Sustainable, low cost, resilient solution for UK Energy Supply **24th November 2021**

Our Challenge: Design, develop and operate the best available solution for a viable, sustainable, adaptable energy supply for the UK to enable sustainable economic growth whilst addressing the very significant and increasingly urgent challenges of global warming, air pollution, reducing biodiversity and increasing levels of international conflict for scarce resources (including fossil fuels, fresh water and biomass).

If the UK were to lead the way by succeeding in this mission for the UK, then the rest of the world would be likely to follow since the solution is both geographically transferable and mutually beneficial.

The dilemma facing us

We can continue indefinitely to research, develop and implement a very wide range of alternative, competing partial solutions to address this incredibly complex and challenging objective in the hope that the "perfect solution" will be discovered to satisfy all of the interested parties involved before it is too late.

Alternatively, we could adopt a solution which is simple and based upon proven, cost effective and relatively easily exploitable on both a national and a global scale. In essence, this solution involves using those natural resources which are readily available and which can be used to generate and to supply electricity and heat energy using proven, cost- effective technology without damaging the environment.

If potential improvements to the solution were proven, then they could be adopted since the solution is flexible.

In essence, we are in the position of participants who are playing speed chess (representing human interaction with the earth's resilient, but not invulnerable, ecosystem) against an AI-driven robot (representing the results of our actions on the earth's ecosystem) for high stakes (the future of the human race) in a situation where the time limit on the "game" is uncertain.

As everyone knows, there are billions of possible moves to be chosen in a game of chess and the AI-driven robot would be very likely to win on time unless the humans were to cooperate constructively and effectively to adopt a viable (in the widest sense) solution.

The Best Available Solution for Sustainable UK Energy Supply

If all UK Communities (Cities, Counties & Regions) were to adopt the completely sustainable, customer-focussed electricity supply system (ref. **Note 2** below) described below rather than maintain the current supplier-focused energy supply system, then the UK would have:

- a completely sustainable energy supply system for its current electricity requirements, domestic and commercial property space heating and hot water, and road transportation; and

- a resilient supply of 100% renewable electricity at the lowest unsubsidised price (4.1 p/kWh) in the world. The National Grid cable network will provide interconnections amongst the Community Grids (Cities, Counties & Regions).

Every individual Community Grid will be balanced at all times so that the Community's expected annual demand for electricity is matched by the Community's forecast annual electricity generation from its own seasonally complementary solar PV systems and onshore wind turbines.

Each Community's V2G (Vehicle-to-Grid), V2H (Vehicle-to-Home) and V2B (Vehicle-to-Business) - enabled EV (cars, LGVs /vans, HGVs, and buses & coaches) battery storage and supply capacity will provide the necessary dynamic, short term electricity supply to cover any temporary shortfalls between electricity generation and electricity demand. V2G and V2B EV charge /discharge points will be installed by each Community in all or most of the car parks within its Community area.

Demand Response measures (e.g. essential EV driving only, working from home) will be developed by each Community to be implemented in the event that multiple consecutive days were forecast with both low daylight intensity and low wind speed which would reduce the Community's solar and wind electricity generation.

Each Community Grid (CG) will be managed by its own Electricity System Operator (ESO) which will actively monitor (and implement agreed dynamic responses, as required):

- current and forecast electricity demand;
- current and forecast electricity supply (primarily based upon daylight intensity and wind speed for solar and wind generation respectively);
- total electricity storage level in CG-connected EV batteries and maximise storage level at all times; and
- whether multiple, consecutive low daylight intensity and low wind speed days are forecast, and will, if necessary, implement Demand Response actions.

The ESOs will make use of Interconnect Agreements with the National Grid to supply electricity in the extremely unlikely event that the above actions are insufficient to avoid any electricity supply-demand shortfalls for their CGs.

The National Grid will install and operate bi-directional interconnectors with other countries and set up renewable electricity export /import electricity supply agreements with those countries which are able to supply renewable electricity. A further level of resilience for UK electricity supply could be provided by interconnectors with countries which are generating non-renewable electricity. The intention is that non-renewable electricity will only be required from other countries in the extremely unlikely situation that all of the other levels of resilience in UK electricity supply have not been able to satisfy the UK electricity demand.

This proposal does not require any public sector funding and it will enable the UK to transition to a Sustainable UK Interconnected Community Grid Network Electricity Supply (SUKICGNES). The benefits of the SUKICGNES include:

1. All commercial and domestic electricity consumers will be charged only 4.1 p/kWh (plus annual indexation of no more than 3% pa) which will make the UK very attractive as a place to live and work. This 4.1 p/kWh tariff is an average for all of the UK Community Grids and it will vary slightly (less than 1 p/kWh) depending upon the local electricity generation performance of solar PV systems and onshore wind turbines;
2. The electricity will be 100% renewable (solar, wind and hydroelectric) so all of the energy-consuming activity which is performed in the UK will be completely sustainable;
3. Optimal mix of roof-mounted solar (summer peak generation) and onshore wind systems (winter peak generation) which have complementary generation seasonality will ensure that supply and demand for electricity are matched precisely throughout the year;
4. EVs will be used as mobile smart batteries with V2G, V2H and V2B capability to store and supply electricity (ref. **Note 4** below) to each local Community Grid as required to balance supply and demand mismatches due to short term fluctuations in generation and /or Time-of-Day electricity demand variability;
5. Use of distributed roof-mounted solar PV system generation will maximise electricity supply directly to the supporting domestic and commercial buildings, and minimising Community Grid loading. Consequently, the existing UK regional Electricity Distribution Networks will be unlikely to require any significant capacity upgrades;
6. There will be no requirement to rely on natural gas or hydrogen supply from the UK Gas Network if air source heat pumps (for space heating and hot water) are installed in all domestic and commercial properties;
7. The assessment of the requirements for loft, cavity wall and solid wall insulation, and secondary glazing will be managed by the local City /County /Region CG Electricity System Operator (ESG) to ensure that only the essential improvements in the insulation of the domestic properties are carried out cost effectively in order to enable effective operation of air source heat pumps in these properties;
8. With the adoption of 100% EVs the air in all UK Communities will be clean and there will be no CO2 emissions from petrol /diesel engines; and
9. There will be no requirement (ref. **Note 5** below) for electricity generation by coal, gas, nuclear, biomass, biofuel, biogas or CHP (combined heat & power) power stations. Also, this proposal does not require any electricity generation from a range of unproven (in cost effectiveness terms) new technologies (including wave, tidal, nuclear fusion, green hydrogen, and carbon capture & storage combined with non-renewable generation) which are not expected to be more cost effective than solar PV systems and onshore wind turbines unless there are significant future electricity generation cost reductions resulting from, currently , unanticipated technology developments.

Based upon a UK assessment of electricity demand, the forecast estimated total electricity requirement is 526 TWh pa (ref. **Note 1** below) after transitioning to 100% air source heat pumps and 100% EVs comprising:

- 104 and 192 TWh pa for existing domestic and commercial electricity usage respectively;
- 110 TWh pa potential electricity required for 100% Air Source Heat Pumps in domestic and commercial properties for space heating, hot water heating and other processes requiring heat energy (ref. **Note 8** below); and
- 120 TWh pa potential electricity required for 100% EVs (ref. **Note 7** below)**.**

The total annual electricity generation for existing installed roof-mounted (7 GW generating 7 TWh pa) and ground-mounted (6 GW generating 6 TWh pa) solar PV systems, onshore (14 GW generating 35 TWh pa) and offshore wind (10 GW generating 41 TWh pa) turbines & hydro-electric systems (2 GW generating 7 TWH pa) less National Grid transmission losses (6 TWh pa) is 90 TWh pa.

The existing installed solar PV systems, wind turbines and hydro-electric systems will be used to directly supply either the nearest or most appropriate (based upon individual Community Grid electricity demand – supply assessments) Community Grid.

The required additional capacities of installed onshore wind systems, Commercial roof-mounted solar PV systems and Domestic roof-mounted solar PV systems to generate at least 436 TWh pa electricity are 130 GW (i.e. 10,830 no. 12 MW wind turbines to generate 342 TWh pa), 100 GW (i.e. solar PV systems covering approx. 80% total available commercial roof space to generate 87 TWh pa) and 26 GW (solar PV systems covering approx. 9% available domestic roof space to generate 21 TWh pa) respectively (ref. **Note 3** below).

The expected annual electricity generation by the proposed additional solar PV system and wind turbine capacities exceed the annual minimum requirement by 14 TWh pa. However, a small surplus in expected annual generation will minimise the risk of any expected time-of-year supply-demand shortfalls.

It is proposed that each Community will set up a **Sustainable Community Fund (SCF)** to fully finance (i.e. without public sector funding) all of the required investments in:

- roof-mounted solar PV systems on commercial and domestic properties, onshore wind turbines;

- EVs for 100% cars, vans /LGVs, HGVs, and buses and coaches (ref. **Note 16** below);

- air source heat pumps for 100% commercial and domestic properties (ref. **Note 17** below); and

- the required improvements in loft, cavity wall and solid wall insulation and in secondary glazing for those domestic properties which are without these forms of insulation and /or double /secondary glazing (ref. **Note 18** below).

The SCFs for all of the UK Communities will deliver a competitive investment return (forecast pre-tax IRR = 4.9% pa on a total investment of £1,885 billion spread over 10 years duration investment programme) for debt funders and equity investors.

Individual domestic and commercial property owners and road transport vehicle owners will be able to use their own funds /funding arrangements to purchase roof-mounted solar PV systems, air source heat pumps and property insulation improvements on their properties and to purchase their own EVs.

The **total cost of additional capacity of installed onshore wind and solar PV systems** for all of the UK Community Grids is **£261 billion** in total comprising £163, £75 and £23 billion for the required additional capacities of installed onshore wind systems, Commercial roof-mounted solar PV systems and Domestic roof-mounted solar PV systems respectively (ref. **Note 6** below).

The **total installed cost (for all UK Communities) of 100% Air Source Heat Pumps in domestic and commercial properties** is **£196 billion** (comprising £165 and £31 billion for domestic and commercial properties respectively). The average air source heat pump installed costs are based upon future achievable costs resulting from economies of scale of manufacturing combined with developments in the design of the main components plus benefit of Community purchasing power.

The **total installed cost (for all UK Communities) of loft, cavity wall and solid wall insulation, and secondary glazing** in domestic properties without loft /cavity wall /solid wall insulation and /or double /secondary glazing is **£111 billion** (comprising £3. £6, £96 and £6 billion for installation of loft, cavity wall and solid wall insulation, and secondary glazing respectively.

The **total cost (for all UK Communities) of 100% replacement of all cars, LGVs, HGVs, and buses & coaches with EVs** is **£1,316 billion** (comprising £960, £176, £150 and £30 billion for Cars, Vans /LGVs, HGVs, and Buses and Coaches respectively. The average EV costs are based upon future achievable costs resulting from economies of scale of manufacturing combined with developments in the design of the main components (including batteries, electric motors and vehicle control units) plus the benefit of Community purchasing power.

Onshore wind turbines located within and /or adjacent to the outer boundary of each Community area will be able to supply electricity to the CG at a tariff of approx..3.3 p/kWh (varies slightly across UK depending upon the local wind speed). By comparison the latest offshore wind farms are supplying electricity as an “input” to the National Grid at a CFD (Contract-for-Difference) price of approximately 5 p/kWh. However, the “output” tariffs to domestic and commercial customers from National Grid electricity suppliers are approximately 21 and 14 p/kWh for domestic and commercial customers. It is anticipated that the residents of UK Communities will almost certainly be in favour of low tariff electricity supplied by local onshore wind turbines directly to their local CG for use by domestic and commercial customers in their Community area only.

The air source heat pumps will be able to supply heat energy more cheaply than a natural gas-fired boiler. Currently, natural gas boilers have an average efficiency of approximately 80% and the current natural gas tariff is approximately 3.85 p/kWh, so the effective tariff for the useable heat energy supplied is approximately 4.8 p/kWh. The tariff for the net heat energy (i.e. 2 kWh net heat energy per kWh electricity based upon a COP [Coefficient of Performance] of 3.0) supplied will be 4.1 p/kWh for MCG domestic and commercial customers.

All owners of cars, vans /LGVs, HGVs, and buses and coaches will have a compelling financial reason to lease EVs procured by the Sustainable Community Funds since the annual lease and electricity costs will be less than the current annual cost of petrol /diesel for their current ICE (Internal Combustion Engine) vehicles.

Annual saving per vehicle owner (ref. **Note 15** below) which will result from **exchanging ICE vehicle for EV**
= [Average annual cost of petrol /diesel for current on-road ICE vehicle] - [Annual net EV rental charge + Average annual cost of electricity] per vehicle

= £113 pa for EV cars
= £206 pa for EV vans /LGVs
= £7,989 pa for EV HGVs
= £1,213 pa for EV buses & coaches

The attached "UK Community Grid Electricity Supply Model" provides more detailed information and analysis to support this proposal for both an example of a Community Grid (1st worksheet; Greater Manchester) and the UK as a whole (2nd worksheet). This model can easily be customised for any other UK Community Grid (i.e. city, county or region).

An example of a Community proposal entitled "Sustainable Manchester Community Grid (MCG) Electricity Supply" is attached and this proposal was emailed to the Mayor of Greater Manchester on 17th November 2021. Similar proposals will be prepared for other UK City, County and Region Communities.

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Note 1: Current & Potential Future Annual UK Electricity Demand

Current: 346 TWh total (104 TWh domestic; 92 TWh industrial; 72 TWh commercial; 18 TWh public administration; 4 TWh agriculture; 6 TWh transport; 24 TWh energy industry use & 26 TWh transmission losses) in 2019 (pre-Covid) with 60 GW peak and 34 GW average power supply via the National Grid.

Potential Additional Future Demand for electricity by 2030 – 2035 depending upon our collective ability to support the adoption of the best available solution (which could be improved over time if alternatives were of proven benefit to the achievement of the overall challenge):

Road Transport – 120 TWh (74 TWh cars; 20 TWh LGVs, 25 TWh HGVs; 1 TWh buses & coaches) based upon 100% EV. [ref. **Note 7**]

Heating – 110 TWh (88 TWh domestic + 22 TWh commercial) based upon 100% air source heat pumps (ASHP or ground or water source heat pumps if more appropriate in specific locations) supplemented with solar thermal systems on roofs of houses /buildings, if necessary. [ref. **Note 8]**

Total Potential Future Demand for electricity by 2030 – 2035 is 576 TWh assuming that electricity demand and supply efficiencies [ref. **Note 9**] per unit of electricity-consuming activity will equal the increased electricity demand driven by future economic growth and the associated increase in overall levels of activity. If the "Best Available Solution" is adopted, then the Total Potential Future Demand for electricity by 2030 – 2035 will be reduced by 50 TWh pa to 526 TWh pa since the energy industry use (24 TWh pa) and transmission losses (26 TWh pa) will be avoided.

Note 2: The “Best Available Solution” for Sustainable Current and Future UK Energy Supply

The key characteristics of the “Best Available Solution” are:

- it harnesses (using proven cost-effective technology) solar, wind and hydro-generated electricity which is freely available and completely sustainable;

- it maximises distributed micro and mini renewable electricity generation and “mobile smart battery” (explained below) capacity which minimises the National Grid capacity requirements for transmission and distribution;

- solar (peak – summer), run-of-the river hydroelectric (peak – winter), and onshore and offshore wind (peak – winter) -generated electricity create a complementary portfolio. The “Best Available Solution” renewable electricity generation portfolio for the UK comprises 22.2% solar, 7.5% offshore wind, 69.0% onshore wind and 1.3% hydro to satisfy the Total Potential Future Demand for electricity (526 TWh pa) by 2030 – 2035 with an expected annual supply of 546 TWh pa;

- the reasons for only using the other existing means of electricity generation during the transition period to the full implementation of the “Best Available Solution” are explained below;

- the total electricity generation capacity of the “Best Available Solution” is matched to the future annual demand for electricity. The generation portfolio is designed to operate at full capacity at all times. Any unexpected short term and expected long term (seasonal) mismatches between the supply of and demand for electricity is addressed by the mitigating actions which are summarised below. This optimised solution minimises the requirement for expensive reserve generation and fixed storage capacity, and also minimises the future liability for “Constraint Payments” (to offshore wind, gas-fired and nuclear power stations in particular) and which have increased significantly in recent years as the UK’s generation capacity portfolio has evolved and the seasonality impact of increased wind generation has not yet been addressed;

- a large fleet of “mobile smart batteries” (EVs) with bi-directional V2G, V2H and V2H capability which is incentivised to be connected to the National Grid or a domestic / commercial property electricity LAN (Local Area Network) at all times when they are not actively providing a means of road transportation. This “mobile smart battery” fleet will provide an adequate amount of short-term electricity storage capacity to minimise /avoid the need for any reserve peak loading electricity generation capacity to be connected to the National Grid;

- bi-directional interconnectors will be installed and renewable electricity export /import electricity supply agreements will be made with countries which are complementary in terms of the seasonality of their renewable electricity generation portfolios. Suitable countries for these interconnector agreements will have either (1) similar seasonal climates to the UK for solar, wind and hydro generation and a generation capacity portfolio mix which is more heavily-weighted towards solar or (2) similar generation capacity portfolio mix to that of the UK and a complementary (i.e. summer /winter season reversal) seasonal climate;

- the "Best Available Solution" requires minimal funding from the public sector since all of the elements in the solution will deliver an economic return to self-funding domestic and commercial property owners, and to funders and investors for third party-funded activities;

- road transport will rapidly transition to exclusively EV since the EVs will provide distributed electricity storage for property owners and for other electricity consumers using bi-directional Vehicle-to-Grid (V2G), Vehicle-to-Home (V2H) and Vehicle-to-Building (V2B) technology as well as a means of transport. This additional use for EVs versus ICE (internal combustion engine) vehicles could generate an annual return of up to £4,000 – £5,500 pa for EV car owners which is not available to ICE car owners. In fact, car EVs. will be operating as a means of transportation for less than 5% of their operating lives and as "mobile smart storage meter-enabled batteries" for more than 95% of the time;

- funders and investors will be attracted to the EV car fleet market since it will offer relatively high, low risk returns on the capital costs of the EVs. The EV drivers will essentially be the operators of the mobile smart batteries and the perk of their "job" is that they will have free /low-cost access to their personal means of road transportation; [ref. **Note 10**]

- EVs will be fitted with smart meters to enable the management of an electricity credit /debit account for the "mobile smart battery". The smart meter will facilitate the charging of the battery at low ToU (Time of Use) tariff times and discharging (when the EV is not being used as a means of road transportation and it is parked in a V2G or V2B-connected space) of the battery at high ToU tariff times;

- complete the installation of smart meters in all domestic and commercial to enable the adoption of Time-of-Use tariffs [ref. **Note 11]** and half hourly billing for Grid electricity supplied to all domestic and commercial properties which will incentivise all consumers to use more electricity at off peak times (including encouraging EV drivers to charge their EV batteries at low Grid supply tariff times or directly from distributed solar PV systems and battery storage. This will help to minimise the peak loading on the National Grid.;

- fixed large battery storage capacity will not be required since the "mobile smart batteries" (EVs) will provide more-than-sufficient storage capacity for the whole electricity supply network;

- all car parks will become “smart electricity exchange hubs” and will be fitted with bi-directional V2G and /or V2B charging /discharging points to enable the charging and discharging of “mobile smart batteries”. If the car park operator is able to achieve a balance of charging and discharging “mobile smart batteries”, then there would be no net requirement to supply electricity to the EVs.

- EV charge-point stations will also become “smart electricity exchange hubs” located at motorway and dual carriageway service stations, other road service stations and car parks to facilitate rapid in-journey EV charging. If required, fixed battery capacity could be provided at EV charge-point stations and this fixed battery capacity will be charged directly from distributed solar PV systems (roof-mounted on adjacent buildings, solar car parks and motorway /dual carriageway solar frames) and from off peak Grid electricity supply; and

- The “Best Available Solution” can easily be modified in the future if alternative means of electricity supply and storage, and heat energy supply were satisfactorily proven to offer an overall improvement to the initial “Best Available Solution” in terms of achieving “The Challenge”. It is possible that the solar – wind electricity generation capacity balance may need to move in favour of wind if the net effect of increasing electrification of road transportation and of heat energy supply for domestic and commercial properties has the effect of increasing electricity demand during the winter compared with the summer.

Note 3: Potential distributed micro (domestic) and mini to large (commercial) solar PV systems [ref. **Note 12**]

Roof-mounted PV systems: 404 GW (279 & 125 GW on domestic & commercial properties respectively) including 7.5 GW existing systems) generating 332 TWh pa (including 7 TWh pa from existing systems) electricity

Existing Large Solar Farms (ground-mounted systems > 5 MW): 6 GW generating 6 TWh pa electricity

Solar car parks: 19 GW generating 17 TWh pa electricity

Motorway & dual carriageway solar frames: 41 GW generating 36 TWh pa electricity

Total for solar PV systems (existing and additional potential installations): 470 GW generating 391 TWh pa electricity

The requirement for additional solar and wind electricity generation would be reduced if additional run-of-of-the-river hydroelectric systems were viable.

Note 4: Potential Grid electricity storage capacity provided by the “Best Available Solution”:

“Mobile Smart Batteries” (EVs): up to 3,187 GWh per charge /discharge cycle (2,354 GWh by 32 million cars @ 75 kWh per car; 440 GWh by 4.4 million LGVs @ 100 kWh per LGV); 325 GWh by 0.5 million HGVs @ 650 kWh per HGV; 68 GWh by 0.15 million buses and coaches @ 450 kWh per bus /coach)

Large batteries at EV charge point stations: 100 GWh assuming 10,000 stations @ 10 MWh battery capacity per station per charge /discharge cycle. Second hand EV batteries (which have degraded to 80% usable capacity after approximately 10 years of operating life) could be used in "battery farms" at charge point stations. 100 GWh is equivalent to 1.25 to 1.67 million second hand EV car batteries @ 80 (i.e. 80% x 100 kWh) to 60 (i.e. 80% x 75 kWh).

Existing utility scale batteries connected to Grid: 1.3 GWh per charge /discharge cycle

Total potential annual battery storage capacity in EVs and at charge point stations assuming 365 charge/discharge cycles pa available to supply Grid during peak loading times

= (3.187 + 0.1) x 365 = 1,200 TWh pa

Existing pumped hydroelectric storage: 2.8 GW providing 4,075 GWh pa

Note 5: Reasons for only using other existing means of electricity generation during the transition period are as follows:

Coal and Natural Gas – fossil fuels (already confirmed as temporary means of electricity generation for shortest possible duration).

Nuclear:

- very expensive compared with solar PV, onshore and offshore wind and hydroelectric; high level of technology risk with new generation of PWR (Pressurised Water Reactor) power stations (currently Hinkley Point C is under construction and its total cost of completion is both increasing over time and uncertain) as it is not successfully operating anywhere in the world;

- long term risk and potentially very significant destructive environmental impact to the atmosphere, groundwater and ground of highly toxic leaks of radioactive resulting from storage container degradation, operational accidents and /or terrorist /hostile force incidents.

- high and uncertain cost of safely storing low, medium and high-level radioactive waste products for centuries.

- nuclear power stations are designed to be operated continuously so the increasing seasonality of the overall generating portfolio will not be cost-effectively addressed by nuclear-generated electricity which is only beneficial during the low generation season for offshore wind.

Biomass:

- only use trees sustainably for biodiversity, CO_2 absorption and as a source of sustainable building materials (with very good heat insulation properties). Focusing the planting, growth and harvesting of trees on the requirements for biomass power generation has generated CO_2 unnecessarily, reduced biodiversity in terms of the range of species and also the total number of trees.

Biofuels (energy crops):

- focusing the planting, growth and harvesting of plants and crops on the requirements for biogas and biofuel power generation has generated CO_2 unnecessarily, reduced biodiversity in terms of the range of species and also the total number of plants.

Waste-to-Energy /Electricity:

- Organic waste (anaerobic digestion) – use organic waste for fertilisers to return nutrients to the ground rather than generating CO_2, methane and other, potentially harmful, gases unnecessarily.

- Inorganic waste – recycle for re-use rather than generating CO_2, methane and other, potentially harmful, gases, liquids and solids unnecessarily. This policy will have the additional benefit of focusing the minds of manufacturers on the recyclability of their products if "Waste-to-Energy" does not offer a "get out of jail free card" to them.

CHP (Combined Heat & Power):

- generates heat energy throughout the year despite this energy primarily being required for heating air in enclosed spaces during the winter months. The continuous requirement for hot water throughout the use is only a secondary level use for the CHP heat energy so it is relatively inefficient.

Reasons for not including other renewables sources of electricity as part of the "Best Available Solution":

Tidal & Wave Energy:

- both of these technologies are unproven in terms of their technical and commercial viability at scale.

CCS and Blue Hydrogen:

- blue hydrogen upon Carbon Capture & Storage (CCS) technology which is unproven in terms of its technical and commercial viability at scale. Also, there is a long-term risk with CCS during operation that a large quantity of CO_2 could be released from the storage "enclosure" as a result of degradation of the wall of the "enclosure", operational accidents and /or terrorist /hostile force incidents.

Green Hydrogen:

- currently uses more than six times the amount (kWh) of green electricity required to produce each unit of useable energy for heating enclosed spaces and hot water compared with the amount of green electricity required for an air source heat pump.

- high capital and operating costs involved in purchasing and operating electrolysis, hydrogen compression and hydrogen distribution /transportation plant plus hydrogen boilers and heat distribution systems in domestic and commercial properties and /or hydrogen-fired power stations to supply the National Grid.

Geothermal:

- limited potential in the UK. However, it is a proven and cost-effective solution in some countries e.g. Iceland.

Nuclear fusion:

- unproven in terms of its technical and commercial viability at scale.

Note 6: Investment required to implement the "Best Available Solution" for the Sustainable UK Energy Supply and the estimated gross return on investment

Distributed Solar PV Generation [ref. **Note 13**]

Roof-mounted solar PV systems on Domestic properties: additional 279 GW with a total installed cost of £251 billion at current prices. The estimated total value of the PV electricity generated by systems will be £17.6 billion pa i.e. 7 % pa gross return on investment (excluding the benefits of future Community Grid electricity tariff inflation and anticipated future reductions in the installed cost of solar PV systems) assuming that all of the solar PV electricity generated will be either used instantaneously, exported to the Community Grid or stored in EV batteries for later use.

Roof-mounted PV systems on Commercial properties: additional 125 GW with a total installed cost of £93.8 billion at current prices. The estimated total value of the PV electricity generated by these systems will be £6.6 billion pa i.e. 7 % pa gross return on investment (excluding the benefits of future Community Grid electricity tariff inflation and anticipated future reductions in the installed cost of solar PV systems) assuming that all of the solar PV electricity generated will be either used instantaneously, exported to the Community Grid or stored in commercial batteries and /or EV batteries (parked in car parks adjacent to the commercial buildings and connected to the electricity distribution systems within these buildings) for later use in the commercial properties.

Solar Car Parks: additional 18.9 GW with a total installed cost of £19.9 billion (@£1,050 per kW) at current prices. The estimated total value of the PV electricity generated by these systems will be £1.4 billion pa (@ 900 kWh pa per kW and a Community Grid electricity tariff of 7.4 p/kWh) i.e. 7 % pa gross return on investment (excluding the benefits of future Community Grid electricity tariff inflation and anticipated future reductions in the installed cost of solar PV systems) assuming that all of the solar PV electricity generated will be either used instantaneously, exported to the Community Grid or stored in commercial batteries and /or EV batteries (parked in car parks adjacent to the commercial buildings and connected to the electricity distribution systems within these buildings) for later use in the commercial properties.

Motorway & dual carriageway solar frames: additional 41.4 GW with a total installed cost of £45.6 billion (@£1,100 per kW) at current prices. The estimated total value of the PV electricity generated by these systems will be £3.2 billion pa (@ 925 and 900 kWh pa per kW for motorways and dual carriageways respectively and a Community Grid electricity tariff of 7.7 p/kWh) i.e. 7 % pa gross return on investment (excluding the benefits of future Community Grid electricity tariff inflation and anticipated future reductions in the installed cost of solar PV systems) assuming that all of the solar PV electricity generated will be either used instantaneously at motorway /dual carriageway charge-point and service stations, and commercial buildings adjacent to the motorways and dual carriageways, exported to the Community Grid or stored in commercial batteries and /or EV batteries (parked in car parks adjacent to the motorways and dual carriageways and connected to the electricity distribution systems within adjacent commercial buildings) for later use in the commercial properties.

The potential total investment required in 464 GW distributed solar generation capacity is £410 billion at current prices and the estimated total value of the PV electricity is £28.7 billion pa i.e. 7 % pa gross return on investment (excluding the benefits of Community Grid supplier electricity tariff inflation and anticipated future reductions in the installed cost of solar PV systems) assuming that all of the solar PV electricity generated will be either used instantaneously, exported to the Community Grid or stored in EV batteries (or other batteries located adjacent to the PV systems) for later use.

Onshore and /or Offshore Wind Generation

The investment which will be required in onshore and /or offshore wind generation capacity is £1.25 billion and /or £2.5 billion per GW respectively (including the associated offshore and onshore National Grid capacity upgrades). However, the upgrades required to the National Grid should be minimal since an equivalent amount of existing Grid capacity required for transitional electricity generation plant will become available as it is replaced by additional wind and solar generating capacity) at current prices and the estimated value of the offshore wind electricity is £0.175 billion pa per GW (based upon a capacity load factor of 0.4 and a CFD (Contract-for-Difference tariff of £50 per MWh) i.e. 7.0% pa gross return on investment (excluding the benefits of future Community Grid electricity tariff inflation and anticipated future reductions in the installed cost of offshore wind systems).

Note 7: Assumptions for road transport electricity demand assessment:

32 million cars @ 8,700 mpa (miles per annum) and 3.75 miles per kWh electricity

4.4 million LGVs @ 12,700 mpa and 2.75 miles per kWh electricity

0.5 million HGVs @ 34,800 mpa and 0.7 miles per kWh electricity

0.15 million buses & coaches @ 17,100 mpa and 2.4 miles per kWh electricity

Note 8: Assumptions for heating electricity demand assessment:

domestic – 28.5 million houses & flats; 92 sqm average floor area per property; 100 kWh pa usable heat energy required per sqm floor area; COP (Coefficient of Performance) = 3.0 for ASHP.

commercial – 548,000 retail properties (average floor area [AFA] = 193 sqm; 350,000 offices (AFA = 289 sqm); 261,000 factories (AFA = 797 sqm); 206,000 warehouses (AFA = 772 sqm); 430,000 other buildings (AFA = 79 sqm); 100 kWh pa usable heat energy required per sqm floor area; COP (Coefficient of Performance) = 3.0 for ASHP.

Note 9: Examples of electricity demand and supply efficiencies:

- improved insulation of domestic and commercial properties; and

- improved operating efficiencies for EVs, electricity storage batteries, ASHPs, solar PV systems, wind turbines, run-of-the-river hydroelectric systems, hydroelectric pumped storage and all electricity-consuming devices.

Note 10: EV batteries could be charged by distributed solar PV and /or by the current "super green" tariff electricity (available for as little as 5 p/kWh between 12.30am and 4.30am every day) during daylight hours or overnight and discharged daily for road travel and /or Grid supply using V2G.

If 100% available EV battery storage were discharged daily, then the value based upon the current difference between the typical domestic electricity tariff (over 20 p/kWh) and the "super green" tariff would generate up to £4,100 - £5,500 pa for an EV car owner for a high-performance 75 – 100 kWh EV battery with 365 charge /discharge cycles pa.

Clearly, this return will be reduced if the V2G /V2H EV owner receives less than 100% standard to "super green" tariff difference, the Depth-of-Discharge (DoD) and Round-Trip Efficiency (RTP) are less than 100% and the EV is used a means of transport at times when V2G /V2H supply is required by the National Grid.

Based upon average annual car mileage 8,700 miles pa, average annual speed of 40 mph for annual total mileage, 75 – 100 kWh usable EV battery capacity, battery charging rate of 20 – 25 kW and 3.75 miles range per kWh charge, then the EV car will be used as a means of transport for

8,700 /40 = 218 hours annual driving time (i.e. 2.5% total available hours pa)

+ 8,700/(3.75 x 20) = 116 hours annual charging time (i.e. 1.3% total available hours pa)

= 334 hours annual driving and charging time (i.e. 3.8% total available hours pa)

This calculation shows that an EV car's primary use is "mobile battery" (V2H. V2B & V2G) and its secondary use is "means of transport".

Note 11: Time-of-Use tariffs (Red [peak]: 16.00 – 19.00 on weekdays; Amber [below peak]: 07.00 – 23.00 on week days; Green: all times excluding the other tariff time periods; "Super Green" [lowest] 00.30 – 04.30 daily).

Note 12: Assumptions for distributed micro (domestic) and mini to large (commercial) solar PV systems:

Roof-mounted PV systems:

- Domestic properties: 22.6 million houses (2.5m bungalows @ 76.9 sqm floor area & 1 storey; 7.8m terraced @ 82.5 sqm floor area & 2 storeys; 7.1m semi-detached @ 96.0 sqm floor area & 2 storeys; 5.1m detached @ 147 sqm floor area & 2 storeys) and 6.0 million apartments (60.9 sqm floor area & blocks of 3 storeys) with 11.2 kW (15.8 kW bungalows; 8.5 kW terraced; 9.9 kW semi-detached; 15.1 kW detached) and 4.2 kW (i.e. 12.6 kW system on average 3 storey apartment block) PV average solar PV system capacities respectively on each property

- i.e. 273 GW in total and generating on average 800 kWh /kW pa [centre of gravity of properties in England is currently Crick which is located on west side of M1 and east of Rugby; average pitch of domestic roofs in UK is 40 degrees; solar array generation performance is 1050, 525, 824 and 806 kWh /kW pa for south, north, east & west orientations in Crick) = 218 TWh pa in total.

- Commercial properties: 608 million sqm roof space (equal to floor space for single storey buildings) with 390 W solar panels (1.84m long x 1.03m wide) providing 0.206 kW capacity per sqm i.e. 125 GW in total and generating on average 900 kWh /kW pa per kW = 112 TWh pa in total.

Existing solar farms (large [> 5 MW] ground-mounted systems): 6 GW in total generating 6 TWh pa @ 950 kWh pa per kW

Solar car parks:

5 million parking spaces (5.0m long x 2.5m wide spaces + 6.0m wide access roads i.e. 20 sqm gross car park area per parking space) with solar frame car park PV array area = 92% (8% reduction due to the combination solar car park frame configuration combined with the assumed length of solar panels) gross unshaded (20% assumed to be shaded) car park area (achieved without affecting the primary purpose of the car park) and 390 W solar panels (1.84m long x 1.03m wide) providing 0.206 kW capacity per sqm i.e. 15 GW in total and generating on average 900 kWh /kW pa = 14 TWh pa in total.

Motorway & dual carriageway solar frames:

- Motorway solar frames: 90% length of 2,705 km motorways in England and Wales with a weighted average total width 33m (based upon 3.5 lanes [@3m wide each] per carriageway, 3m wide emergency lane and 3m wide half of central reservation per carriageway) with 390 W solar panels (1.84m long x 1.03m wide) providing 0.206 kW capacity per sqm i.e. 17 GW in total and generating on average 925 kWh /kW pa = 15 TWh pa in total.

- Dual Carriageway solar frames: 80% length of 7,950 km dual carriageways in England and Wales with a weighted average total width 19m (based upon 7m wide carriageways and 2.5m wide emergency lanes) with 390 W solar panels (1.84m long x 1.03m wide) providing 0.206 kW capacity per sqm i.e. 21 GW in total and generating on average 900 kWh /kW pa = 19 TWh pa in total.

Note 13: Investment required in additional solar PV capacity at current prices and estimated gross return on investment

Distributed Solar PV Generation

- Roof-mounted PV systems on Domestic properties – 3 GW existing capacity comprising 3 kW (average system size) PV systems on 1 million houses. Additional solar PV system is 270 GW with an average system size of 11.3 kW.

[Note: Some houses may be unsuitable for cost-effective solar PV systems and some may facilitate significantly larger than average system capacities. Many flats will be located in multistorey buildings so the PV systems will be installed on the roof above the top floor.]

Total additional PV system installation cost on domestic properties = 273 GW @ £900 per kW for average 11.3 kW system capacity = £246 billion.

If these PV systems generate 800 kWh pa per kW installed and the average domestic electricity tariff is currently 21 p/kWh, then the total value of the PV electricity generated will be 273 x 0.8 x £0.21 = £45.9 billion pa i.e. 18.7% pa gross return on investment (excluding the benefits of future Grid supplier electricity tariff inflation and anticipated future reductions in the installed cost of solar PV systems) assuming that all of the solar PV electricity generated will be either used instantaneously or stored in domestic batteries and /or EV batteries for later use in the domestic properties.

- Roof-mounted PV systems on Commercial properties – 4.5 GW existing capacity covering 28 million sqm roof space @ 0.16 kW per sqm (average energy density per sqm of solar panels in 2014 when 50% current existing capacity had been installed). 119.5 GW additional capacity covering 580 (i.e. 608 – 28) million sqm of available roof space @ 0.206 kW per sqm.

[Note: Some commercial roofs may be unsuitable for cost-effective solar PV systems. However, this potential reduction in available commercial roof array will be compensated by the fact that some commercial properties may include co-located land which may be suitable for ground-mounted PV systems which directly supply the adjacent commercial buildings.]

Total additional PV system installation cost on commercial properties = 119.5 GW @ £750 per kW = 119.5 GW x £0.75 billion installation cost per GW = £89.6 billion.

If these PV systems generate 900 kWh pa per kW installed and the average commercial electricity tariff is currently 14 p/kWh (including the Climate Change Levy), then the total value of the PV electricity generated will be 119.5 x 0.9 x £0.14 = £11.7 billion pa i.e. 14.0% pa gross return on investment (excluding the benefits of future Grid supplier electricity tariff inflation and anticipated future reductions in the installed cost of solar PV systems) assuming that all of the solar PV electricity generated will be either used instantaneously or stored in commercial batteries and /or EV car batteries (parked in car parks adjacent to the commercial buildings and connected to the electricity distribution systems within these buildings) for later use in the commercial properties.

Note 14: Typical examples for self-funded and /or community-funded domestic and commercial property owners of investment required at current prices and estimated gross return on investment

Example No. 1: Domestic property owner – average size (82.5 sqm) terraced house & owner drives petrol /diesel car

Package of investments (purchase /installed prices in £; total price = £42,650):

o 8.5 kW solar PV system (£7,650)

o 16 kW Air Source Heat Pump (£5,000)

o EV (£30,000 cost; battery - 75 kWh useable depth of discharge) with smart meter-enabled battery and bi-directional V2G, V2H and V2B charging /discharging capability

o Smart meter to enable half hourly Time-of-Use billing (no charge from Grid supplier)

o V2H and V2G bi-directional EV charger

Current annual expenditure of terraced house and petrol /diesel car owner:

- electricity for house: 2,800 kWh pa @ £0.21 per kWh = £588 pa

- gas for house space heating & hot water: 10,300 kWh pa @ 125 kWh pa (generating 100 kWh usable heat energy) per sqm based upon average boiler efficiency = 80%; annual cost of gas = £395 @ £0.0383 per kWh

- petrol /diesel assuming annual mileage is 8,700 miles (average for UK cars) @ 36 mpg petrol (@ £1.44 /litre) and 43 MPG diesel (@ £1.48 /litre) for average UK car (used and new); 4.55 litres per gallon; annual Road Tax (£155 does not apply to EVs)

Annual petrol /diesel cost = £1,580 petrol pa or £1,360 diesel pa

Assuming that the terraced house is located at the centre of gravity (i.e. Crick next to M1 & east of Rugby) of properties in England and that the solar PV is average slope (40 degrees) and 25% oriented north, south, east and west, then the 8.5 kW solar PV system will generate 6,800 kWh pa PV electricity @ 800 kWh /kW pa.

The Air Source Heat Pump will require 2,750 kWh pa electricity @ 100 kWh usable heat required per sqm, 82.5 sqm floor area and COP = 3.0

EV will require 2,320 kWh electricity @ 8,700 annual mileage and 3.75 miles range per kWh electricity

Total annual electricity consumption for existing electricity uses + Air Source Heat Pump + EV = 2,800 + 2,750 + 2,320 = 7,870 kWh pa which exceeds solar PV annual electricity generation by 1,070 kWh pa. If this excess electricity were provided by the Community Grid at a tariff of 4.1 p/kWh, then the total annual electricity cost would be £44 pa.

The total annual saving for the terraced house and EV owner

= (£588 - £44) electricity + £395 gas + £1,470 (average diesel /petrol) +£155 (Road Tax on ICE car)

= £2,560 pa

If the EV were used as a “mobile high-performance smart meter-enabled storage battery” for V2H, V2B and V2G supply during working hours on weekdays, then the EV could generate an additional £925 pa by charging via V2G by the Community Grid and supplying via V2G to the Community Grid @ 4.1p per kWh electricity tariff for 300 no. charge – supply cycles pa.

The total annual financial benefit derived from the “investment package” would be:

£3,500 pa on a total investment of £42,650 i.e. gross return in the first year = 8.2 % pa.

Private sector funding would be made available at these levels of annual financial benefit which would minimise the requirement of UK Government financial support required during the implementation of the “Best Available Solution”.

Example No. 2: Commercial property owner – average size (797 sqm) factory

Package of investments (purchase /installed prices in £; total price = £163,000):

- 164 kW solar PV system (£123,000)
- 150 kW Air Source Heat Pump (£40,000)
- Smart meter to enable half hourly Time-of-Use billing (no charge from Grid supplier)

Current annual expenditure of factory owner:

- electricity: 200,000 kWh pa @ £0.14 per kWh = £28,000 pa

- gas for space heating & hot water: 200,000 kWh pa @ 250 kWh pa (generating 200 kWh usable heat energy) per sqm based upon average boiler efficiency = 80%; annual cost of gas = £5,000 @ £0.025 per kWh

Assuming that the factory is located at the centre of gravity (i.e. Crick next to M1 & east of Rugby) of properties in England and that the solar PV is average slope (10 degrees) and 25% oriented north, south, east and west, then the 160 kW solar PV system will generate 139,200 kWh pa PV electricity @ 870 kWh /kW pa.

The Air Source Heat Pump will require 53,300 kWh pa electricity @ 200 kWh usable heat required per sqm, 800 sqm floor area and COP = 3.0

Total annual electricity consumption for existing electricity uses + Air Source Heat Pump = 200,000 + 53,300 = 253,000 kWh pa which exceeds solar PV annual electricity generation by 113,800 kWh pa.

The total annual saving for the factory owner from the “investment package” would be:

= (139,200 – 53,300) x £0.14 per kWh = £12,030 electricity + £5,000 gas

= £17,030 pa

on a total investment of £163,000 i.e. gross return in the first year = 10.4% pa

Private sector funding would be made available at these levels of annual financial benefit which would minimise the requirement of UK Government financial support required during the implementation of the “Best Available Solution”.

Note 15: Annual saving per vehicle owner (ref. **Note 7** above) which will result from exchanging ICE vehicle for EV

= [Average annual cost of petrol /diesel for current on-road ICE vehicle] - [Annual net EV rental charge + Average annual cost of electricity] per vehicle:

Cars: £1,697 – [(£2,100 - £610) + £94] = £113 pa per EV based upon 200 EV battery charge /discharge cycles per annum to store and supply electricity to the MCG & 8,700 mpa (miles per annum)

Vans /LGVs: £2,889 – [(£2,800 - £305) + £188] = £206 pa per EV based upon 75 EV battery charge /discharge cycles per annum to store and supply electricity to the MCG & 12,700 mpa (miles per annum)

HGVs: £29,689 – [(£21,000 - £1,322) + £2,022] = £7,989 pa per EV based upon 50 EV battery charge /discharge cycles per annum to store and supply electricity to the MCG & 34,800 mpa (miles per annum)

Buses & Coaches: £14,588 – [(£14,000 - £915) + £290] = £1,213 pa per EV based upon 50 EV battery charge /discharge cycles per annum to store and supply electricity to the MCG & 17,100 mpa (miles per annum)

Annual net EV rental charge = [Annual gross EV rental charge] – [Average value of electricity supplied by EV battery charge /discharge cycle to MCG per EV via V2H, V2B or V2G within Community Grid area]

Note 16: Average EV costs are based upon future achievable costs resulting from economies of scale of manufacturing combined with developments in the design of the main components (including batteries, electric motors and vehicle control units) plus the benefit of Community purchasing power.

Note 17: Average air source heat pump installed costs are based upon future achievable costs resulting from economies of scale of manufacturing combined with developments in the design of the main components plus the benefit of Community purchasing power.

Note 18: The installed cost of insulation & secondary glazing years will be recovered in full over 20 years by the SCF from the owners of the domestic properties which require insulation improvement by means of annual installed cost contributions with zero interest payments. If necessary, the annual payments can be lower in the early years and higher in the later years over the 20 years duration of the repayments.

These annual repayments of the installed insulation /secondary glazing cost are likely to be self-financing since the improvement in the insulation performance of the property will result in a reduction in the required supply of heat energy.