Please cite this article in press as: Yavuz, How to reach carbon emission targets with technology and public awareness, Matter (2022), https://doi.org/10.1016/j.matt.2022.06.029

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How to reach carbon emission targets with technology and public awareness

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Our best option in curbing greenhouse gas emissions is to include heavy carbon emitters in a viable, sustainable, transitional solution based on a versatile syngas-based circular carbon economy and to establish a universal carbon emissions metric rather than fighting an endless war of politics, policies, and empty promises.

The climate crisis is unlike any other global challenge we have tackled. The carbon emissions of over 40 billion tons per annum are simply too large for any single solution to be effective.[1] In 2020, a vast majority (83%) of the global energy demand was supplied by fossil fuels.[2] Then there are hard-to-abate sectors, like chemicals, cement, and steel industries, that require carbon as an input or output. Our needs for energy continue to increase, having roughly doubled since the last century (Figure 1). However, renewables cannot address this demand, particularly because they are not yet manufactured at the scale required and have at least several years of breakeven requirements.[3] Until we completely move away from carbon-emitting fuels,[4] we need to find low-carbon fuels as transitional energy sources.

Transitional technologies to decarbonize fuels

Any alternative energy source would need a completely new infrastructure and energy-intensive production of the equipment. Infrastructure replacement is considerably more carbon emissive than an upgrade, hence the urgent need for carbon-based transition fuels. Planetary boundaries also dictate that renewable, non-fossil carbon sources need to be limited (e.g., to 25%–75% of the carbon demand)[5] and the remaining has to be balanced from fossil fuels.

To devise a sustainable energy portfolio under the planetary and practicality constraints, we must consider a hybrid model of renewable-energy-powered low-carbon fossil fuel production as a transitional energy technology. Such untethered demand would also provide the natural growth and gradual implementation flexibility that the renewables industry needs to build to scale.

At the heart of a potential transitional energy technology platform is synthesis gas (syngas), a mixture of gaseous carbon monoxide and hydrogen (Figure 1). Syngas is currently the primary source of hydrogen for fuel cell vehicles and has been the core building block in the chemicals industry for liquids, particularly alcohols, olefins, and low-molecular-weight fuels. We have recently shown that switching syngas production from steam reforming to dry reforming[1] could provide up to 20 gigatons of CO_2 avoidance without significantly altering our lifestyle. Net CO_2 consumption rates of 490 kg CO_2/TNm[3] by using e-furnaces in dry reforming[6] has also been reported. An electric reformer with a potential of 1% global CO_2 emission reduction[7] was even proposed. These examples point to a central position of syngas in providing a tangible framework for a smooth transition to a carbon-zero energy future and low-carbon chemicals (Figure 1).

In a syngas-based circular carbon economy, chemicals and transition fuels would be made using syngas from the dry reforming of hydrocarbons. An estimated 15%–50% reduction in carbon emissions is possible without any change to the infrastructure. Further reductions would be introduced if syngas was produced from a range of sources, such as biomass, waste, plastics, or paper, and if the direct conversion of syngas to more chemicals was feasible. Biomass as a source is particularly important because transport of large quantities of solids with high-oxygen content is energy inefficient.[8] As for the circular production of chemicals from CO_2 and derivatives, CO is significantly less energy intensive to reduce than CO_2, leading to more sustainable processes.

Raising public awareness with a carbon emissions factor

All industrial processes, including renewable energy production, are essentially carbon positive because of the additional considerations such as machinery, fertilizers, human labor, and waste. In addition, public opinion does not consider safe gases like water vapor to be greenhouse gases, which is not accurate. To help consumers

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https://doi.org/10.1016/j.matt.2022.06.029

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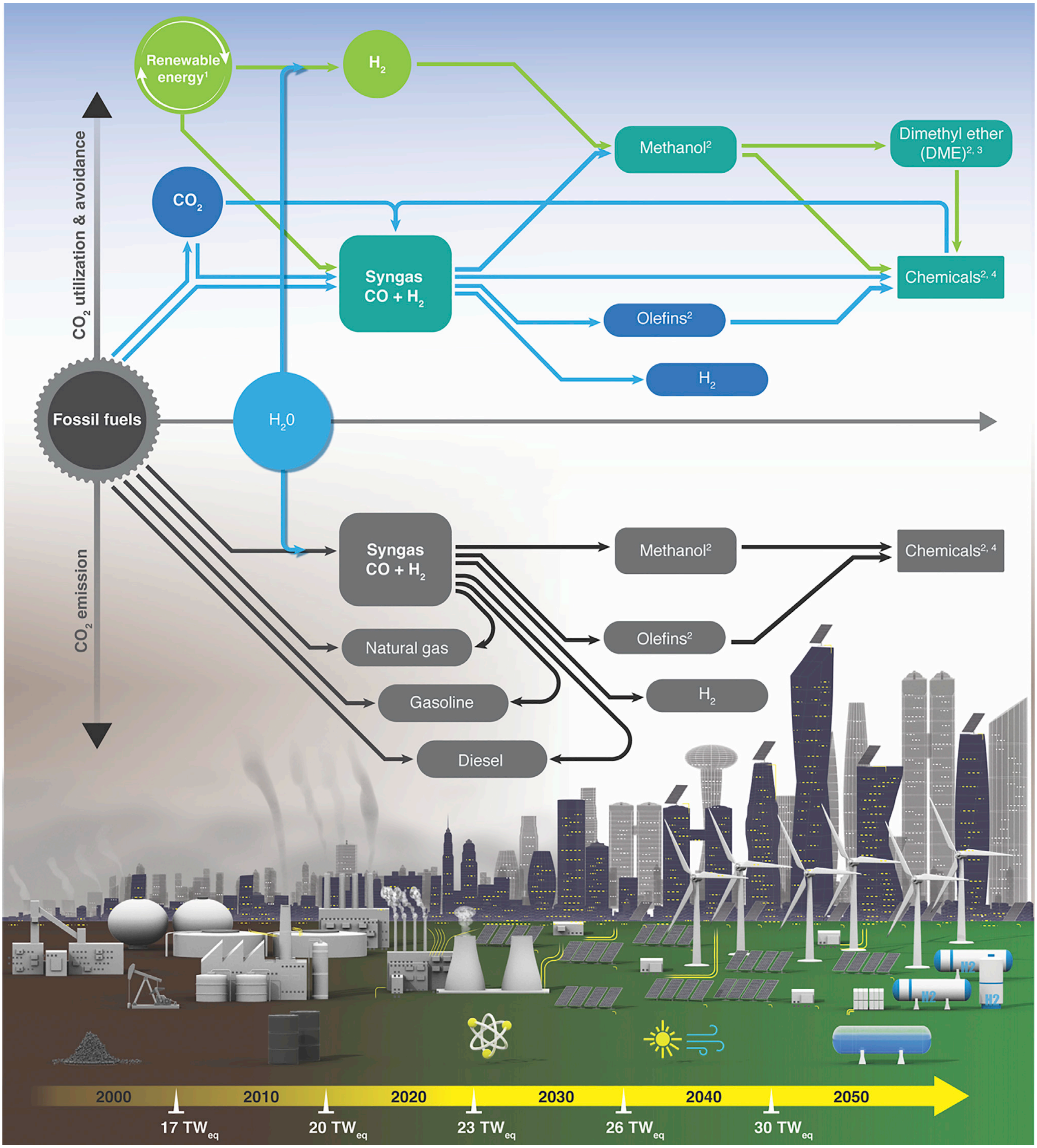

Figure 1. Proposed transitional technologies within the framework of "syngas economy"

Syngas refers to synthesis gas, a mixture of carbon monoxide and hydrogen, made by steam (H_2O) or dry (CO_2) reforming of hydrocarbons. TWeq, terawatt equivalent. Footnotes: (1) renewable energy from solar, wind, waves, or biomass. (2) Must contain carbon. (3) DME is widely accepted as a low carbon diesel substitute. (4) Chemicals refer to, but are not limited to, pharmaceuticals, detergents, polymers, plastics, solvents, lubricants, pesticides, dyes, ink, and coatings. Illustration by Heno Hwang/KAUST.

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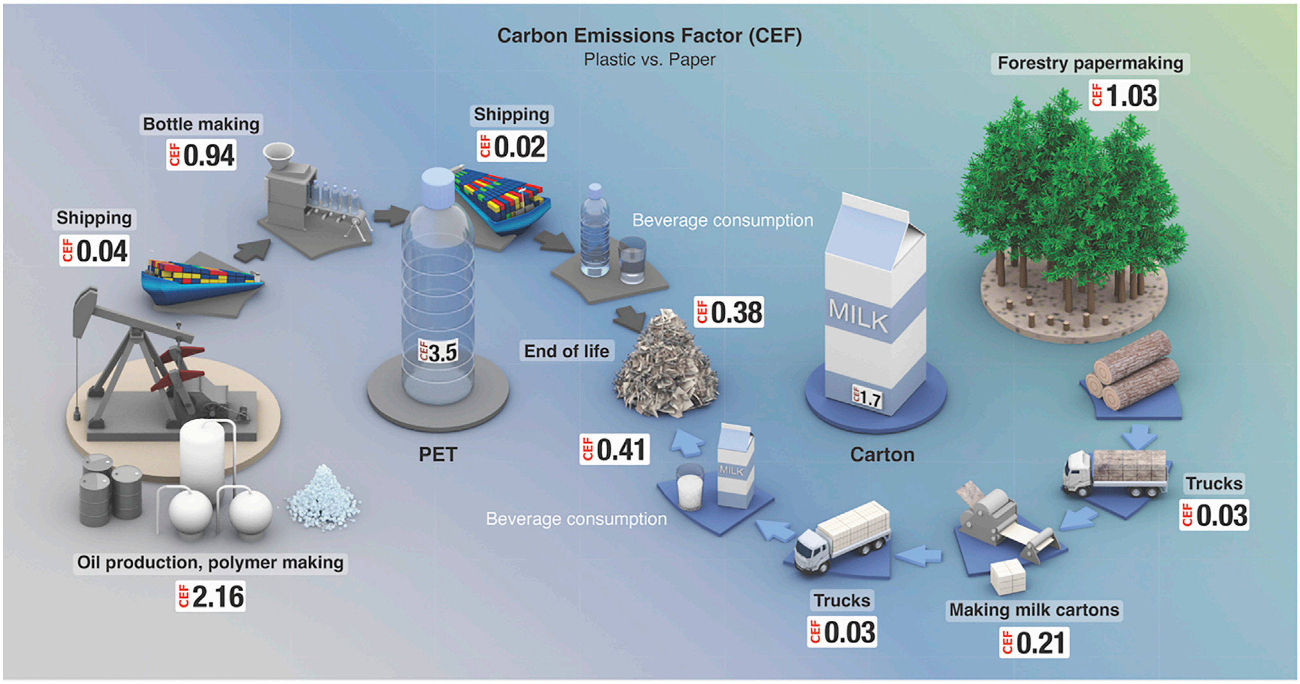

Figure 2. Example of a carbon (or combined) emissions factor (CEF) calculation

Plastic (PET) versus paper (carton) bottles for beverages. Data from BillerudKorsnäs paper company through a 2015 Swedish Environment Institute, IVL, report.[10] Illustration by Heno Hwang/KAUST.

make the right choices for the planet, we need widespread public awareness on how carbon emissive a product or process is, based on peer-reviewed data.

The good news is that the public is familiar with numeric calculations, such as the energy efficiency of appliances and calories in food. The bad news is that there is no common metric to understand how much a product or process contributes to global warming. This creates uninformed trends in consumer behavior; for example, glass bottles actually have a carbon footprint four times higher than plastic bottles.[9] If an item displayed one universal carbon emissions value on their packaging, an environmentally aware user would choose the one with the lower pollution potential. This would provide healthy competition between producers and lead to positive changes in waste management.

Here, I propose a unitless carbon emissions factor (CEF) that would include all carbon (and equivalent) emissions from the production, use, and disposal of a product, calculated by the weight of CO_2 emitted per weight of the product. The user would then articulate the scale of emissions from the product to understand its carbon footprint. The unitless feature of this metric would allow the comparison of all consumer products regardless of their complexity. The scope is limitless, from food to fuel, plastics to airplanes, medicine to furniture, coal to batteries, and so on. Even within the same product line—for example, bottled drinks—a CEF would enable an environmentally responsible consumer decision between the choices. For up-and-coming technology and products, CEF would be a simplified gateway to push for a carbon-free future.

The metric global warming potential (GWP) provides an excellent starting point to calculate CEF. Introduced by the Kyoto Protocol of 1997, the GWP equalizes the impact of all greenhouse gases into unified CO_2 equivalence (CO_{2eq}). For instance, methane emissions would be considered 26 times CO_{2eq} (100-year time span) and nitrous oxide would be 265 times CO_{2eq}, which are the other prominent greenhouse gases contributing 16% and 6%, respectively. Hence, for the more technically savvy, CEF could also be referred to as a "combined emissions factor."

Plastic versus paper bottles is a good example of a CEF calculation because the choice is an active discussion among consumers, and detailed life-cycle analysis data are also available.[10] From the data provided by the Gruvön and Skärblacka mills of BillerudKorsnäs (Sweden), we arrive at a CEF of 1.7 for a paper-based Fibre-Form packaging bottle produced locally in Sweden and a CEF of 3.5 for a PET bottle made and imported from Indonesia (Figure 2). The breakdown of the CEF for the paper bottle is 72% for raw materials and production, 4% for transport, and 24%

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for end of life, whereas a plastic bottle has more raw material-intensive emissions: 88%, 1%, and 11%, respectively. Overall, the paper carton bottle is 50% less carbon emissive than the plastic version, but if the plastic bottle is reused just once, both plastic and paper bottles have an almost equal CEF.

Gasoline would have an average CEF of around 5 (although a more precise calculation is needed). Of that, fuel combustion contributes slightly more than 3, and production (upstream and downstream) and transport to the users contributes the remaining 2. Depending on the grade of the fuel and the level of renewable input (including bio-ethanol blending), the CEF would drop and allow the consumer to choose between performance and environmental impact.

The calculation of CEF would be quick and reliable with an open-source database hosted by an international agency like United Nations Framework Convention on Climate Change. Citizen scientists of any age could also contribute to building up the database because no complex calculations or heavy computing are required. Governments could correlate legislation around this transparent, universal metric and impose carbon taxation and credits accordingly.

ACKNOWLEDGMENTS

The views reported here are those of the author alone and are not necessarily endorsed by research sponsors or organizations with which the author is affiliated. The author gratefully acknowledges funds from the King Abdullah University of Science and Technology (KAUST).

DECLARATION OF INTERESTS

The author declares no competing interests.

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