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A strategy for achieving net-zero emissions by 2050

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To achieve greenhouse gas (GHG) emissions targets of net zero requires an integrated strategy to remove all fossil fuel and other GHG emitters, less natural absorption and carbon capture and storage (CCS), possibly combined with atmospheric CO2 extraction. Clean electricity generation is achievable with known technologies, but storage is essential for when renewables cannot generate power. Small modular nuclear reactors (SMRs) could help with background supply, but storage can be facilitated by decarbonizing the transport sector then using electric vehicles plugged into an intelligent vehicle-to-grid network also helping balance electricity flows. Batteries alone seem inadequate for this, so we propose supplying electric vehicles with supercapacitors using graphene-based nanotubes (GNTs) which can charge and discharge rapidly, offset by reducing costs in vehicle manufacture from eliminating catalytic convertors. GNTs could supply trains in place of diesel-electric, and are very light so help developments in electric aircraft. By ensuring continuity of renewables electricity supply, capacity can expand. This could sustain methane pyrolosis or electrolysis production of hydrogen gas when electricity demand is low, for fuel cells and to replace households' methane use while liquid hydrogen offers a high heat source for industry. New buildings must be constructed as net zero.

Renewables electricity is fully price competitive, especially given free storage from GNT vehicles; graphene prices are falling and there may be `Moore's laws' for nanotube manufacture and SMRs. Hydrogen is a more expensive fuel than methane, but its production at `off-peak' could be cost saving by sustaining 100% continuous renewables' generation. All these developments interact and should maintain employment in new industries with real per-capita growth, while retrofitting vehicles and housing. Relevant skills already exist, from off-shoring, manufacturing and supply, through making electric engines. Taxing non-recyclable and high-carbon content products (as with plastic bags) would incentivise alternatives. The usual tools of carbon pricing, cap and trade, research support, prizes for great ideas etc., remain available.

Methane, nitrous oxide and CO2 emissions are by-products of modern food production. Ruminant emissions can be reduced by dietary changes, and nitrous oxide by reducing nitrogen fertiliser use, replacing some by basalt dust that also absorbs CO2. Animal dietary changes could be cost saving with lower feed input, as their methane production wastes energy; and mineral rich basalt dust is far cheaper than artificial fertilisers. Crop production efficiency can be greatly improved, benefitting the environment and reducing cropland, along with vertical and underground farms. Aquaculture (including seaweed production) could be greatly improved, noting that off-shore wind farms also act as marine reserves. Human dietary changes to eating less mammal meat are

feasible. Pandemic responses confirm rapid adjustment is feasible.

The analysis is illustrated by the UK because it created the Industrial Revolution leading to the GHG problem; its Climate Change Act of 2008 has markedly reduced its emissions at little aggregate cost; and we have modelled its performance in economic and climate terms.