Abstract

In the pre-industrial world, transport of people and goods across the landscape was driven by human and animal muscle power, using mainly unrefined carbohydrates as their fuel, produced by photosynthesis. The energy was ultimately derived from nuclear fusion of hydrogen into helium within our offshore nuclear reactor – the sun. Since food was produced within a season of plant growth, it could be said to be the product of endlessly renewable solar energy currency.

The explosive growth of human population which followed the industrial transition in the 19th century harnessed energy from the prodigious combustion of fossilised hydrocarbons, i.e. non-renewable solar energy capital. The resulting exponential atmospheric pollution by the greenhouse gas carbon dioxide, together with massive

destruction of vegetation, has led to global warming and consequent climate instability which threatens the survival of our own and countless other species.

Mitigation of global warming by reduction of carbon pollution is becoming increasingly urgent if catastrophe is to be avoided. Current developments in clean renewable energy are becoming cost-competitive with fossil fuels. One largely unexplored energy solution for transport, and ultimately for base load power generation is to use nitrogen as a hydrogen carrier (i.e. anhydrous ammonia, NH3), which can be synthesised using clean renewable energy currency, atmospheric nitrogen and hydrolysis of water for hydrogen, with oxygen as a by-product. Use of this carbon-free fuel both for transport and also for base load electricity generation has a track record in Canada and USA.

Early history of transport – the carbohydrate era

Our hunter-gatherer ancestors moved across and worked in the landscape using their own muscle power directly, fuelled mainly by high-fibre unprocessed carbohydrates recently formed in plant materials, photosynthesised by solar energy, which combined atmospheric carbon dioxide and water to form glucose via chlorophyll. Their largely unrefined carbohydrate diet was supplemented by animal proteins and fats. The electron transport system which drives living processes was beautifully summarized by Nobel Laureate in Chemistry and founder of the science of submolecular biology, Albert Szent-Gyorgi as follows: “What drives life is a little electric current kept up by the sunshine. All the complexities of intermediary metabolism are but a lacework around this basic fact”.

The agricultural transition in the fertile crescent between the Tigris and Euphrates rivers which followed the end of the ice age some 12,000 years ago enabled humans to selectively breed and store cereal products and to harness animal power for movement and tillage of the soil. Apart from firestick farming used by some indigenous peoples, such as Australian Aborigines, there was little net addition of carbon dioxide to the atmosphere, its concentration remaining constant at around 280 ppm. This period of relative climate stability is referred to by geologists as the holocene era. The variety of low carbon transport modes, assisted by natural forces, sails, wheels and animal power during the agricultural transition is summarized below:

Varieties of Low Carbon Transport

Air gliders, kites, hydrogen and helium balloons

Water boats, rafts, punts, surfboards, swimming, currents, tides, sails

Land roads, wheels and rails

Muscle power- human walking, running, bicycles, prams, skis, skates, rickshaws

- animal camels, dogs, donkeys, elephants, goats, horses, oxen

Wood-fired steam engines

Ammonia (and NH_3 fuel cells) - manufactured from atmospheric nitrogen, water and clean renewable energy

Hydrogen (H_2 fuel cells) - manufactured by hydrolysis from clean renewable energy

Electric battery and hybrid cars - power from renewable energy

Solar cars

Compressed air from windmills

In terms of human health, reversion to the lifestyles of the carbohydrate era, including more muscular activity, consumption of more vegetables, fruit, unrefined cereals, natural oils, fish and nuts in place of refined carbohydrates (including sugars added to tinned food and beverages), and saturated fats, would reduce the burden of the preventable metabolic syndrome of obesity, Type 2 diabetes and associated cardiovascular disease which currently overwhelms so-called health care systems of the industrial era .

The century of the horse

In pre-industrial Western civilization, much farm work and travel in rural areas depended on energy derived from the carbohydrate metabolism horses. In cities, most working-class people travelled on foot up to the beginning of the 19^{th} century, horse-drawn carriages being reserved for the wealthy. As human population and wealth increased in cities during the 19^{th} century, horses became essential for the functioning of society, for personal transportation, freight haulage and mechanical power. The rate of increase in the horse population outstripped that of people, congestion, pollution and disease becoming intolerable.

London Transport late 19th century

The first international conference on urban planning was held in New York City in 1898, whose population density rose from 39,183 per square mile in 1800 to 90,366 per square mile in 1900. Human crowding was accompanied by disproportionally greater horse crowding. One topic dominated the conference discussion. It was not housing, land use, economic development, or infrastructure. The delegates were driven to desperation by horse manure **(Ref. 1 – From Horse Power to Horsepower)**. “In 1894, *The Times* of London had estimated that given “business as usual”, by 1950, every street in the city would be buried nine feet deep in horse manure. One New York prognosticator of the 1890s concluded that by 1930 horse droppings would rise to Manhattan’s third story windows….A public health and sanitation crisis of almost unimaginable proportions loomed.” Frustrated by their failure to reach any mitigating solution to the problem, the New York conference declared its work fruitless and broke up in three days instead of the scheduled ten. Unrecognised at the time was the influence on global warming from the thousands of tonnes of the powerful greenhouse gas methane from rotting horse manure and corpses.

Despite the subsequent decline in urban horse transport, horses have remained an important part of human culture, for warfare, gambling, romance and sport:

Grandparents' honeymoon in Killarney (c1895)

Grandson kitted for international equestrian games event, 2010.

From carbohydrate to hydrocarbons – the industrial transition

In 1754 the Scottish engineer James Watt invented the first effective steam engine using locally-mined coal as a fuel:

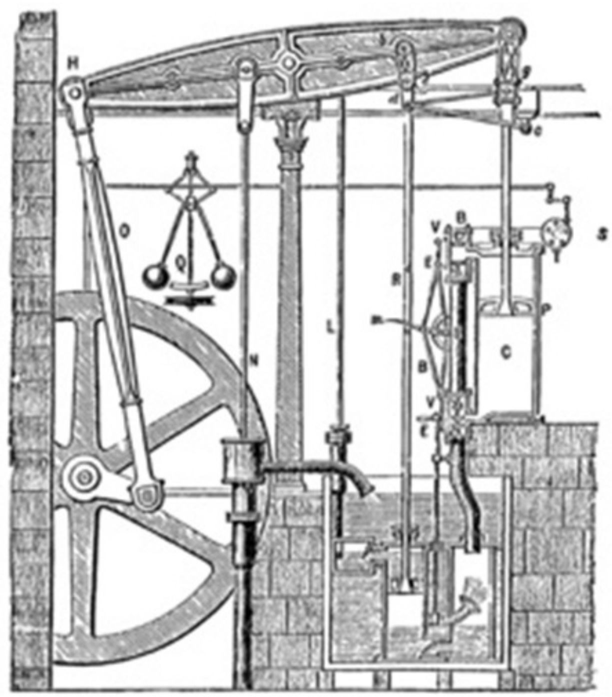
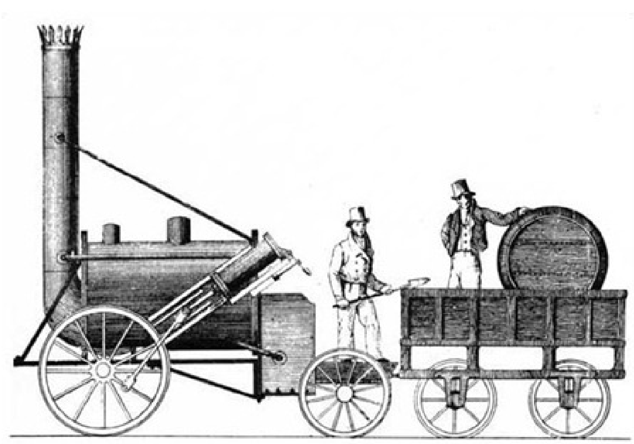


Fig 2

This launched the industrial transition. 75 years later, in 1829, Robert Stephenson invented the first effective steam locomotive, called the Rocket:



It was used to transport cotton fibre from ports to mills and people and goods across the countryside and within and between developing cities.

These dramatic changes eventually replaced horses by steam engines for transport and released workers from boring repetitive manual labour on cotton and wool spinning looms. In other words, carbohydrate metabolism in muscles of humans and horses was progressively replaced as an energy source by hydrocarbon combustion using steam-driven factory machinery and later by petroleum and diesel driven internal combustion engines. In our mania for rail speed, the ultimate has been the very fast train, predominant in France and Japan, run on a mixture of uranium and testosterone.

Fig 4

Although Britain's wealth and influence in the world were increased by the industrial revolution, social and health impacts of the transition were initially appalling. There was a mass migration of agricultural workers from the countryside to the "dark satanic mills" of northern England and Scotland, where women and children worked under conditions of virtual slavery and poor hygiene. Friedrich Engels in 1845 published his study on *The Condition of the Working Class in England* **(Ref. 2)**, in which he describes the malnutrition and high mortality rate of mothers in childbirth, of children from infectious disease, the high incidence of rickets (vitamin D deficiency), scurvy (vitamin C deficiency), tuberculosis and venereal diseases. Not often mentioned in history books, throughout the British Empire actual slavery and other injustices prevailed, including the capture and forcible transportation of West Africans to the West Indies and North America to work as slaves in cotton and sugar cane fields to feed the world's burgeoning appetite for cotton goods and sugar.

From horse pollution to local atmospheric pollution

The most obvious environmental effect of burning coal in power stations and open fires were the choking impenetrable "pea-souper" fogs which I experienced in pre-war Manchester winters. It was impossible to see more than a yard ahead, and the only viable transport was the tramcar, led by its conductor carrying a flare and followed by a line of cars, which finished up at the tram depot because side roads were invisible.

Later, as a house physician in central London I was on casualty duty during the Great London Smog of 1952, caused by cold and temperature inverson, exacerbated by the burning of additional dirty coal containing sulphur, which was combusted to acrid sulphur dioxide. Street signs could not be seen, and visibility reduced to less than a yard. The smog caused 4000 extra deaths over the weekend of 5-7 December, this total eventually increasing to over 12,000 more than expected deaths and 100,000 additional cases of respiratory illness over ensuing months, mostly amongst the very young and the elderly and those already suffering from cardio-respiratory disease. Since there was no air conditioning or safe assisted ventilation in those days, the smog penetrated hospital wards and the only effective treatment was to advise patients to travel by underground tube train to Harrow-on-the Hill, which was above the smog, or to find one of the few air conditioned cinemas in which to sit. The eventual government response was a NIMBY one by passing the Clean Air Act of 1956, which forbade the burning of coal in open fires, while transferring the problem by establishing coal-fired power stations along the East coast, whence pollution was carried by prevailing winds to Scandinavia, falling as acid rain and destroying many forests. The additional deaths from coal combustion over the three months of the Great London Smog were eventually followed by approximately 13,000 additional annual deaths nationally and over 4000 in London, attributable to emissions from the growing numbers of internal combustion engines, particularly from diesel-driven buses which by then had replaced electric trams. The Great London Smog was said to have been Britain's greatest public health disaster since the cholera epidemic of 1854 **(Ref.3)**.

As additional coal burning and vehicle emissions accompanied economic development in the mega cities of the developing world, additional deaths and respiratory diseases have occurred. At times, living conditions have become intolerable in Beijing, whose human population has increased by 66% and vehicle population by 200% between

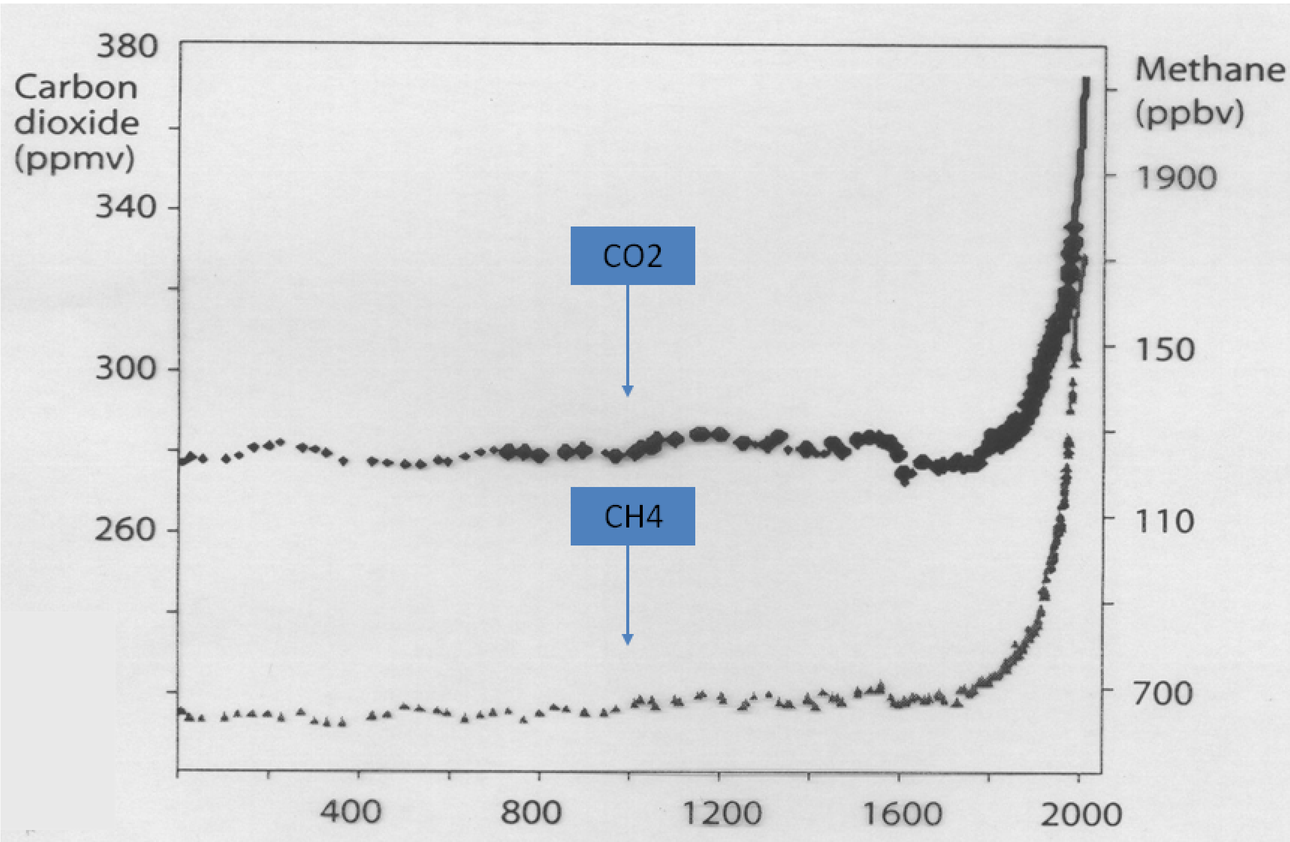
1968 and 2012, its air pollution exceeding four times the daily limit recommended by WHO. Djakarta and Mexico City are even worse affected. The chief environmental officer in Mexico City has located over 20 monitoring devices throughout this conurbation of 23 million people and issued different coloured number plates. When pollution becomes intolerable, vehicles with a particular plate colour are ordered off the road until pollution level becomes less dangerous. Despite its growing fossil fuel dependency, China is becoming aware of the wider issues of air pollution and progressing with its R&D of clean renewable energy technologies, which are becoming cost-competitive with fossil fuels.

Effects of local particulate air pollution are less widely reported in the scientific literature than are observations on global chemical pollution, although there are reputable press reports. Thus, *The Washington Post* has declared "air pollution kills more than high cholesterol". The UK *Guardian* claims "The latest figures suggest 29,000 people die prematurely every day from local pollution in Britain, twice as many as from road traffic, obesity and alcohol combined, and air pollution is now second only to smoking as a cause of death". Air pollution, especially from diesel engines, is a neglected 'hidden killer', children and old people being especially at risk, according to Dr Ian Mudway, a lecturer in respiratory toxicology with the environmental research group at Kings College, London University **(Ref 4)**. "There is strong evidence that if you live near main roads you will have smaller lungs", he says. "They will not reach capacity and will be stunted. When, or if, people move they still do not recover the function they lost. We have good evidence that every child born in Tower Hamlets will have a reduction in the volume of their lungs by the age of eight. The point is, people die of lung disease later on".

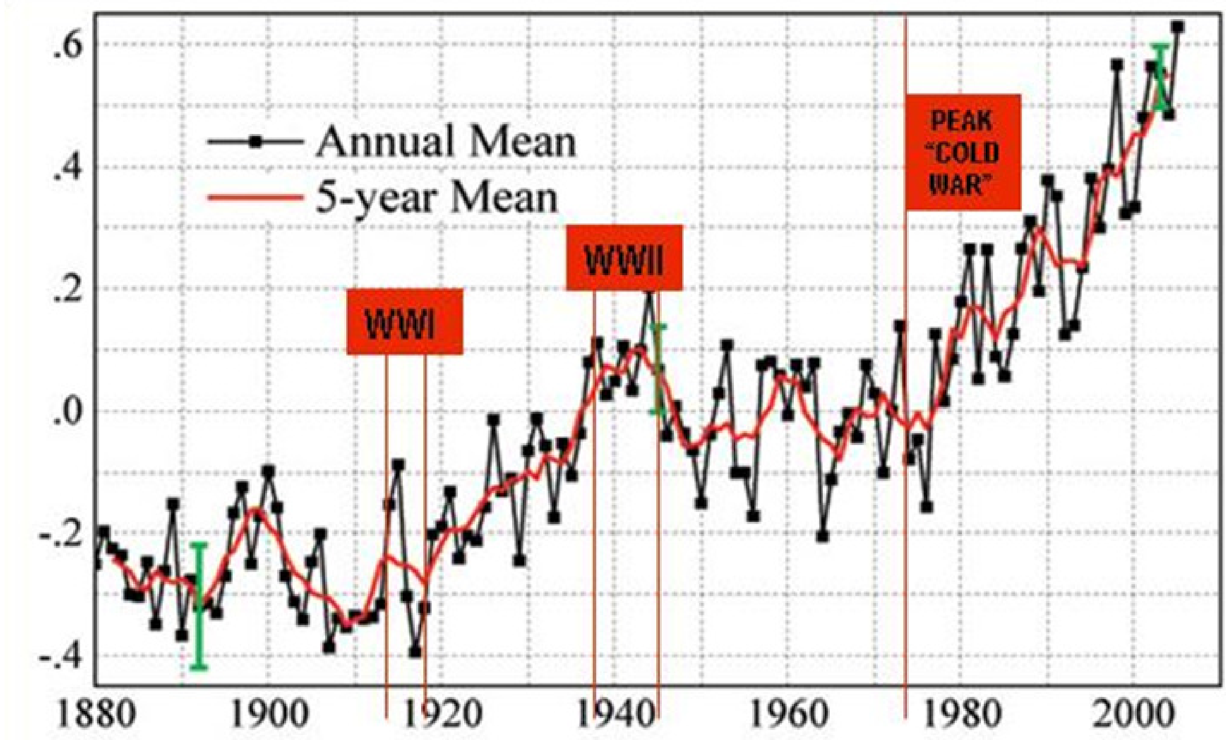
In Australia, local air pollution is a public health problem in Newcastle and the Hunter Valley, where extra deaths and morbidity in children have been reported, due to particulate spread from the constant procession of open coal trucks proceeding to the docks. An estimated 4 million coal wagons pass through Newcastle each year, set to increase by 50% if a fourth coal terminal is approved. Under the Freedom of Information Act regarding the Australian Rail Track pollution licence, The Hunter Community Environment Centre has gained access to email correspondence between the CEO of the NSW Environment Protection Agency and Rail Track, which revealed a massive level of cover-up and denial concerning coal dust pollution **(Ref 5).** Another inadequately addressed problem has been the extensive Hazelwood open-cast brown coal fire in the Latrobe Valley in Victoria, which burnt for four weeks, emitting 10-15 times the recommended maximum small particle and carbon monoxide pollution causing the evacuation of many Morwell homes. Alas, short-term profits from the transport, combustion and export of fossil fuels remain paramount in our economic arrangements, despite our abundant supplies of sunshine and expertise in renewable technologies.

The anthropocene and its discontents

The prodigious combustion of coal and natural gas, followed by diesel and petroleum which accompanied the invention of the internal combustion engine in the late 19th century, imposed severe damage to both the natural environment and human health, not only through local, but also atmospheric pollution. The global effect was first recognized as early as 1896 by the Swede Svant Arrhenius, Nobel laureate in chemistry who described "the greenhouse effect" of trapping the sun's energy in the earth's atmosphere by water vapour, carbon dioxide, methane and other chemicals, which were emitted from combustion of hydrocarbons. He predicted that global temperature would rise by 4-5 degrees by the end of the 21st century, if rate of increase in GHGs continued. Careful monitoring of atmospheric gases during the past century has shown an exponential rise in atmospheric carbon dioxide and methane proportions:



with a parallel rise in average global temperature anomalies: .



The extensive damage to the biosphere and human health from global warming, widespread destruction of forests and reduction of biodiversity led Paul Crutzon, Nobel laureate in chemistry to declare in 2000 that the present era should be re-named the anthropocene, a term which is widely accepted by climate scientists and is being currently examined by the Geological Society of London to have official status (**Ref 6)**. Impacts of the anthropocene are already becoming apparent, in terms of extreme weather events, rising sea levels, droughts and threats to food and water security. Mitigation of these events through drastic reduction in fossil fuel combustion, establishment of clean renewable energy and low carbon-emitting technologies are being urgently addressed by the majority of developed industrialized nations, with the notable exception of Australia.

Carbon-free fuels

One of the adaptations required for a sustainable energy future is to implement clean, low carbon fuels to replace hydrocarbons for transport and eventually scaled up to provide base-load electricity for remote areas. Transport accounts for a significant proportion of GHG emissions, comprising 29% of the total in USA and 19% in Australia, where the Australian Bureau of Statistics estimate that emissions were 29% higher in 2008 than in 1990 (41.6 million tonnes in total). Energy carriers alternative to fossil fuels which are currently being researched include hydrogen as gas, liquid and within fuel cells, and the denser and safer anhydrous ammonia, which contains three atoms of hydrogen to one atom of nitrogen (NH3).

Three Ways to use Ammonia as Fuel

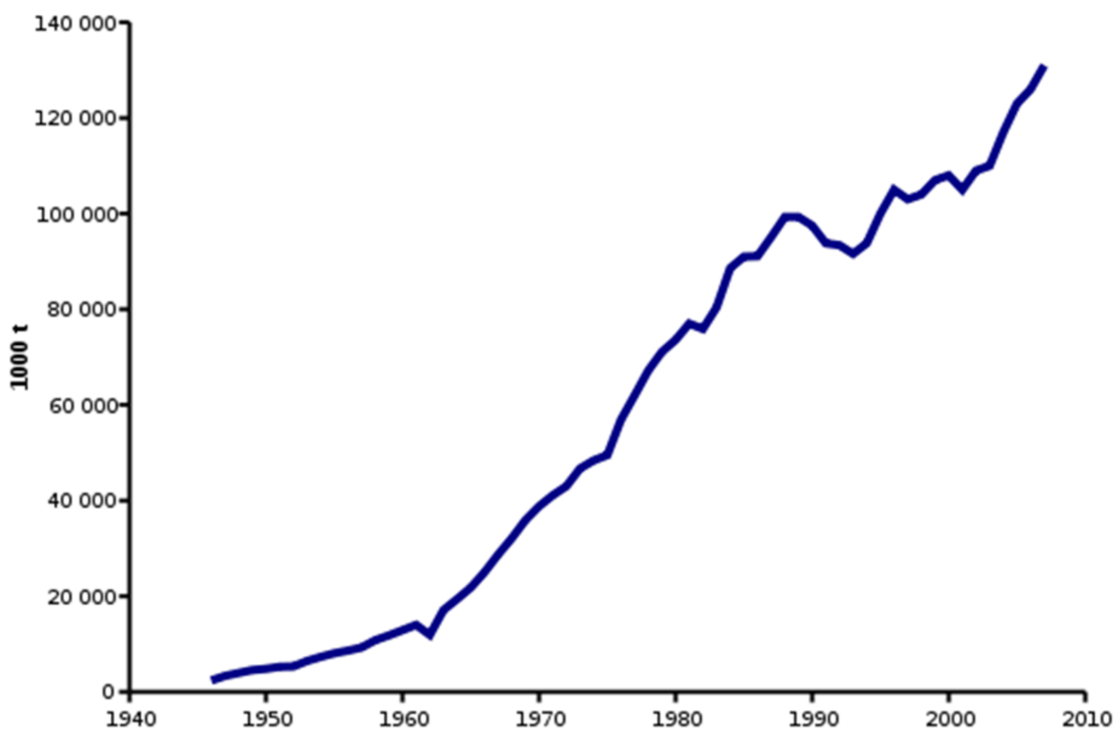
- In a spark ignited piston engine- hybrid or pure NH_3 (safely stored and transported at 150 psi).
- In an ammonia-fuelled turbine for generating base load electricity, replacing natural gas generators. Especially useful in isolated areas where NH_3 can be locally synthesised from N_2 and H_2O.
- In a NH_3 fuel cell - in development stage. Could supplant hydrogen fuel cells.

Ammonia is the only liquid fuel that:

- Is carbon-free: clean burn or conversion; no CO2, excellent hydrogen carrier, easily cracked to H2
- Has reasonably high energy density
- Has energy cycle that is inherently pollution free; potentially all RE-source: elec + water + nitrogen; cost competitive with hydrocarbon fuels
- Has had decades of global use, infrastructure; practical to handle, store and transport; end-use in ICE, turbine, fuel cell; self-odorizing; safety regs; hazard.

At a lecture to the Cambridge University Heretics Society in 1923, the distinguished evolutionary biologist and physiologist JBS Haldane foresaw the exhaustion of coal for power generation in Britain and proposed a network of hydrogen-generating windmills:"Personally I think that four hundred years hence the power question in England may be solved somewhat as follows: The country will be covered with rows of metallic windmills working electric motors, which in their turn supply current at a very high voltage to great electric mains. At suitable distances, there will be great power stations where during windy weather the surplus power will be used for the electrolysis of water into oxygen and hydrogen. These gases will be liquefied, and stored in vast vacuum jacketed reservoirs…….which will enable wind energy to be expended for decentralized industry, transportation, heating and lighting, and no smoke or ash will be produced". **(Ref 7)**.

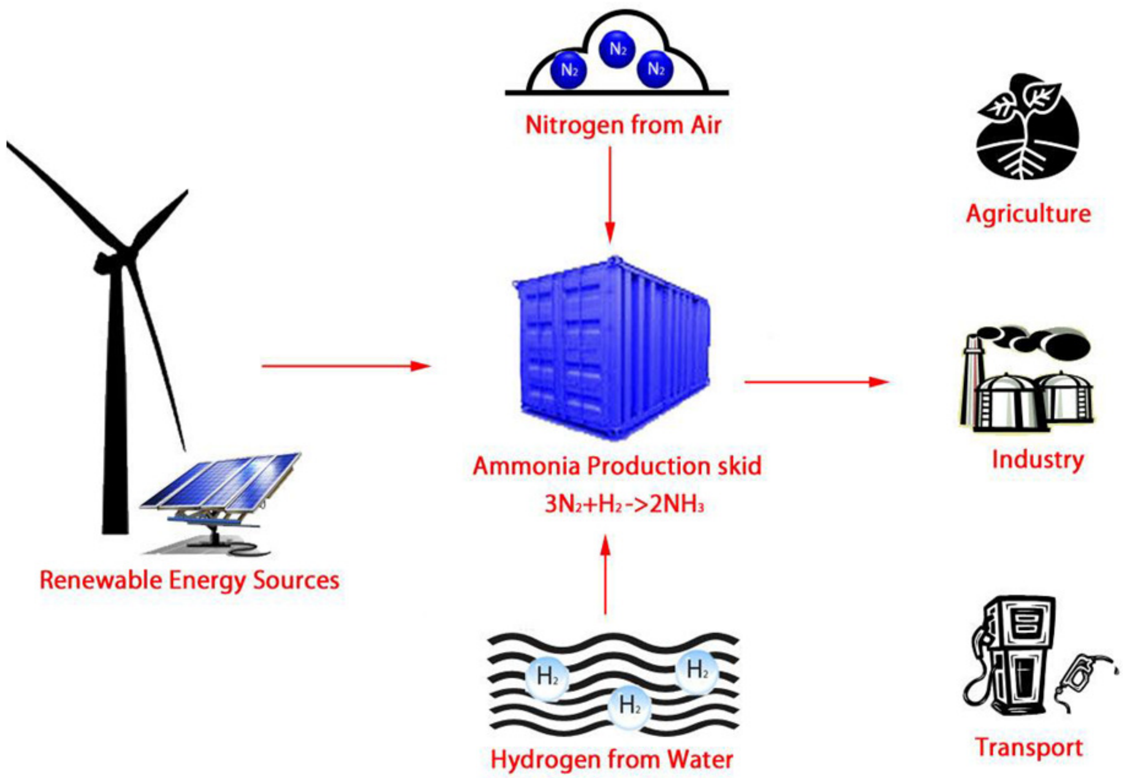
Haldane's prescience did not foresee the difficulties of hydrogen, which requires low cryogenic temperatures, and high pressure (c.10,000 psi) for storage, and has dangerous explosive potential, although its high energy to bulk ratio would not detract from its use in aeroplanes, where weight is more important than bulk. As a transport fuel, anhydrous ammonia (NH3) is a more attractive proposition than hydrogen, there being a well established infrastructure for manufacture and storage **(Ref. 8)**.



World Ammonia Production

There has been a considerable increase in anhydrous ammonia manufacture since 1945, mainly as a nitrogenous fertilizer for agriculture, but also for refrigeration plants, and potentially for scrubbing sulphur dioxide from power house emissions, the resultant ammonium sulphate being useful as a fertilizer. Anhydrous ammonia combustion is cleaner for engines than petroleum and diesel and can be stored in steel cylinders or large tanks at 150 psi at ambient temperature. It can be manufactured locally from clean renewable energy or combusted in turbines to produce electricity:

Renewable Local Ammonia Synthesis



The self-contained skids can easily be transported to remote areas or replicated in series according to local energy requirements. As industrial manufacture develops, small household units could be made to "top up" with anhydrous ammonia, in the same way that electric cars can be charged from home electricity.

The potential of ammonia as fuel is greatest in isolated situations, where there is a plentiful supply of renewable energy such as from wind power in the Alaskan islands

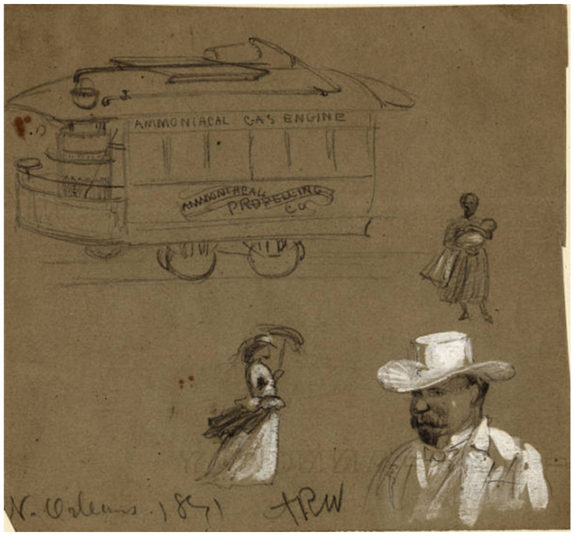
NH_3 Transport in Alaska

and potentially from solar power in isolated regions of Australia. In North America, small self-contained household units are available to synthesise ammonia from air, water and solar or wind power. Vehicle hybrid engines can be adapted to burn ammonia at no greater cost than for methane, and they produce virtually no greenhouse gas emissions except from initial ignition by petrol or diesel.

NH_3 Hybrid Engine

Some early and recent uses of ammonia (NH3) as a fuel:

"Ammoniacal gas engine" New Orleans street car, 1871



Utility carrying cylinder of ammonia fuel (1920s).

Brussels ammonia-fuelled bus, 1938

Ammonia-fuelled freight train, Canada

Ammonia hybrid tractor

World speed record (rocket engine)

From anthropocene to sustainocene?

Although many benefits have accrued to humankind from the industrial transition to the anthropocene era, there is well established scientific evidence that dangers, in terms of excessive greenhouse gas emissions and unprecedented global warming are beginning to outweigh benefits from the excessive combustion of hydrocarbons. Many climate scientists maintain that fossil fuels should be left in the ground and reserved for manufacturing purposes for future generations, and a new low-carbon sustainable industrial revolution established, based on clean renewable energy and preservation of soils and forests **(Ref 9)**.

As in the case of many proposed cultural changes, objections are raised on political, ideological or vested interest grounds. Global investment in renewable energy has become widespread, and economically competitive with fossil fuels, but further progress is hindered by great disparities in government subsidies. According to the International Energy Agency (IEA), global subsidies for fossil fuels amounted to $ 523 billion in 2011, having increased by 30% from 2010, compared to $88 billion for renewable energy. Fatih Birol, chief economist of the IEA at its annual conference in 2013 stated that global fossil fuel subsidies are public enemy no. 1 to sustainable energy development.

Summary and Conclusions

All animal movement requires energy stored in carbon compounds from photosynthesising plants. Fossilised plant remains have provided human society with a large source of additional energy for their machines, together with an exponential increase in population. On the other hand, using that energy has produced significant particulate pollution of the local environment and unprecedented gaseous pollution of the atmosphere with carbon dioxide and other greenhouse gases (GHGs), resulting in a parallel increase in global warming.

"Business as usual" by increasing GHG emissions threatens the survival, health and wellbeing of our own and countless other species. Mitigation requires preservation of environmental chlorophyll, particularly in forests and algae, while leaving fossilized carbon fuels where they are formed, below the earth's surface. Transport contributes a significant proportion of GHG emissions. An environmentally friendly way to store, transport and combust mobile energy is to use nitrogen rather than carbon to carry hydrogen, namely as anhydrous ammonia (NH3), manufactured from renewable energy sources, a technology which has proved to be feasible and cost-competitive with fossil fuels in North America. It could provide employment opportunities for skilled motor vehicle engineers in Australia who have been made redundant by closure of the fossil-fuelled car industry.

The political, social and individual adaptations required to achieve a sustainable energy future will be no less challenging than those involved in transition from the holocene to the anthropocene era, and might be called the sustainocene era (www.sustainocene.com.au)

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