

Capabilities Regarding Emissions

As the pressure to reduce pollution increases drastically, a high mitigation potential is found in alternative fuels. For now, electric powered aircraft, sustainable aviation fuel (SAF) and hydrogen, both in a fuel cell and direct combustion, are mostly discussed. There are other alternatives such as liquified methane, ammonia, methanol etc. But as technology is not pushed forward for those fuels, looking at potential environmental impacts does not make much sense. Electric aircrafts and hydrogen in a fuel cell do not cause emissions during flight, they are not the center of attention here as well. Since there is not much research yet, an overview of existing capabilities for direct combustion of hydrogen and SAFs are presented.

Sustainable Aviation Fuel (SAF)

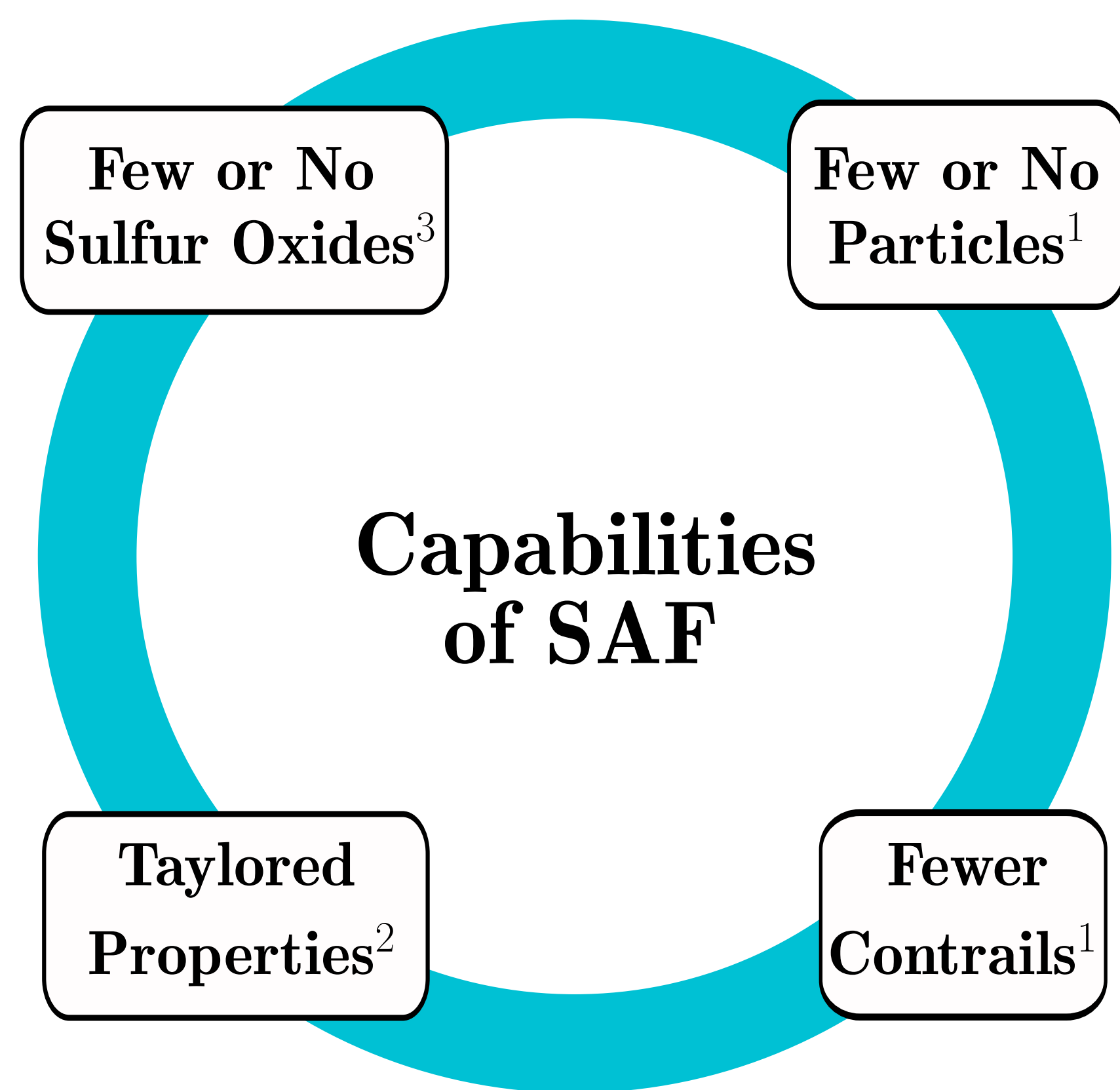


Fig. 1: Capabilities of SAF combustion.

Tests with 100% SAF have been successful, but the SAF does not meet all criteria for jet fuel specified in the ASTM D1655 [1]. This is not necessarily bad, it is just unknown what happens in the long term when jet fuel is out of the specification range [2]. Many chances lay in exploring chemistry changes in fuel, as the available has been taken as a standard in the past but contexts were not explored.

1: The graphic displays the simplified emissions from the combustion process. Because of fewer aromats and naphthalenes in SAF, the particles reduce [3]. Soot reduces by 30-60% [1]. Therefore SAF is less likely to form contrails as there are fewer nuclei for condensation [4].

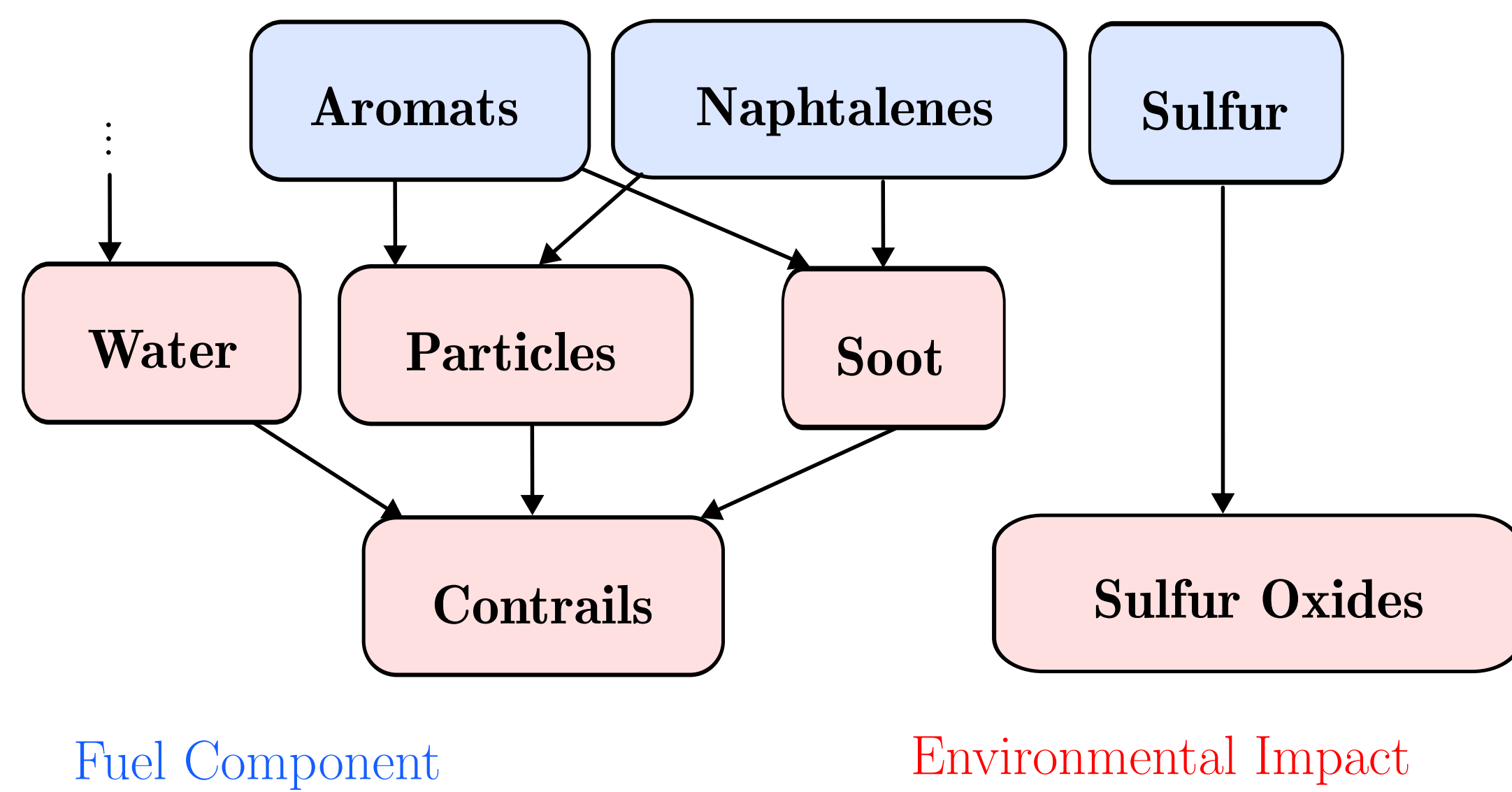


Fig. 2: Simplified reactions in the combustion process.

2: As there are different sources and diverging procedures to gain SAF, it differs in composition. Jet-A1 is a mixture as well which is usually averaged by $C_{12}H_{23}$ [4]. This cannot be done for SAF as two SAFs differ a lot from each other, but much less in itself than Jet-A1. So kinds of SAFs need to be considered as varying fuels. Chances lay in these differences and mixing seems to be a good solution to get tailored properties. But by mixing non-linear reactions are caused and there is a lack of understanding how to achieve all the wanted properties.

3: The sulfur portion in SAF is significantly lower than in Jet-A1 if there is any sulfur at all [2]. This improves the coking performance significantly and there are few to no reactions causing sulfur oxides.

Hydrogen

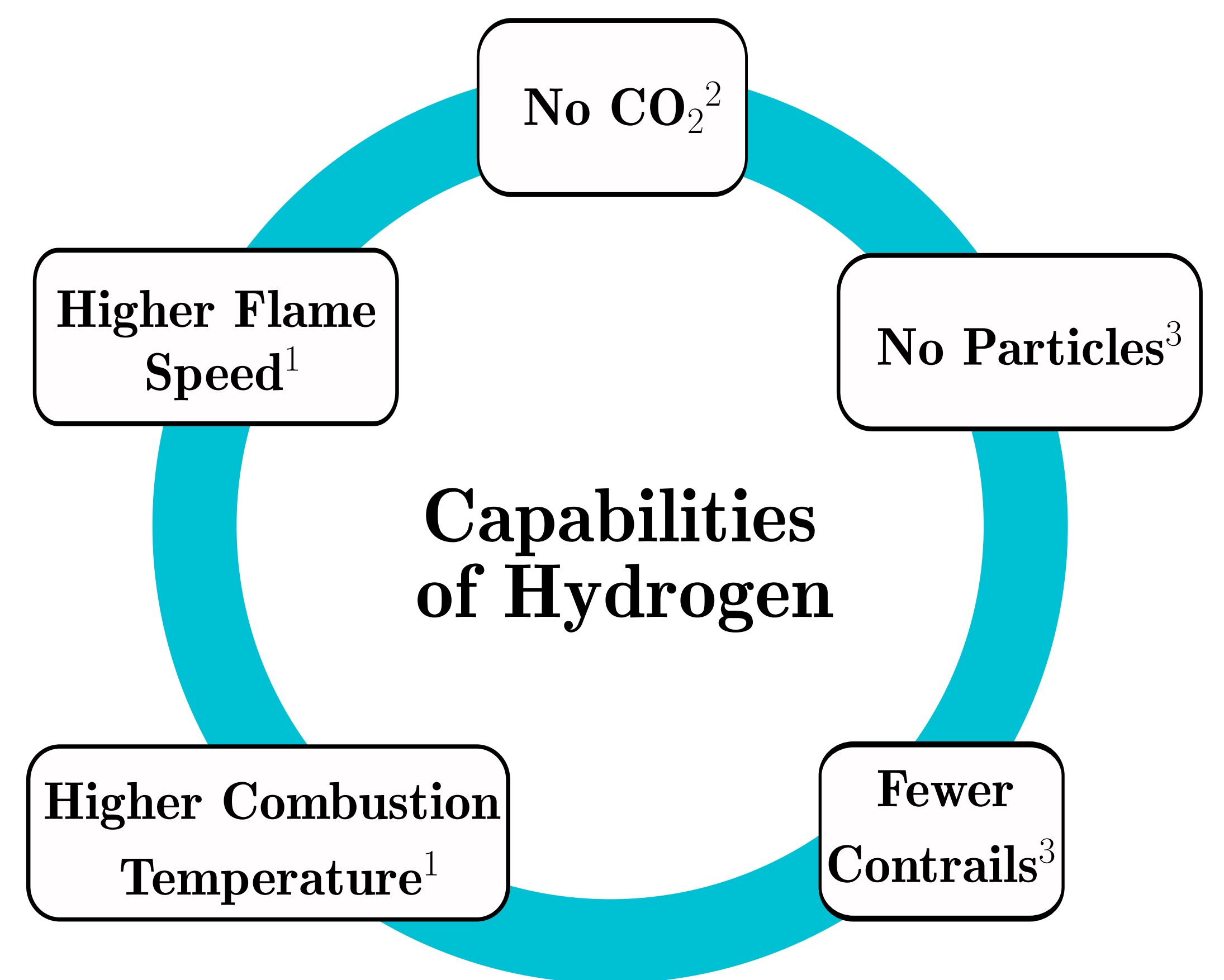


Fig. 3: Capabilities of hydrogen combustion.

1: Estimating NO_x is a big challenge, as it depends on the combustion chamber design and there are no NO_x emissions measured for hydrogen combustion chambers yet. Predictions vary between 90% less and same amount of NO_x [5] as when burning Jet-A1. This is because hydrogen has different combustion characteristics than kerosene. In the diagram, the lines represent possible configurations. The marked area is where the burning process is most likely to happen in future.

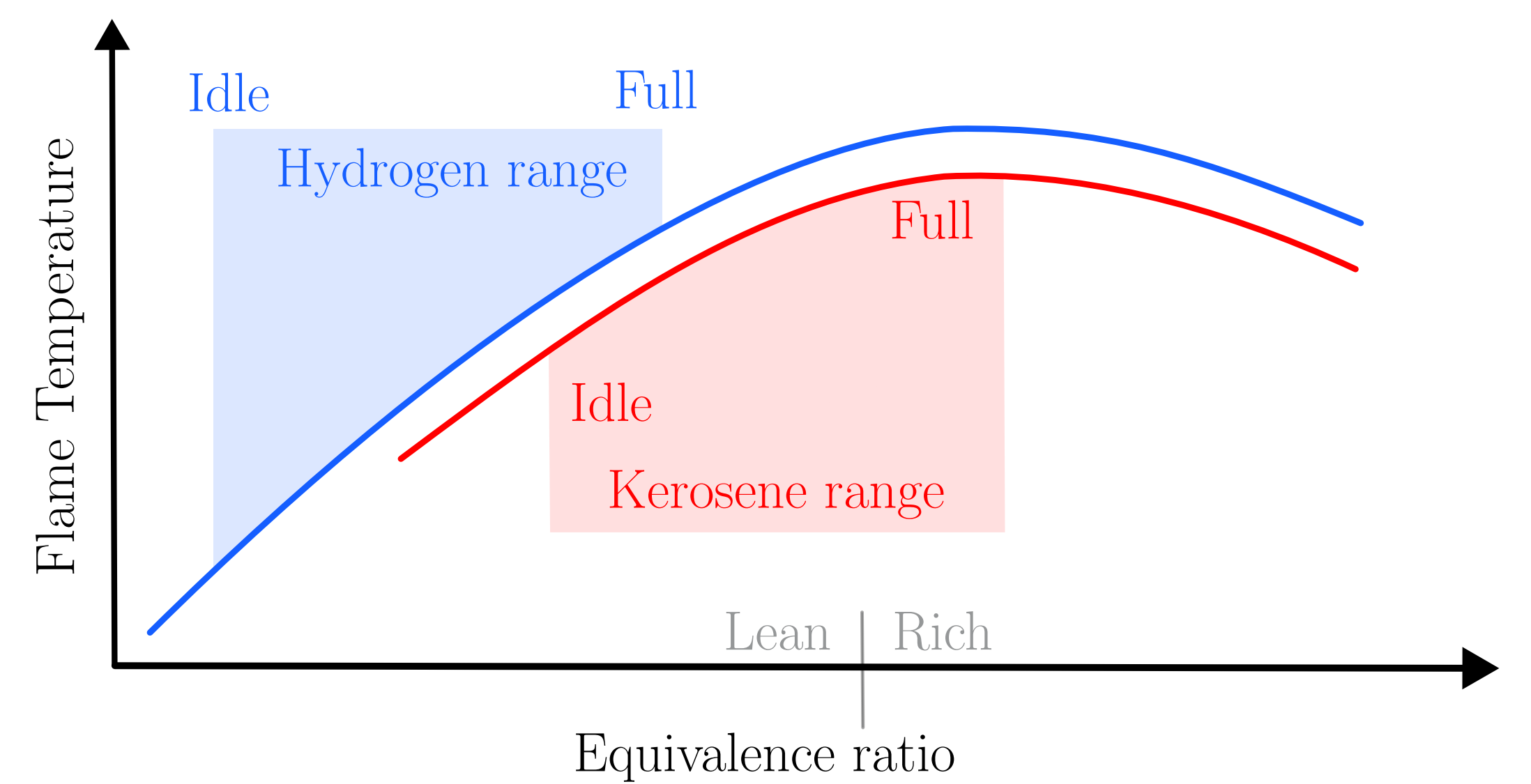


Fig. 4: Combustion characteristics of hydrogen compared to kerosene.

2: By mixing hydrogen with air and subsequent combustion, mainly water and nitrogen oxides are caused. All other reactants occur in negligible little amount [6]. Assuming hydrogen fully reacts to water, we get the following equation. By balancing the equation we get the emission index (EI).

$$a \cdot H_2 + b \cdot O_2 + c \cdot N_2 \rightarrow d \cdot H_2O + e \cdot NO_x + f \cdot O_2 + g \cdot N_2$$

$$EI_{H_2O} = \frac{a}{a} \cdot \frac{2 \cdot M_H + M_O}{2 \cdot M_H} = 8,936 \left[\frac{g}{kg} \right]$$

The EI for water in a JET A-1 combustion is $1,239 \frac{g}{kg}$ [7]. We assume the same amount of energy needed for a mission. As the energy density is $43.2 \frac{MJ}{kg}$ for Jet A-1 and $120 \frac{MJ}{kg}$ for hydrogen [8], there will be 2.6 times more water for the same mission, which is the conclusion of [9] as well.

3: There are no particles in the exhaust fumes, but in the surrounding air. The emitted water finds very little nucleus and contrails reduce significantly [5].

Sources

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