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Prospects for Zero Emission Hydrocarbon Fuelled Vehicles with Sustainable Carbon Recycling

Reginald Mann and Helen Dutton
Department of Chemical Engineering and Analytical Science
The University of Manchester
PO Box 88, Manchester, M60 1QD, UK

ABSTRACT

An application of closed cycle combustion, to an internal combustion engine (ICE), is evaluated, based on the concept of a zero emission petrol vehicle (ZEPV). Closed cycle combustion requires that relatively pure O_2 mixed with recycled exhaust gases is supplied to the engine, in order to replace the air used in the conventional combustion process. This enables the excess exhaust gases, which contain mostly CO_2, to be liquefied by compression to 70 bar at or below 30 ^oC. The practicalities of installing a liquefaction system and air separation unit on-board a vehicle are assessed and the power requirements of these devices estimated. Consideration is also given to how the CO_2 produced and stored on-board can be subsequently sequestered or recycled (by hydrogenation in a reconfigured refinery). The latter, in principle, allows for perfect carbon recycling, thereby eliminating the requirement for fossil fuel use in transportation. Experimental work, to laboratory demonstrate closed cycle combustion for butane and cylinder O_2, has been performed. In addition to proving that closed cycle combustion was feasible for this arrangement, it was shown that the amounts of CO and NO_x produced by a lean-burn closed cycle engine are likely to be significantly less than those produced by a conventional ICE. The present study concludes that, while the ZEPV concept is technically feasible, it may only become economically viable in an appropriate carbon taxing framework However, zero emission vehicles fuelled by methanol and/or incorporating a fuel cell offer significant advantages over the petrol based ZEPV concept and could become economic sooner.

INTRODUCTION

Global warming due to CO_2 in the atmosphere remains an unproven threat to the quality of life of future generations. Our proper stewardship of the planet's health demands that we research potential abatement and avoidance technologies. It is apparent that over 20% of world-wide CO_2 emissions arise from transportation[1], being mostly due to the burning of fossil-fuel derived petrol (gasoline) in ICEs. Simultaneously with this global threat, it is already evident that petrol fuelled vehicles cause significant air pollution both at street level and more generally by accumulation in unsuitable geographical locations (Los Angeles being a prime example). The accumulation of unburnt hydrocarbons and carbon monoxide results in serious chemical smogs. Legislation around the world is reducing allowable emissions and California is pioneering zero emission constraints for motor vehicles. Battery driven cars have well known limitations, although they are perfectly clean on the street[2].

BMW has developed hydrogen as an alternative to petrol/diesel [3], but this solution requires the entire refuelling infrastructure to be expensively replaced. In this brief outline, we put forward the concept of the 'Zero Emission Petrol Vehicle'. This uses conventional ICEs, but, by closed cycle combustion (CCC), it is possible to store liquefied CO_2 on board. This CO_2 will be traded in at the filling station, returned to the refinery and chemically converted to petrol using water as hydrogen source. As well as being perfectly clean at street level (hence as clean as a battery vehicle) , this approach presents the possibility of sustainable transport using renewable sources of energy, with otherwise minimal changes to our transport dominated lifestyles.
In the present study, the economic viability of CCC is assessed on the basis of the ZEPV concept. The assessment of the technical feasibility incorporates the laboratory demonstration of the CCC of butane with cylinder oxygen. The implications of the results obtained in this experimental investigation, with regard to the technical feasibility of the ZEPV concept, are considered.

The Zero Emission Petrol Vehicle

The ZEPV concept utilises a petrol fuelled, closed cycle internal combustion engine (CCICE) and requires that the exhaust CO_2 be liquefied, and stored on board in the periods between refuelling. In order that the exhaust gases can be conveniently and easily liquefied, the N_2 is removed from the inlet air stream in a miniature Air Separation Unit (ASU). This means that the engine can be operated lean, as the need to reduce NO_x emissions is eliminated as a constraint for engine design optimisation. Lean burn engines have much reduced CO and HC emissions[4] and, hence, the exhaust gas stream will consist l of virtually pure CO_2, plus H_2O. A flow sheet for the proposed engine is shown in figure 1, along with possible modifications.

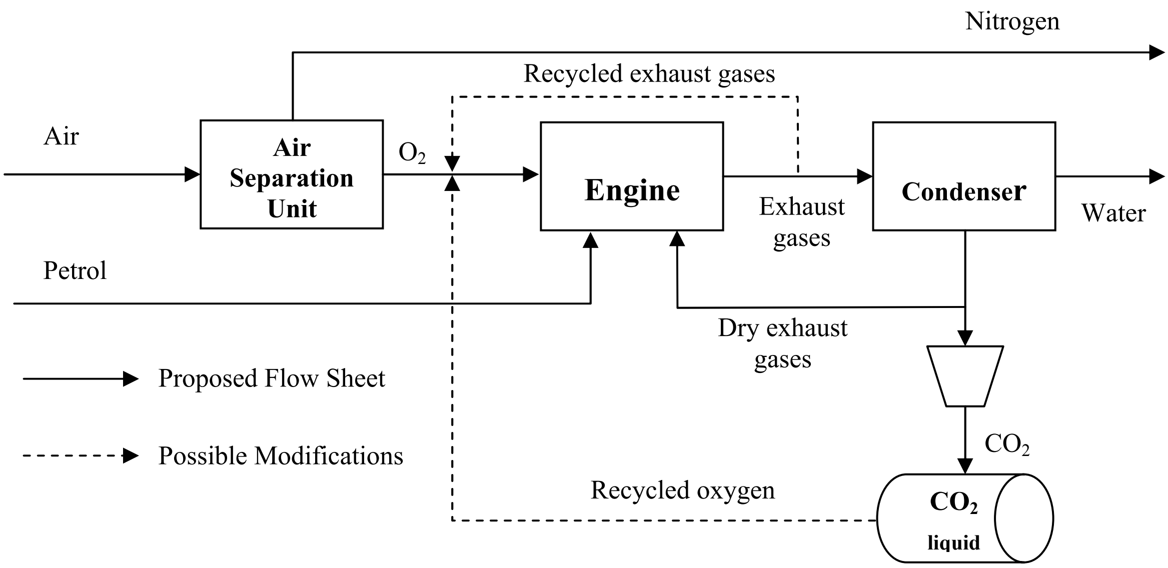


Figure 1 – Schematic of closed cycle combustion for an ICE

The use of exhaust gas recycling is required in order to regulate combustion temperature, in the absence of the heat capacity of the nitrogen found in conventional ICEs. Dale[5] proposed that the water be separated from the exhaust stream before it is recycled. While cooling of the recycled exhaust gases is likely to be required for use with conventional engine materials, there is no clear case to support the need to

separate water at this point. The use of water vapour as a diluent has been demonstrated by Quadar[4] to reduce fuel economy to a lesser extent than a CO_2 diluent.
It is proposed that the carbon dioxide be stored in liquid form and that this is achieved, at ambient temperatures, by compression of the exhaust stream purged from the recycle loop. Separation of water prior to compression is beneficial, as it reduces the potential of damage, by water droplets, to the compressor as well as lowering its power requirement. The water, assuming it contains minimal dissolved pollutants, can be vaporised and released harmlessly to atmosphere.
The non-condensables (mostly oxygen if the engine is operated lean) must be purged from the CO_2 storage tank to prevent their accumulation. A possible modification to the proposed scheme is to recycle this stream back to the inlet manifold, in order that the oxygen content can be utilised. A smaller purge stream would still be required in order to prevent the build up of other non-condensables, such as any argon and N_2 present as impurities in the feed from the air separation unit.

Carbon Recycling

The CO_2 produced by ZEPVs is to be off-loaded at specially adapted service stations during refuelling. The two strategies considered for dealing with these concentrated emissions were sequestration and recycling. Almost all CO_2 sequestration is currently used in Enhanced Oil Recovery (EOR), where the improved yield makes its use profitable[6]. Alternative methods of sequestration include storage in geological formations on land, pumping it into old oil and gas fields or ocean disposal[6,7].

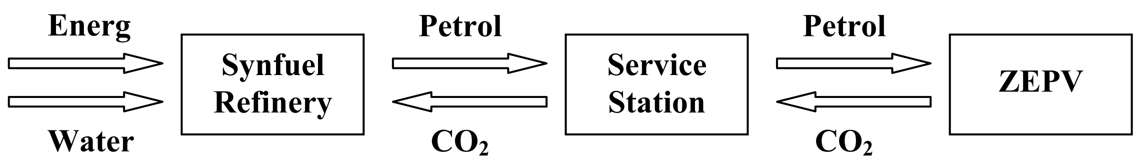
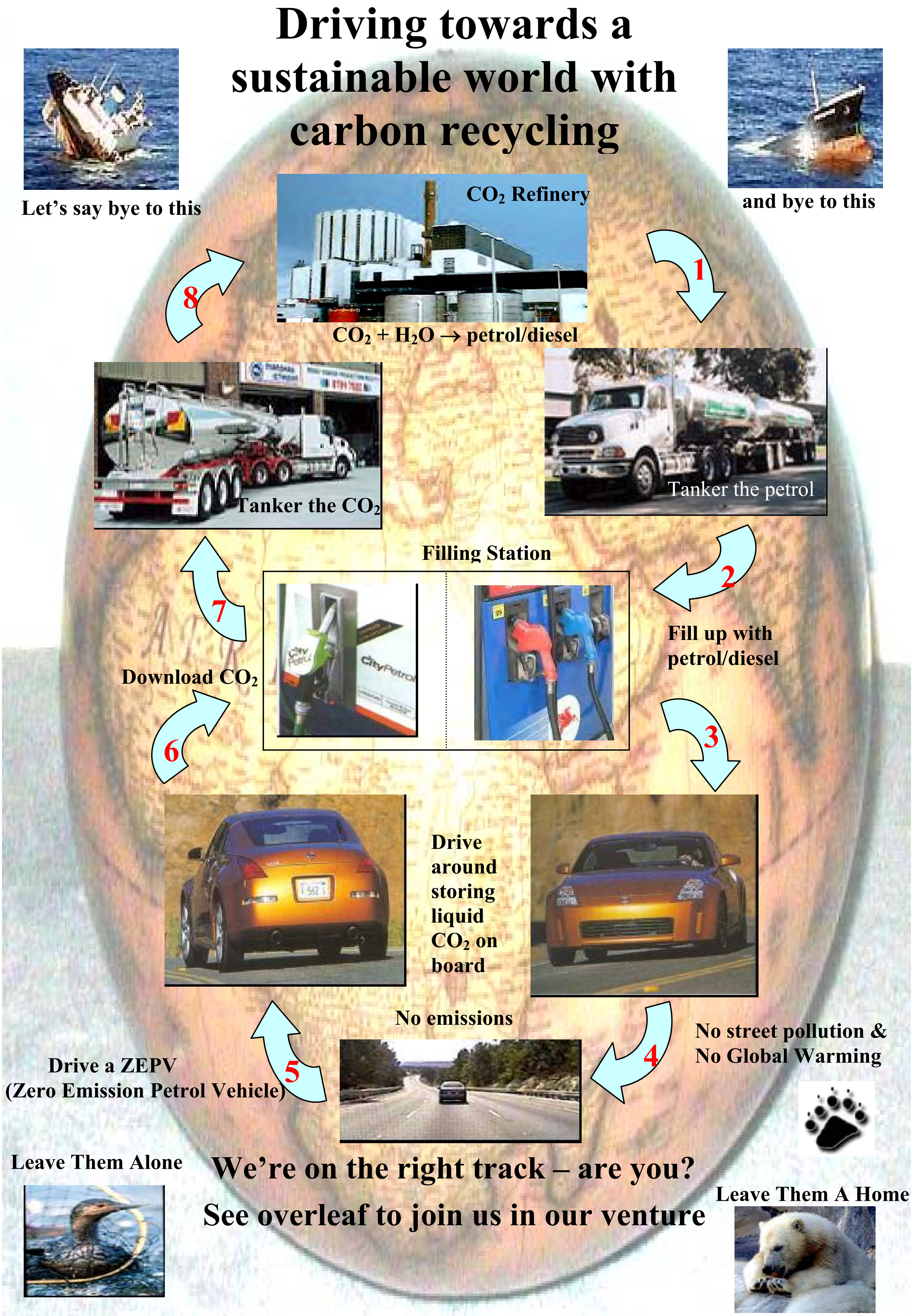


Figure 2 – Schematic of carbon recycling in the transportation sector

However for the full benefit of the ZEPV concept to be realized, carbon recycling, as depicted in figure 2, is required. The petrol for the vehicle would be a synthetic fuel produced in a refinery from recycled carbon dioxide and water. It is proposed that the carbon dioxide be tankered from service station to refinery by making modifications to the existing distribution infrastructure. The major infrastructure changes required would be on service station forecourts, where pumps would have to be modified to simultaneously dispense fuel and receive a high-pressure liquid carbon dioxide stream.
CO_2 recycling is not a new concept and was proposed on a global scale for stationary applications by Hashimoto et al[8]. A working recycling plant was constructed in 1996 using solar power as the energy input and CH_4 as the hydrocarbon energy vector. The generation of syngas and its subsequent conversion into commodity chemicals, such as methanol, is a mature industry[9]. The production of methanol from CO_2 and the subsequent conversion to petrol has been the subject of extensive investigation and has been demonstrated in several studies[10,11,12].
The attached flyer "advertises" the concept and reiterates some of the research issues.



Driving towards a sustainable world with carbon recycling
Let's say bye to this
and bye to this
CO_2 Refinery
$CO_2 + H_2O \rightarrow$ petrol/diesel
1
Tanker the petrol
2
Fill up with petrol/diesel
Filling Station
3
Drive around storing liquid CO_2 on board
4
No street pollution & No Global Warming
No emissions
5
Drive a ZEPV (Zero Emission Petrol Vehicle)
6
Download CO_2
7
Tanker the CO_2
8
Leave Them Alone
Leave Them A Home
We're on the right track – are you?
See overleaf to join us in our venture

Confidential

A zero-emission IC-engine with CO_2 recovery and recycling to gasoline

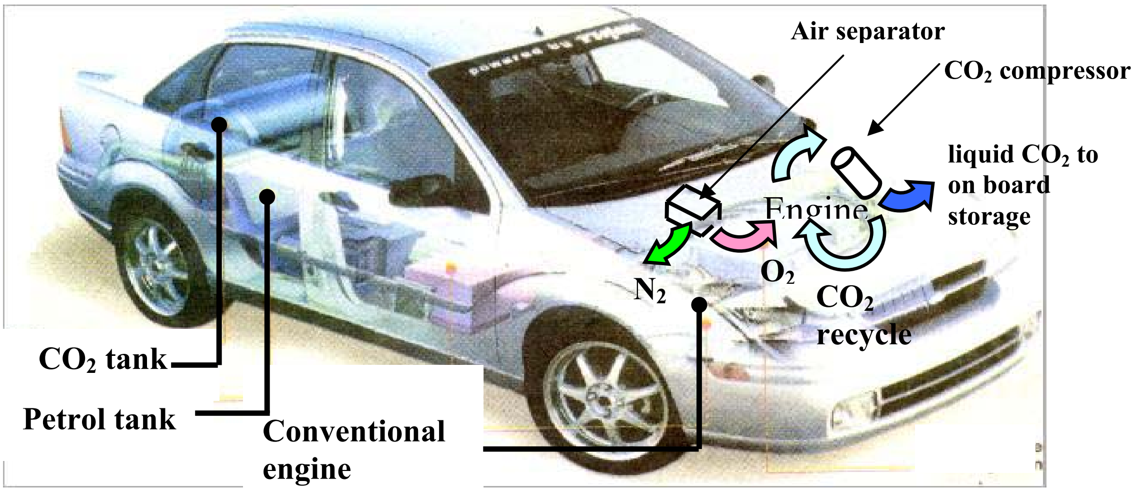
This invention relates to adaptations to a conventional petrol-fuelled vehicle such that:-

- Petrol is ignited and burned with oxygen instead of air
- The oxygen is fed in conjunction with recycling CO_2 to control engine temperature
- CO_2 is cooled/compressed from the recycle and condensed to form a liquid at 70 bar
- The liquid CO_2 is stored on board in a pressurised container
- Oxygen is supplied on demand from air by a miniature on-board cryogenic separator

The benefits are no emissions whatsoever at street level, so that the vehicle is as clean as a battery driven one

Subsequently, the on-board CO_2 can be returned to the petrol station and discharged for local storage concurrently with refuelling with petrol. The locally stored CO_2 is returned by tanker to the refinery. It serves as a carbon source for converting back into petrol using appropriate catalytic reactor technology such as methanol to gasoline or other suitable process. The whole cycle is driven by renewable energy sources (wind, waves, etc).

Further benefit is that this complete carbon recycling gives a sustainable transport fuel system, with no further requirement for exploration, production and refining of crude oil



UMIST has filed a patent to protect the overall concept. Within this patent, technical solutions are required to demonstrate a ZEPV (zero emissions petrol vehicle). We propose to set up a research consortium to undertake a closely integrated programme to deliver the following technologies adapted for the ZEPV.

- Miniature electrothermal cryogenic on-board air separator
- CO_2 compressor/liquefier
- Compact micro-exchanger with heat integrated separation/liquefaction
- Catalyst technology using water as hydrogen source to recycle CO_2 to gasoline

If you possess expertise in any of these technologies we invite you to apply to join the ZEPV consortium

Each component in the overall concept will offer potentially enormous licensing revenues in future. We intend to seek to gear-up commercial investments by accessing public sector research funding in the initial stages.