Applied Thermal Engineering 53 (2013) 299–304

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

# A syngas network for reducing industrial carbon footprint and energy use

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ARTICLE INFO

*Article history:*
Received 6 December 2011
Accepted 14 February 2012
Available online 20 February 2012

*Keywords:*
Syngas
Synthesis gas
Pipelines
Networks
Carbon footprint

ABSTRACT

This paper makes a case for building syngas networks as a means of contributing to the reduction of industrial carbon footprints. After exploring historic and conventional approaches to producing syngas (or synthesis gas) from fossil fuels on increasingly large scales, the paper looks at ways of producing it from renewable sources and from surplus resource (or waste) from industrial, domestic, urban and agricultural systems. The many ways of converting syngas into power, industrial heat, fuels, chemical feedstocks and chemical products are then outlined along with the associated syngas purification requirements. Some of the processes involved provide an opportunity for cost-effective capture and storage of $CO_2$. Pathways through this range of possibilities that enable a net reduction in energy footprint or in $CO_2$ emissions are identified and exemplified. Recognising that those opportunities are likely to involve industrial facilities that are distributed spatially within a geographic area, the case for building an interconnecting syngas network is explored. Issues surrounding sizing the network, timing its growth, determining ownership and access arrangements, and planning/regulatory hurdles are found to be similar to the analogous case of building an industrial $CO_2$ network, with the added complication that the term “syngas” tends to be used to cover a fairly wide range of gas compositions.

## 1. Introduction

Industry accounts for 40% of global energy-related $CO_2$ emissions. In 2007 the global figure for $CO_2$ emissions from industry was 7.6 Gte of direct $CO_2$ emissions to which could be added 3.9 Gte of indirect $CO_2$ emissions from power stations supplying electricity to industry [1]. Governments around the world are setting targets and taking action to reduce $CO_2$ emissions in general. In the UK, for example, the Climate Change Act 2008 sets a target for 2050 that UK greenhouse gas emissions must be 80% below the 1990 level, with intermediate 5-yearly binding carbon budgets being set along the way [2]. Energy supplies of around 1200 PJ per year for manufacturing industry are still dominated by fossil fuels [3, page 18].

There is also a cost issue as energy prices continue on their inexorable upward trend. Natural gas prices in particular are expected to rise very sharply as China’s demand continues to grow and countries like Japan and Germany revise their policy on nuclear power. The importance of finding ways of reducing $CO_2$ emissions from energy-intensive manufacturing plants is underlined in a recent report by the social policy think tank *Civitas* where they suggest that UK government green taxes in their present form will spell the end for Britain’s chemical industry [4].

The chemical and petrochemical industries use natural gas not only as an energy source or fuel but also as a chemical feedstock. As supplies come under pressure, the question is starting to be asked in various regions around the world: is natural gas too good to burn? Those same industries produce waste gases which are sometimes used as alternative fuels where the calorific value is sufficiently high.

Gas mixtures that contain varying amounts of carbon monoxide (CO) and hydrogen are usually referred to as syngas or synthesis gas. The term derives from its use as a chemical intermediate for the production of ammonia, methanol and many other chemicals and derivatives. There is increasing interest in its use as an intermediate in producing synthetic petroleum oils for use as fuels and lubricants. Since it is combustible it is often also used as a fuel source. Because of its flexible use as a chemical feedstock or as a fuel source within many production processes, there is sometimes a financial case for moving syngas between chemical production plants in pipelines, leading to mini-networks. With some sources of syngas there is often a significant methane component within the gas mixture. Depending on the proposed end use for the syngas, this may be an unwanted contaminant or a useful addition.

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doi:10.1016/j.applthermaleng.2012.02.032

This paper examines the case for building syngas networks as a means of contributing to the reduction of industrial carbon footprints. The structure of the paper is as follows. The paper looks first at traditional ways of producing syngas from fossil fuels across a range of industries, including chemicals and petrochemicals, power generation and steel-making. It then turns to ways of producing syngas from renewable sources, with particular emphasis on routes that can produce the large volumes that are typically required in energy-intensive industries. The gas mixtures produced can have a wide range of compositions depending on production route. The paper then goes on to look at the wide range of uses to which syngas has been put in the past and also explores some newer uses which are currently attracting interest, drawing attention to the varying requirements on syngas purity. The ideal ratio of hydrogen to CO (and to any other components that may be present) depends very much on the intended end use for the syngas. A range of processes for purifying syngas to make it suitable for various end uses is then explored.

Having mapped out a range of syngas sources and an array of purifying steps and upgrading technologies that enable its use in many different processes, the paper considers the practical implications of building a comprehensive, versatile syngas network. From the many possibilities identified, the paper then goes on to examine the net effect on $CO_2$ emissions and energy consumption, determining the conditions under which a significant net reduction is achieved.

## 2. Syngas sources

### 2.1. Syngas from fossil fuels

The history of producing syngas from coal goes back a long way [5]. The conversion of coal into coke plus a “coal gas” by-product dates back to 1665 in England. The conversion of coke into hydrogen and CO goes back to the late eighteenth century. Coal gas was first used for lighting purposes in Philadelphia in 1796. By the 1850s, “town gas” (produced from the gasification of coal) was widely used in London for lighting. Over time, the use of industrial gas extended from direct use in lighting and cooking to heating, and then as a chemical feedstock for producing ammonia, methanol and their many derivatives including various fertilisers.

The development of fully continuous gasification processes like the Lurgi moving-bed pressurised gasification process in 1931 and the Koppers-Totzek entrained-flow process in the 1940s had to await improvements in gas-tight equipment to enable operation above atmospheric pressure and also the commercialisation of cryogenic air separation technology in the 1920s [6]. When other countries started to switch to oil and natural gas as the basis of their petrochemicals industry, in South Africa Sasol continued to develop their coal gasification and alkane synthesis technology, with the result that they now have the largest gasification centre in the world [7]. Meanwhile, oil crises in 1973 and in 1980 rekindled interest in coal gasification on a wider basis. Parallel technology paths have opened up for gasification of solids and for gasification of liquids. Complex refineries now generally have a gasification unit for upgrading heavy residual oil fractions into a more valuable syngas stream.

The exothermic reactions which generate the heat for the main gasification reactions are:

$$C + O_2 \rightarrow CO_2 \qquad \Delta H = -393.8 \text{ kJ/mol} \tag{1}$$

$$C + ½O_2 \rightarrow CO \qquad \Delta H = -123.1 \text{ kJ/mol} \tag{2}$$

The gasification reactions are:

$$C + H_2O \leftrightarrow CO + H_2 \qquad \Delta H = 118.5 \text{ kJ/mol} \tag{3}$$

$$C + CO_2 \leftrightarrow 2CO \qquad \Delta H = 159.9 \text{ kJ/mol} \tag{4}$$

In these reversible, endothermic reactions (3) and (4), higher temperatures favour the production of hydrogen and carbon monoxide. Lower pressures also favour the production of carbon monoxide while higher pressures favour the production of carbon dioxide, providing some control over syngas composition. The other main reaction is the exothermic water gas shift reaction in which CO reacts with steam to form $CO_2$ and additional hydrogen:

$$CO + H_2O \leftrightarrow H_2 + CO_2 \qquad \Delta H = -41 \text{ kJ/mol} \tag{5}$$

There is also an important methanation reaction:

$$C + 2\ H_2 \leftrightarrow CH_4 \qquad \Delta H = -87.5 \text{ kJ/mol} \tag{6}$$

The relative proportions of gases at the gasifier exit depend on process conditions and the composition of the feedstock.

There is a vast, largely untapped source of additional syngas in the form of the world’s 18 trillion tonnes of unmineable coal resource [8]. The basic idea is that by using directional drilling technology to drill a small pilot hole through deep or narrow coal seams, oxygen and steam can be injected in order to gasify the coal *in situ*, with the syngas being brought to the surface via a production borehole. Work on this development path has migrated over the last hundred years from North East England to Russia, to China, to the USA, then South Africa and now Australia as the economics of alternatives have changed. The range of gas compositions produced is quite wide depending on gasification depth and coal rank: 11–35% hydrogen; 2–16% CO; 1–8% methane; 12–28% $CO_2$ [9]. The deeper seams being considered in North East England now lead to relatively high methane yields, which can be helpful or unhelpful depending on the proposed end use.

Another source of hydrogen-rich gas is the coke oven on a steel works. Table 1 captures the composition of a typical coke oven gas, consisting predominantly of hydrogen and methane. For some end uses the methane component is desirable: for others it would need to be removed or converted (for example by reforming it with steam to produce hydrogen, CO and $CO_2$). On a steel works it is normal to use about half of the coke oven gas to fire the coke ovens themselves, with the remainder being available for other uses. It could be used, for example, to boost the hydrogen content of a syngas derived from coal or from hydrocarbon residues.

### 2.2. Syngas from renewables and waste streams

Biomass from a wide range of sources can be converted into syngas via gasification [5,10,11]. If the biomass is a coppiced wood grown in a short rotation (e.g. short rotation coppice willow harvested on a 3-year cycle), then the syngas comes close to being carbon-neutral since the $CO_2$ emitted if the syngas is burnt is effectively reabsorbed during the photosynthetic growth of the

**Table 1**
An example of coke oven gas composition, in which 93% of the components can also be found in a typical raw syngas in varying proportions.

| Composition | % v/v | Contaminants | g/$m^3$ |
|---|---|---|---|
| Hydrogen | 61 | Dust | Nil |
| Methane | 25 | Ammonia | 0.1 |
| Carbon monoxide | 5 | Naphthalene | 0.5 |
| Carbon dioxide | 2 | Benzole | 4–15 |
| Ethane | 1 | Hydrogen sulphide | 1–5 |
| Ethylene | 2 | Hydrogen cyanide | 0.1–5 |
| Nitrogen | 4 | | |
| Oxygen | 0.2 | | |