Synopsis

Title: Decarbonizing Fischer-Tropsch Synthesis for a Sustainable Energy Transition

The Fischer-Tropsch (FT) process has been a vital technology for turning synthesis gas (syngas)—a mix of carbon monoxide (CO) and hydrogen (H_2)—into fuels and chemicals. For many years, it relied on fossil fuels like coal or natural gas, making it a big source of CO_2 emissions. Today, as the world works toward a cleaner energy future and net-zero emissions, we need to rethink how FT synthesis fits in. This perspective explores how we can decarbonize the FT process, making it sustainable while keeping its importance for industries like aviation and shipping, where electrification is difficult.

One major way to decarbonize FT synthesis is by changing its raw materials. Instead of fossil fuels, we can use biomass (like agricultural waste) or CO_2 captured from industries to make syngas. Biomass is carbon-neutral because plants absorb CO_2 as they grow, and captured CO_2 can be recycled into useful products. Another key step is using renewable energy. Green hydrogen, produced from water using solar or wind power, can replace hydrogen made from fossil fuels, cutting emissions further. These ideas are part of a system called Power-to-Liquids (PtL), where clean energy drives the whole process.

Catalysts are also central to this change. As a catalysis researcher, I see great potential in designing new catalysts that work at lower temperatures and make more of the products we want, like diesel or jet fuel. Nano-sized catalysts and hybrid metals (like iron-cobalt mixes) can improve efficiency and last longer. Beyond this, we can trap CO_2 emissions with carbon capture and storage (CCS) or reuse carbon in a circular economy, turning FT fuels into a sustainable option for hard-to-fix sectors.

But there are hurdles. green hydrogen and CO_2 capture are costly, and lab ideas—like advanced catalysts—don't always work in big factories. We also need to check the full environmental impact with life-cycle analysis to avoid hidden emissions. Governments and companies can help by giving money for research, taxing fossil fuels, and building partnerships.

In this perspective, we will share how these strategies can transform FT synthesis into a tool for a low-carbon future. By solving these challenges, we can make sustainable fuels that support global climate goals. This presentation will inspire researchers, engineers, and policymakers to work together on this exciting journey toward decarbonization.

The tentative flow of the perspective is presented below.

1. Feedstock Transition: Replacing fossil-based syngas with biomass or captured CO_2 to reduce carbon emissions.
2. Energy Efficiency: Using green hydrogen, waste heat recovery, and low-temperature catalysts to save energy.
3. Catalysis Advancements: Designing better catalysts to improve product quality and process stability.
4. Systemic Strategies: Using carbon capture and storage (CCS) and circular carbon practices to lower emissions.

5. Policy and Economic Support: Highlighting the need for subsidies, carbon pricing, and partnerships to encourage adoption.
6. Challenges and Research Needs: Addressing high costs, scalability issues, and the importance of lifecycle analysis for true sustainability.

Recent Key Publications

1. Brübach, L., Wolf, M., & Pfeifer, P. (2025). Fischer-Tropsch synthesis. In N. Bullerdiek, U. Neuling, & M. Kaltschmitt (Eds.), *Powerfuels: Status and Prospects* (pp. 605–645). Springer Nature Switzerland. `https://doi.org/10.1007/978-3-031-62411-7_22`

2. Beiermann, D. (2025). Refining of Fischer–Tropsch products. In N. Bullerdiek, U. Neuling, & M. Kaltschmitt (Eds.), *Powerfuels: Status and Prospects* (pp. 647–666). Springer Nature Switzerland. `https://doi.org/10.1007/978-3-031-62411-7_23`

3. Ekins, P. (2023). *Stopping climate change: Policies for real zero* (1st ed.). Routledge. `https://doi.org/10.4324/9781003438007`

4. Korolev, E. V., Merinov, V. A., Mikhailov, M. N., & Rudyak, K. D. (2022). Possible ways to decarbonize oil and gas industry using small-scale associated gas utilization technologies. *Chemistry and Technology of Fuels and Oils, 58*(5), 725–730. `https://doi.org/10.1007/s10553-022-01442-z`

5. Gruber, H., Groß, P., Rauch, R., Reichhold, A., Zweiler, R., Aichernig, C., Müller, S., Ataimisch, N., & Hofbauer, H. (2021). Fischer-Tropsch products from biomass-derived syngas and renewable hydrogen. *Biomass Conversion and Biorefinery, 11*(6), 2281–2292. `https://doi.org/10.1007/s13399-019-00459-5`

6. Medrano-García, J. D., Charalambous, M. A., & Guillén-Gosálbez, G. (2022). Economic and environmental barriers of CO_2-based Fischer–Tropsch electro-diesel. *ACS Sustainable Chemistry & Engineering, 10*(36), 11751–11759. `https://doi.org/10.1021/acssuschemeng.2c01983`

7. Apolinar-Hernández, J. E., Bertoli, S. L., Riella, H. G., Soares, C., & Padoin, N. (2024). An overview of low-temperature Fischer–Tropsch synthesis: Market conditions, raw materials, reactors, scale-up, process intensification, mechanisms, and outlook. *Energy & Fuels, 38*(1), 1–28. `https://doi.org/10.1021/acs.energyfuels.3c02287`

8. Konarova, M., Aslam, W., & Perkins, G. (2022). Chapter 3 - Fischer-Tropsch synthesis to hydrocarbon biofuels: Present status and challenges involved. In S. K. Maity, K. Gayen, & T. K. Bhowmick (Eds.), *Hydrocarbon Biorefinery* (pp. 77–96). Elsevier. `https://doi.org/10.1016/B978-0-12-823306-1.00006-6`

9. Maaß, H.-J., & Möckel, H.-O. (2020). Combined decarbonization of electrical energy generation and production of synthetic fuels by renewable energies and fossil fuels. *Chemical Engineering & Technology, 43*(1), 111–118. `https://doi.org/10.1002/ceat.201900384`

10. Meurer, A., & Kern, J. (2021). Fischer–Tropsch synthesis as the key for decentralized sustainable kerosene production. *Energies, 14*(7), 1836. `https://doi.org/10.3390/en14071836`

11. Moodley, D., Botha, T., Crous, R., Potgieter, J., Visagie, J., Walmsley, R., & Dwyer, C. (2024). Catalysis for sustainable aviation fuels: Focus on Fischer–Tropsch catalysis. In *Book Title* (pp. 73–116). `https://doi.org/10.1002/9781119870647.ch6`

12. Li, J., He, Y., Tan, L., Zhang, P., Peng, X., Oruganti, A., Yang, G., Abe, H., Wang, Y., & Tsubaki, N. (2018). Integrated tuneable synthesis of liquid fuels via Fischer–Tropsch technology. *Nature Catalysis, 1*(10), 787–793. `https://doi.org/10.1038/s41929-018-0144-z`

13. Zheng, Q., Williams, J., van Thiel, L. R., Elgersma, S. V., Mantle, M. D., Sederman, A. J., Baart, T. A., Bezemer, G. L., Guédon, C. M., & Gladden, L. F. (2023). Operando magnetic resonance imaging of product distributions within the pores of catalyst pellets during Fischer–Tropsch synthesis. *Nature Catalysis, 6*(2), 185–195. `https://doi.org/10.1038/s41929-023-00913-8`

14. Böller, B., Durner, K. M., & Wintterlin, J. (2019). The active sites of a working Fischer–Tropsch catalyst revealed by operando scanning tunnelling microscopy. *Nature Catalysis, 2*(11), 1027–1034. `https://doi.org/10.1038/s41929-019-0360-1`

15. Ellis, P. R., Enache, D. I., James, D. W., Jones, D. S., & Kelly, G. J. (2019). A robust and precious metal-free high performance cobalt Fischer–Tropsch catalyst. *Nature Catalysis, 2*(7), 623–631. `https://doi.org/10.1038/s41929-019-0288-5`

16. Wolf, M., Fischer, N., & Claeys, M. (2020). Water-induced deactivation of cobalt-based Fischer–Tropsch catalysts. *Nature Catalysis, 3*(12), 962–965. `https://doi.org/10.1038/s41929-020-00534-5`

17. Vogt, E. T. C., & Weckhuysen, B. M. (2024). The refinery of the future. *Nature, 629*(8011), 295–306. `https://doi.org/10.1038/s41586-024-07322-2`

18. Goodwin, C. M., Lömker, P., Degerman, D., Davies, B., Shipilin, M., Garcia-Martinez, F., Koroidov, S., Katja Mathiesen, J., Rameshan, R., Rodrigues, G. L. S., Schlueter, C., Amann, P., & Nilsson, A. (2024). Operando probing of the surface chemistry during the Haber–Bosch process. *Nature, 625*(7994), 282–286. `https://doi.org/10.1038/s41586-023-06844-5`

19. Kourou, A., De Langhe, S., Nelis, L., Ureel, Y., Ruitenbeek, M., Biesheuvel, K., Wevers, R., Ouyang, Y., & Van Geem, K. M. (2024). Electrification pathways for sustainable syngas production: A comparative analysis for low-temperature Fischer-Tropsch technology. *International Journal of Hydrogen Energy, 81*, 974–985. `https://doi.org/10.1016/j.ijhydene.2024.07.305`

20. Wang, D., Gu, Y., Chen, Q., & Tang, Z. (2023). Direct conversion of syngas to alpha olefins via Fischer–Tropsch synthesis: Process development and comparative techno-economic-environmental analysis. *Energy, 263*, 125991. `https://doi.org/10.1016/j.energy.2022.125991`

21. Liu, C. M., Sandhu, N. K., McCoy, S. T., & Bergerson, J. A. (2020). A life cycle assessment of greenhouse gas emissions from direct air capture and Fischer–Tropsch fuel production. *Sustainable Energy & Fuels, 4*(6), 3129–3142. `http://dx.doi.org/10.1039/C9SE00479C`

22. Jones, M. P., Krexner, T., & Bismarck, A. (2022). Repurposing Fischer-Tropsch and natural gas as bridging technologies for the energy revolution. *Energy Conversion and Management, 267*, 115882. `https://doi.org/10.1016/j.enconman.2022.115882`

23. Kullmann, F., Linßen, J., & Stolten, D. (2023). The role of hydrogen for the defossilization of the German chemical industry. *International Journal of Hydrogen Energy, 48*(99), 38936–38952. `https://doi.org/10.1016/j.ijhydene.2023.04.191`

24. Kourou, A., De Langhe, S., Nelis, L., Ureel, Y., Ruitenbeek, M., Biesheuvel, K., Wevers, R., Ouyang, Y., & Van Geem, K. M. (2024). Electrification pathways for sustainable syngas production: A comparative analysis for low-temperature Fischer-Tropsch technology. *International Journal of Hydrogen Energy, 81*, 974–985. `https://doi.org/10.1016/j.ijhydene.2024.07.305`

25. Wang, D., Gu, Y., Chen, Q., & Tang, Z. (2023). Direct conversion of syngas to alpha olefins via Fischer–Tropsch synthesis: Process development and comparative techno-economic-environmental analysis. *Energy, 263*, 125991. `https://doi.org/10.1016/j.energy.2022.125991`