives & deliverables were performed to satisfactory standards, there was identified through reflection that perhaps minor mistakes, borne of inexperience, were made – most notably in the development of the initial schedule.

The first minor failing on the part of the group was the decision to elect to continue to maintain the original work scope intended for a four person group & not reduce the scope in line with the group size that would be tackling the project (three persons). This decision was borne of a group desire to over-deliver and an ambition to ensure a strong grade in the assessment of the project, when relevant. However, this approach was identified to be flawed and, although the group negotiated access to the additional 400hrs of the fourth group members, realistically the additional workload could not be sustained with the considerations of the additional classes within syllabus & with significant external commitments. Again, this ties back to the group's unfamiliarity with 'Tier 5' credits and the implementation of a new, 11-week semester schedule where-in critically there was no provision of a study period for revision purposes prior to the December examinations; meaning this was required to be performed during the allocated 11-week semester schedule, detracting from abilities of the group to commit additional hours to the ME519 group-based project. In addition, it was identified by the group that the initial schedule had been ambitious in that there was insufficient allocation of time to the development of the contract, interim report & final reports initially. In addition, another minor issue with the initial schedule that was identified was the insufficient allocation of time to development of group processes & a group organisation structure, which as defined previously, was rather significant and extremely beneficial to the group's effectiveness. These issues were identified at the conclusion of semester one and were suitable changes were incorporated within the oral presentation. Feedback was then received and incorporated within the semester two schedule from the oral assessors; with the principal feedback that the group should refine the scheduling of the long-term research task to a greater degree than had been performed to aid in performance. Notable is that issues pertaining to delays of report compilation were unrelated to scheduling.

For reference purposes, Figure 93, of Appendix Sheet G.3., presents the semester one schedule.

12.14. ACHIEVEMENT OF DELIVERABLES & OBJECTIVES

To conclude the reflection section of this report, the group would like to address the degree completion of the work scope, as stated within the contract. Principally the group has successfully been able to perform all mandatory objectives stated within the contract; from performance of the familiarisation task through to the conclusion of a decision pertaining to a promising concept. However, there were delays with respect to realised delivery date and over-delivery in terms of output with respect to a small handful of the required aspects of the long-term research task. With respect to the actual delivery date, most prominent of this issue was most notably the Final Report submission was not fully compiled nor in a state reflective of the group's efforts on time to meet the stated deadline. As such, the group elected to submit an "as-now" version of the report, in-line with course syllabus requirements. A brief period of time was subsequently spent recompiling the report to facilitate meaningful readability on the part of the assessors, the results of which are this report; note this is denoted version B1 to reflect this recompilation. Primarily the group has identified several reasons for the occurrence of this delay. Most notably was inaccurate estimation by individuals on the required time investment for drafting & review of the respective sections of the report. This was minimally by the over-extension of some aspects of the research task, which though beneficial, required a small additional investment of time to compile. Upon reflection, the group recognizes that, although it was believed at the time that there was sufficient time to compile the report, when it was first identified that there may have been even a small risk of failure to meet the deadline, notifications should have been passed to all relevant parties; principally the assessors & client. In addition, lessons have been learnt where-in the group now feels better equipped with respect to performance of estimations for required time investment in draft creation. An approach of under-promise & then hopefully subsequent over-delivery has been recognised as being something worthwhile to implement in all future individual & group-based projects to be undertaken in future and should aide in the mitigation of potential for delays & missed deadlines. Essentially providing a significantly larger buffer period which can be utilized if future activities begin to overrun. In terms of evidence of taking a valid approach to the issue, the group is confident that the decision to perform a recompilation and deliver a report in-line with the quality standards expected demonstrates both the degree of commitment applied to the project and that the group responded well to the issue experienced; that we did not offer excuses nor ignore the issue.

With regards to the original work scope & the subsequent renegotiation to remove the mandating of the conceptual development section of the objectives set, the group unambiguously agrees that significantly meaningful learning has been achieved. Principally, the reasons for the requirement to reduce the work scope stemmed from insufficient allocation of time for group structure development, failures with regards to estimations of 'Tier 5' credit requirements, unfamiliarity with implemented 11-week semester schedule and the group's initial naivety to accept a work scope intended for four. Ultimately the group have learnt that whilst the acceptance of tasks beyond that expected by the Client would be highly beneficial, it is imperative to ensure that such additions are capable of being delivered to a high standard within the required timeframe. The group would like to highlight that we feel upon reflection that although mistakes were made the issue was handled in a just & valid manner; namely the issues of scope completion were raised through appropriate means with the Client and the work scope adjusted suitably. In addition, that the group has over delivered in some aspects, namely the infrastructure research, we feel demonstrates that considerations were made to ensuring a satisfactory & meaningful output. Also, since the group has made significant preparations on behalf of subsequent groups we feel also demonstrates appropriate management of the issues experienced; refer to procurement of software on behalf of future groups.

13. CONCLUSIONS

As stated within the report introduction, the primary purpose of this project was to facilitate development of knowledge pertaining to current & forecasted HEV & EV technologies and to utilize said information to identify a proposed conceptual vehicle architecture; specifically a vehicle concept believed to be capable of achieving market leading status within a 2-yr lifecycle. To this extent the group has been successful, where-in as presented within Section 6. A grid-dependent parallel-architecture petrol hybrid compact SUV has been identified as the most promising vehicle concept likely to prove commercially viable within a short-medium term outlook. This conclusion was informed through in-sight gained through a comprehensively performed preliminary familiarization task and a subsequent, intensive, long-term research & analysis of the HEV & EV market; principally assessing trends within the current automotive market, present technology readiness levels & forecast growth of capabilities, thorough assessments of the principal barriers to HEV & EV up-take & how such barriers may be alleviated, historic & future investment in infrastructure (incl. assessments of the current capabilities of existing standards), and a detailed assessment of both current energy storage mediums & those forecast for future maturation.

In regards to the secondary purpose of the project, that of both refining and demonstrating MEng level project & group communications skills, the group again is confident that this requirement has been satisfactorily accomplished. As defined throughout the report previously, a great amount of structuring was performed both in regards to group organisation and in regards to task performance; where-in detailed processes were identified and adhered to successfully to deliver satisfactory outcomes for all tasks undertaken. In addition the group has shown through post-project reflection that a very strong synergy was developed from both a personal & professional stand-point, which facilitated provision of constructive, meaningful & critical feedback when relevant. In addition, and as depicted throughout the reflection section of this report, the group has identified numerous positive and worthwhile learning outcomes, most notably with regards to risk-reward and in regards to identification of realistic achievable goals; though as stated previously with respect to both of these the group are confident that successful mitigations were employed to ensure that there were meaningful outcomes delivered by the project conclusion which could be utilized by subsequent project groups, most notably achieved through laying groundwork preparations for conceptual design, incl. procurement of required software suites and through utilization of the group’s budget to accommodate website hosting for subsequent groups.

With regards to recommendations, Project Group K’s most notable are outlined as follows;

- ✓ The performance of an equivalent familiarization task should be mandatory; this task facilitated development of familiarity with industry terminology, technology influences & each other’s work styles
- ✓ The reperformance of a brief review of government incentives should be mandatory; incentives such as the UK Plug-in Car Grant & Scottish Govt’s EV loan scheme are currently under, or planned for, review
- ✓ Software suites Matlab, Simulink & Simscape Driveline should be employed for conceptual design tasks
- ✓ Project Group K’s primary deliverable, that of a proposed concept, should be employed for design

For details of the group’s recommendations & personal conclusive reflections pertaining to the ME519 Project undertaken here-in, please refer to the group website at www.HEVTechStrath.com.

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G. REPORT APPENDICES

G.1. SEMESTER ONE AVAILABILITY TRACKER

ME519 Group Availability
Semester 1

24/10/16 – 30/10/16
Week 13

	Time / Day	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30
Alex	MON					Dynamics											
Ross																	
Paolo																	
Alex	TUE																
Ross																	
Paolo																Pressurised Systems	
Alex	WED																
Ross												ARP Meeting				Electrical Power Systems	
Paolo																	
Alex	THUR																
Ross																	
Paolo																	
Alex	FRI																
Ross																	
Paolo																	

Colour Key	
"Blank"	Available
	Coursework
	Exam
	Lecture
	Other

Figure 91 *Group availability tracker employed throughout semester one of the project.*

G.2. SEMESTER TWO AVAILABILITY TRACKER

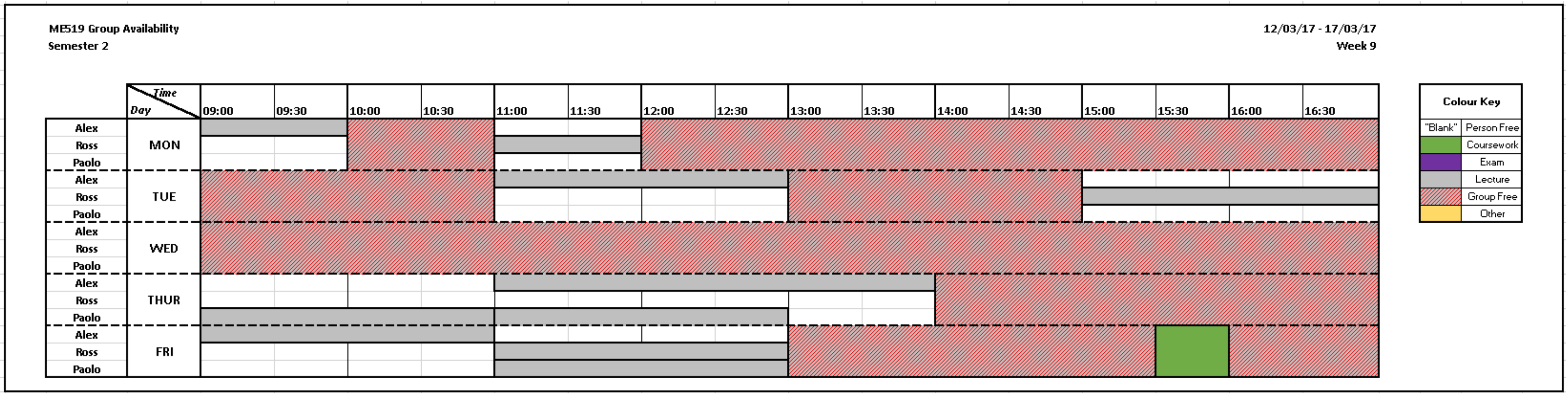
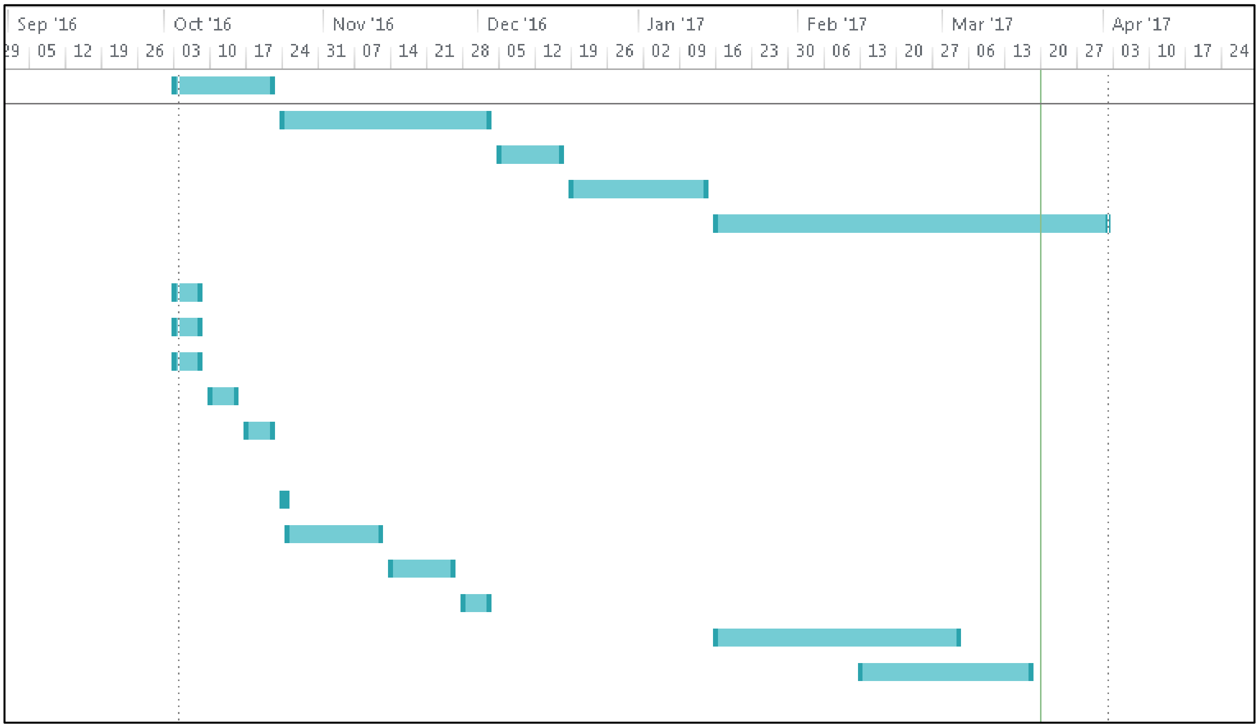


Figure 92 *Group availability tracker employed throughout semester two of the project.*

G.3. SEMESTER ONE SCHEDULE EXEMPLIFICATION



Task Mode	Task Name	Duration	Start	Finish
	Task Set 1	15 days	Mon 03/10/1	Fri 21/10/16
	Task Set 2 (i) Pre-break	30 days	Mon 24/10/1	Fri 02/12/16
	Exam Period	10 days	Mon 05/12/1	Fri 16/12/16
	Christmas Break	20 days	Mon 19/12/1	Fri 13/01/17
	Task Set 2 (ii) Post-break	56 days	Mon 16/01/1	Sat 01/04/17
	1.1 Select 15 HEV vehicles	5 days	Mon 03/10/1	Fri 07/10/16
	1.2 Calculate the cost to MPG ratio	5 days	Mon 03/10/1	Fri 07/10/16
	1.3 Choose 5 cars; explain the cost to MPG ratio	5 days	Mon 03/10/1	Fri 07/10/16
	1.4 Discuss the difference between the Liftback & Plug-in	5 days	Mon 10/10/1	Fri 14/10/16
	1.5 Explain why the Nissan Altima was discontinued	5 days	Mon 17/10/1	Fri 21/10/16
	2.1 Decide on a category of car	1 day	Mon 24/10/1	Mon 24/10/1
	2.2 Perform long-term research upon design & the market	14 days	Tue 25/10/1	Fri 11/11/16
	2.3 Repeat 2.2 for alternative propulsion system / technology	10 days	Mon 14/11/1	Fri 25/11/16
	2.4 Summarise findings & conclude upon decision	5 days	Mon 28/11/1	Fri 02/12/16
	2.5 Design a vehicle	35 days	Mon 16/01/1	Fri 03/03/17
	2.6 Write the report	25 days	Mon 13/02/1	Fri 17/03/17

***Figure 93** Group's estimated schedule as of Semester One initiation - subsequently revised.*