COMBUSTION IN THE 21\textsuperscript{ST} CENTURY?

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ABSTRACT

This paper examines the prospects for combustion in the 21\textsuperscript{st} century, especially in the industrial countries. We examine in turn the various approaches for reducing oil and gas use, and cutting greenhouse gas emissions. We find that combusted fuels will still dominate in 2020. Beyond 2020, we argue that combustion will probably decrease in importance, because of improved energy efficiency and growth in both passive solar energy and renewable electricity. Further, any remaining fossil fuels used may well be converted to hydrogen, and used in fuel cells. Combustion may only survive in specialised applications such as air travel.

KEYWORDS: alternative energy sources, clean coal, combustion futures, energy efficiency.

INTRODUCTION

Until the 20\textsuperscript{th} century, the history of inanimate energy was the history of combustion. Fig. 1 shows the market share of the various fuels since the year 1800. Today, non-combusted energy accounts for only 9.4\% of global fuel inputs, up from 2.8\% in 1973 [1]. For Australia the figure is only 1.5\%. What is the future for combustion in the 21\textsuperscript{st} century? The shape of the curves suggests that natural gas could be the next major combusted fuel, following wood, coal, and oil. But how long can global natural gas reserves maintain gas in this position, and what fuel takes over from gas?

The International Energy Agency (IEA) [1, 2] has recently analysed world energy prospects out to 2020. They project energy demand to increase by 65\% compared with 1995, and CO\textsubscript{2} emissions by 70\%, in their ‘business-as-usual’ scenario. Fossil fuels—oil, gas and coal—are expected to provide 95\% of this additional energy. Increasingly after 2010, non-conventional oil (tar sands, shale oil, heavy oil) will be required to satisfy oil demand if present consumption trends continue [2]. Later, probably after 2030, non-conventional sources of gas will also be needed, but even before that date, gas from remote fields will increasingly either have to be liquified or converted to methanol for shipment to markets [4]. As the world increasingly turns to non-conventional oil and gas, or gas remote from markets, the cost—in both money and energy terms—to produce a given amount of oil or gas for final use will rise. For example, 30–40\% of primary energy is lost in converting natural gas to methanol [4]. The environmental advantages of these convenient fuels over coal will therefore steadily disappear.
The Organisation for Economic Cooperation and Development (OECD) countries agreed in Kyoto in 1997 to reduce their CO$_2$ emissions by an average of about 7% (based on 1990 values) by 2010. This first step in mitigating global warming will require OECD countries to cut emissions by an average of about 28% below those in the IEA ‘business-as-usual’ scenario [2]. As most energy is derived from CO$_2$-producing combustion processes, such a reduction in CO$_2$ will probably also require significant reductions in combustion-related activities.

The central aim of this paper is to examine the prospects for combustion in the 21st century, especially in the OECD. The next century is divided into two time periods: from now to 2020, a period that will be strongly affected by energy infrastructure decisions made today, and the rest of the century, when projections are necessarily far more speculative. This paper examines in turn the various approaches for reducing oil and gas use, the fossil fuels in shortest supply, and cutting greenhouse gas (GHG) emissions. We find that combusted fuels will still dominate in 2020, even if the amounts burnt are less than in the IEA ‘business-as-usual’ scenario. Beyond 2020, we argue that combustion will probably become increasingly less common, because of improved energy efficiency and growth in both passive solar energy and renewable electricity. Further, any remaining fossil fuels used may well be converted to hydrogen, and used in fuel cells. Combustion may only survive in specialised applications such as air travel.

**ENERGY EFFICIENCY AND CONSERVATION**

Energy efficiency improvements and conservation have the potential to cut not only oil and gas use, but also global (and local) air pollution. Here, energy efficiency improvement refers
to an increase in the efficiency of some device, for example an electric light. Conservation refers to reductions in energy use that occur independently of efficiency gains, for example, by simply switching off an unneeded light. For brevity, the term energy efficiency will here cover both.

Energy efficiency is the most cost-effective way of cutting GHG emissions and oil/gas use. A number of studies in Australia and overseas [5-7] have shown that some 20% or even more of present CO$_2$ emissions (and energy use) could be eliminated at zero or even negative cost by implementing presently available efficient technologies in domestic appliances or vehicles, for example. Further large savings are possible at low cost per tonne of CO$_2$ equivalent avoided. Indeed, Amory Lovins [5] claims that fuel consumption for standard-size cars can be cut by 80%, with an eventual cost no higher than an equivalent conventional car. In the OECD, transport overall accounts for about 33% of final energy use, most of it for road transport [1].

The continuing drive for efficiency will impact on combustion. Existing fossil-fuel power stations differ greatly in their efficiency, with coal-fired units being usually much less efficient than gas-fired ones. Further, the much lower carbon to hydrogen ratio of NG means that the CO$_2$ output for a given energy input will also be less in gas-fired plants. Thus, big improvements in electrical end-use efficiency translate also into improvements in power station efficiency and CO$_2$ releases, because less-efficient units can be either closed down or used less often. If necessary, coal-fired units could be re-powered with NG turbines [7]. For transport, combustion itself may become obsolete. It is increasingly recognised [5, 7] that big improvements in vehicle efficiency require some form of electric drive. If, as is likely, these vehicles also eventually use efficient fuel cells, on-board combustion will not occur at all.

Energy efficiency improvements will not happen automatically, even if presently cost-effective. The example of US car fuel economy trends shows that technological advance alone will not reduce energy use: government policies for increased efficiency and/or fuel cost rises are also required [5-7]. US car fuel economy improved while both high oil prices and progressive fuel economy standards were in place. But since the demise of both, fleet fuel economy has not noticeably improved, because potential efficiency gains have been converted instead into higher performance. Overall, big reductions in fossil fuel use will not occur unless OECD governments impose significant carbon taxes, or international oil and gas prices rise.

**ALTERNATIVE ENERGY SOURCES**

Alternative energy (here defined as all non-fossil energy sources), like energy efficiency, can potentially help solve all the problems facing fossil fuel use, especially in the period after 2020. The most cost-effective alternative is solar energy. Passive solar can be used for water heating, space heating and cooling, and even lighting, and so can replace much of the fossil fuel energy presently used in buildings or for low-temperature process heat in industry [5, 6]. For transport, biomass-derived alcohols are often proposed as future fuels. The OECD countries may today have surplus agricultural land for biomass production, but the growth in world population, combined with such global problems as fresh water scarcity, soil erosion and loss of fertile land to non-agricultural uses, suggest that all such OECD land will be
needed for food, fibre and forestry products in the coming decades. Nevertheless, some biomass will be available on a sustainable basis from farm and forestry wastes. Alternative energy’s share of electricity in 1995 was 40% in the OECD, mainly hydro and nuclear [8]. In the 21st century, fossil fuel electricity may only be needed if the combination of alternative energy electricity and electrical energy efficiency is insufficient. Until 2020, fossil fuel power stations are unlikely to have either their share or absolute output reduced much. Beyond that date, if energy efficiency achieves deep cuts in OECD energy use, fossil fuel inputs would progressively decline in both absolute and relative terms, as fossil fuel units, especially coal-fired, are closed down. Any new electric capacity required will likely be from wind or photovoltaic (PV) systems, which will become increasingly cost-effective as their costs continue to fall [7], global oil and gas costs rise, and carbon taxes are imposed. In Denmark, for example, wind electricity is already competitive with coal-fired electricity [9]. Even later in the century, electricity surplus to grid requirements from these intermittent sources could be converted to hydrogen [10], for use in fuel cells.

CLEAN COAL TECHNOLOGY

Natural gas is presently the most cost-effective fossil fuel for GHG reductions, but its advantage over coal will steadily disappear in the 21st century, as its cost, in both money and CO₂ terms, rises. In the post-2020 period, clean coal technology will offer a way for coal to take over the residual role that fossil fuels must fill [11]. Coal gasification can produce hydrogen not only for electricity generation, but also for vehicles. In both cases the hydrogen can either be combusted, or used in a fuel cell without combustion. Gasification can also produce hydrogen or low energy content gas for reticulation. If combined with CO₂ storage, it could be a competitor for alternative energy.

The CO₂ from coal gasification is already in a concentrated form for separation. It could be stored in disused oil or gas fields, in remote aquifers, in the ocean depths, or even incorporated into minerals. Presently there is much uncertainty about the cost per tonne of CO₂ for separation and disposal, the safe capacity of the storage sites, and the length of time for which the CO₂ would remain sequestered [12]. These uncertainties suggest that coal gasification will be unable to compete with, for example, wind power, which is already competitive with fossil-fuel electricity in some locations [7, 9]. However, more modest programs of coal gasification may be appropriate even if the CO₂ is not sequestered. Such programs could be justified if a combination of energy efficiency and alternative energy reduced GHGs to tolerable levels.

DISCUSSION AND CONCLUSIONS

Changes away from present use of fossil fuels will be needed both to reduce GHG emissions, and to decrease reliance on oil and gas, which are likely to become increasingly expensive in the coming decades, in both money and energy cost terms. The most cost-effective way of making the necessary adjustments is to implement both energy efficiency and conservation measures. For many devices, the useful output is only a small fraction of total energy input, giving large scope for efficiency improvements [5]. The impact of conservation is particularly difficult to predict, since although the potential is large and reductions can be made quickly,
by merely reducing the intensity of use of existing equipment, major social changes are required. Both the timeliness and depth of cuts in energy use will depend on the scope of policy changes, including carbon taxes, and the magnitude of oil and gas price rises. Deep cuts could eliminate the need for new electric plants of any type for some decades.

Alternative energy provision can also be used to cut GHGs and reduce dependence on oil and gas. Passive solar energy is a cost-effective way of reducing fossil fuel use for low-temperature heat, for example. Later in the 21st century, electricity from wind and PV cells should be cheaper than fossil fuel electricity, because of further technical advances, cost increases for NG, and carbon taxes. As oil and NG are progressively depleted, a combination of efficiency improvements and alternative energy could steadily erode the market share of fossil fuels—and thus combustion.

By the second half of the 21st century, coal will not only be much cheaper than the remaining oil and gas, but will probably also have similar GHG emissions per unit of delivered energy. Coal gasification could be used to provide gaseous fuels for both transport, electricity generation, and general heating. Sequestration of CO$_2$ would be an option with coal gasification, in principle making coal a ‘clean fuel’ like wind or PV power. Whether clean coal can prevail over alternative energy depends not only on the relative costs, but also on whether CO$_2$ sequestration is feasible. But even with coal gasification, the drive for efficiency may require that fuel cells are used, rather than direct combustion.

REFERENCES