

Small-scale reforming of diesel and jet fuels to make hydrogen and syngas for fuel cells: A review



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HIGHLIGHTS

- Issues of reforming of heavy hydrocarbon fuels are reviewed.
- The advantages of autothermal reforming over other types of reforming are discussed.
- The causes and solutions of the major problems for reforming reactors are studied.
- Designs and startup strategies for autothermal reforming reactors are proposed.

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ABSTRACT

This paper reviews the technological features and challenges of autothermal reforming (ATR) of heavy hydrocarbon fuels for producing hydrogen and syngas onboard to supply fuels to fuel cells for auxiliary power units. A brief introduction at the beginning enumerates the advantages of using heavy hydrocarbon fuels onboard to provide hydrogen or syngas for fuel cells such as solid oxide fuel cells (SOFCs). A detailed review of the reforming and processing technologies of diesel and jet fuels is then presented. The advantages of ATR over steam reforming (SR) and partial oxidation reforming (POX) are summarized, and the ATR reaction is analyzed from a thermodynamic point of view. The causes and possible solutions to the major problems existing in ATR reactors, including hot spots, formation of coke, and inhomogeneous mixing of fuel, steam, and air, are reviewed and studied. Designs of ATR reactors are discussed, and three different reactors, one with a fixed bed, one with monoliths, and one with microchannels are investigated. Novel ideas for design and startup strategies for ATR reactors are proposed at the end of the review.

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1. Introduction

Energy is one of the most fundamental necessities of our society. In recent years, the potential risk of depletion of fossil fuels has been looming over us. In 1949, Hubbert first predicted the tendency of fossil fuel depletion [1], and many researchers followed his methodology and have modified and improved upon the prediction. Fig. 1 shows a prediction of world oil production versus years for different estimated ultimate oil recovery values (EUR) [2]. For three different values of the EUR, the predicted year to reach peak production is 2004, 2019, and 2030, respectively. The figure shows that with higher EUR, which is the maximum reserve, the time that a peak oil production followed by a decrease will come later. The curve on top in the figure is for the case assuming that not only the EUR is 4000 billion barrels, but also the world demand reaching to 30 billion barrels/year at the peak year of 2030. In the last 10 years, the world production of oil has continued to increase, to the level of 26 billion barrels/year. However, the identified reserve is almost flat. Unquestionably, in future decades, oil will still be the major source of the world's energy supply, as shown in Fig. 2 [3]. However, it is also clear to us that increasing

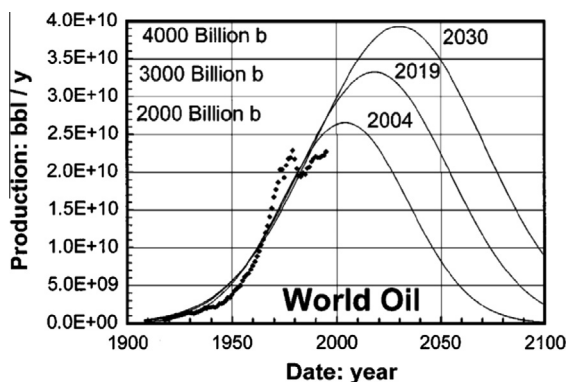


Fig. 1. Prediction of world oil production [2] (1 bbl = 158.9873 l).

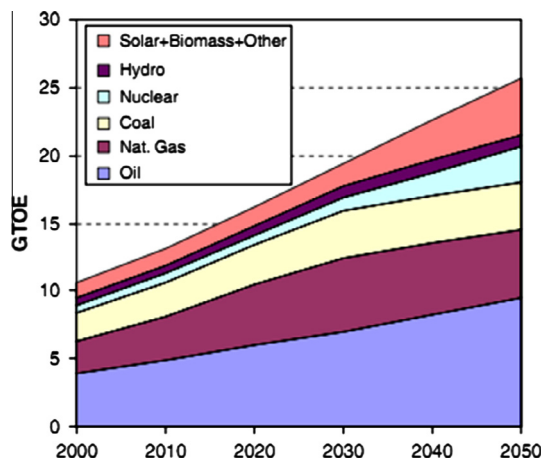


Fig. 2. World energy production survey [3]. (GTOE = gigatons of oil equivalent).

oil production in the future will become more and more unsustainable. The usage of fossil fuel is also widely believed to be responsible for global warming. The United Nations (UN) has proposed to limit greenhouse gas emissions, which makes research on clean energy technology more important for the sustainability of the environment and human society.

Power generation by fuel cells, using hydrogen and syngas from reformed hydrocarbon fuels, is one of the important approaches among clean energy and alternative energy technologies because of the following three advantages: it will (a) supply more clean fuels, (b) increase energy utilization efficiency, and (c) decrease pollutants and greenhouse gas emissions [4].

When it comes to sustainable energy technologies, the transportation sector is usually faced with many challenges [5]. In the US, 28.6% of the total primary energy was consumed by transportation in 2007 [6]. Over 70% of the fuel energy is wasted as conversion loss due to the thermodynamic limitations of heat engines. To have a better solution, hydrogen fuel cell vehicles were proposed two decades ago as promising to reduce the dependence on oil combustion and to lower the harmful emissions. Fuel cell stacks can potentially supply required auxiliary electrical power [7] in transportation vehicles, ships, and aircraft. However, one big problem is that there is no existing infrastructure for hydrogen production and storage, particularly for transportation vehicles [8]. In recent years, onboard fuel processing systems have been proposed to convert fossil fuels into hydrogen or syngas for fuel cells. Since traditional gas/oil is used as the fuel supply in such a system, no hydrogen storage unit is required, and therefore, high-pressure gas or the cryogenic system involved in hydrogen storage [9] is avoided. Besides traditional transportation fuels, synthetic and bio-fuels (such as, biodiesel and bio jet fuel) can also be processed in the same reforming system to produce hydrogen or syngas for fuel cells. Moreover, liquid hydrocarbon fuels contain more chemical energy per unit volume than hydrogen, and thus, it is better to carry hydrocarbon fuels than hydrogen. As a trend, onboard fuel processing systems combined with fuel cell stacks have emerged as a very promising selection for transportation tools.

Among different types of fuel cells, a solid oxide fuel cell (SOFC) has two distinguished characteristics that make it a good candidate for power generation onboard of transportation tools: (a) the operating temperature of most SOFC systems is between 650 and 1100 °C [10], which allows high-temperature reformates after the fuel processor to be fed to the fuel cells without cooling, (b) the high operating temperature also solves the CO poisoning issue, and CO can even be used as fuel [11].

As a matter of fact, many big automobile companies developed onsite fuel reforming systems based on methanol or other light hydrocarbon fuels in prototype vehicles in the late 1990s. In the US, the R&D of on-board fuel processing technology for fuel cells as major power source on transportation tools was terminated by the DOE On-Board Fuel Processing Go/No-Go Decision Team on 2004. Key contributors to the No-Go decision include: low probability of reaching start-up time and start-up energy targets, no clear path to reach all the ultimate targets simultaneously, competition of gasoline/battery hybrids technology and low market interest. This decision only affects the on-board fuel processing for fuel cells providing the vehicle 100% traction power. Since then, the investigation activities focus on fuel processing for stationary

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