Bosch Process Technology Development for Air Revitalization

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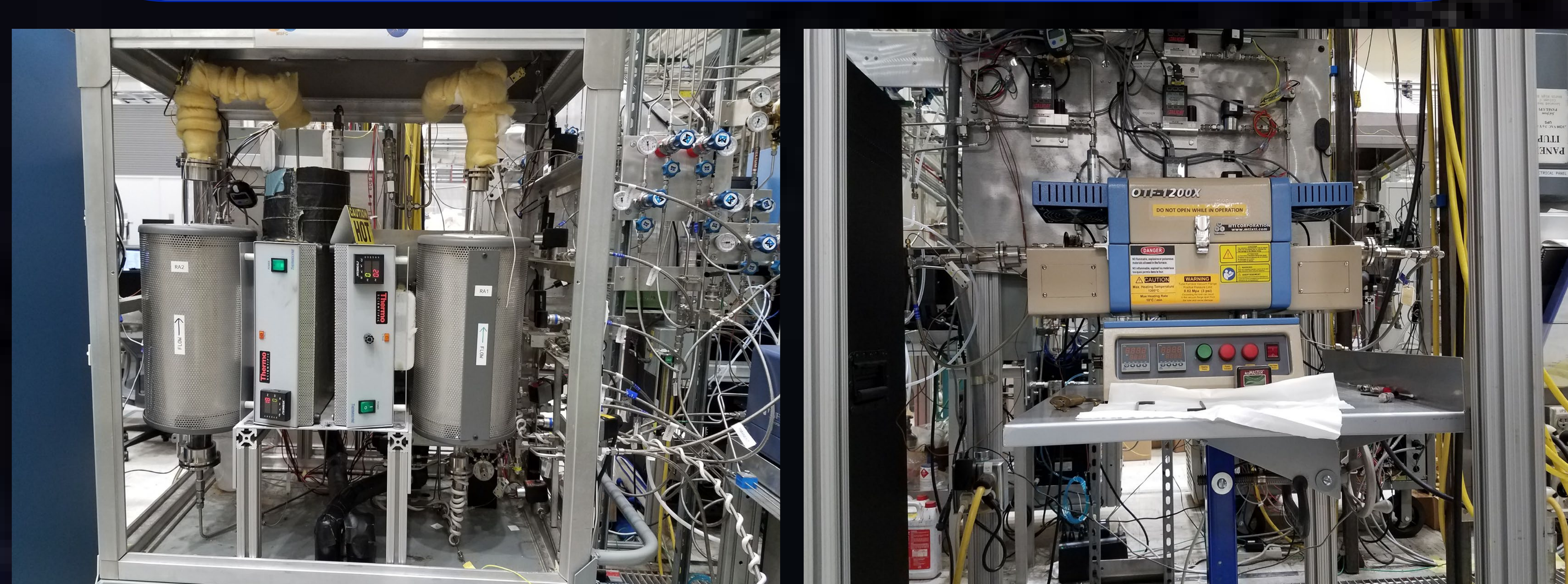
Abstract:

Closed-loop Environmental Control and Life Support Systems (ECLSS) aim to fully recover resources needed to keep astronauts alive in space– primarily, this means reclaiming oxygen (O_2) to breathe and water (H_2O) to drink from metabolic products. In air revitalization, this requires reclaiming the oxygen tied up in metabolic carbon dioxide (CO_2). The current state of the art for the International Space Station (ISS) uses a Sabatier reaction in a system that has demonstrated a 50% O_2 recovery rate. While there are several ongoing projects to improve the recovery of the Sabatier-based process, there are also projects working on an alternative approach centered around the Bosch process. Unlike the Sabatier, which has theoretical limits on maximum O_2 recovery, the Bosch process can theoretically recover all of the O_2 trapped in metabolic CO_2 with only solid carbon (C) as a byproduct. However, the C generated in the process poses a significant challenge, introducing issues with clogging, contamination, and catalyst degradation that ultimately make the Bosch process unfeasible for flight at the current state of development. This poster overviews the promise and challenges of the Bosch process, prior investigations conducted, and current work towards advancing the TRL of Bosch-based O_2 recovery systems and dealing with the (C) buildup. It also discusses potential uses of the carbon itself, which could prove to be a useful product in *in-situ* resource utilization (ISRU) applications.

The Bosch Process

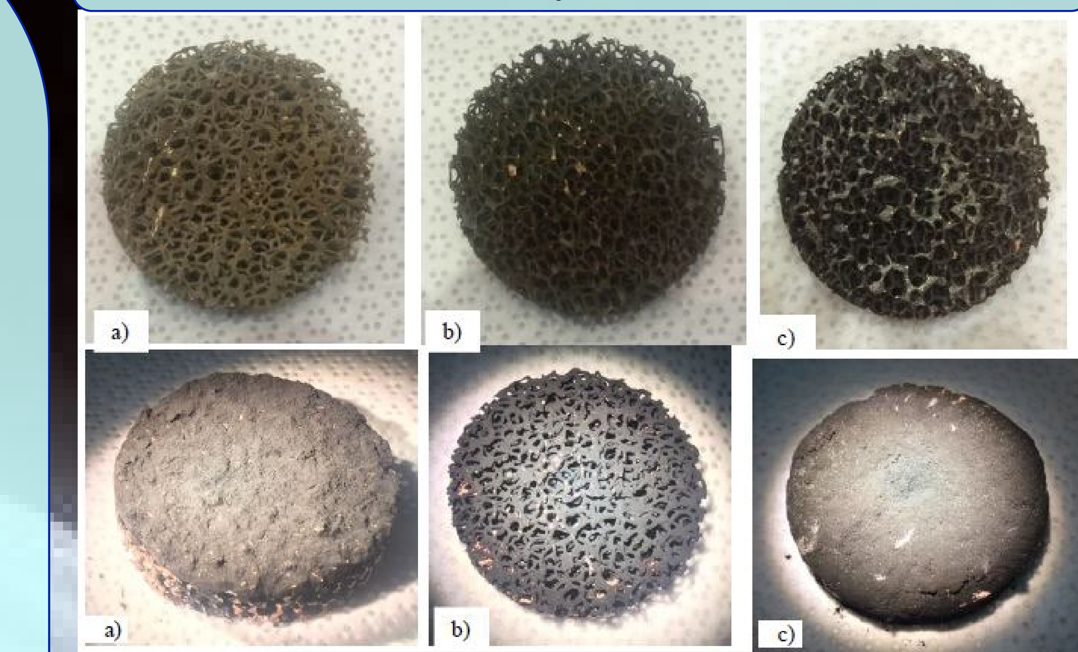
The Bosch process requires a nickel (Ni), iron (Fe), or cobalt (Co) catalyst and temperatures of 550-700 °C. It consists of three reactions that can be split into two categories. First is the Reverse Water-Gas Shift (RWGS) reaction in Equation (1), which produces no solid C but contains oxyen in a waste stream of CO. The second are the C-Formation (CF) reactions, which consist of CO Hydrogenation in Equation (2) and the Boudouard reaction in Equation (3). The total Bosch process is the following:

RWGS	$CO_2 + H_2 \leftrightarrow H_2O + CO$	(1)
CO Hydrogenation	$CO + H2 \leftrightarrow H_2O + C(s)$	(2)
Boudouard	$2CO \leftrightarrow CO_2 + C(s)$	(3)
Total Bosch	$\mathbf{CO_2 + H_2 \leftrightarrow H_2O + C(s)}$	**(4)**

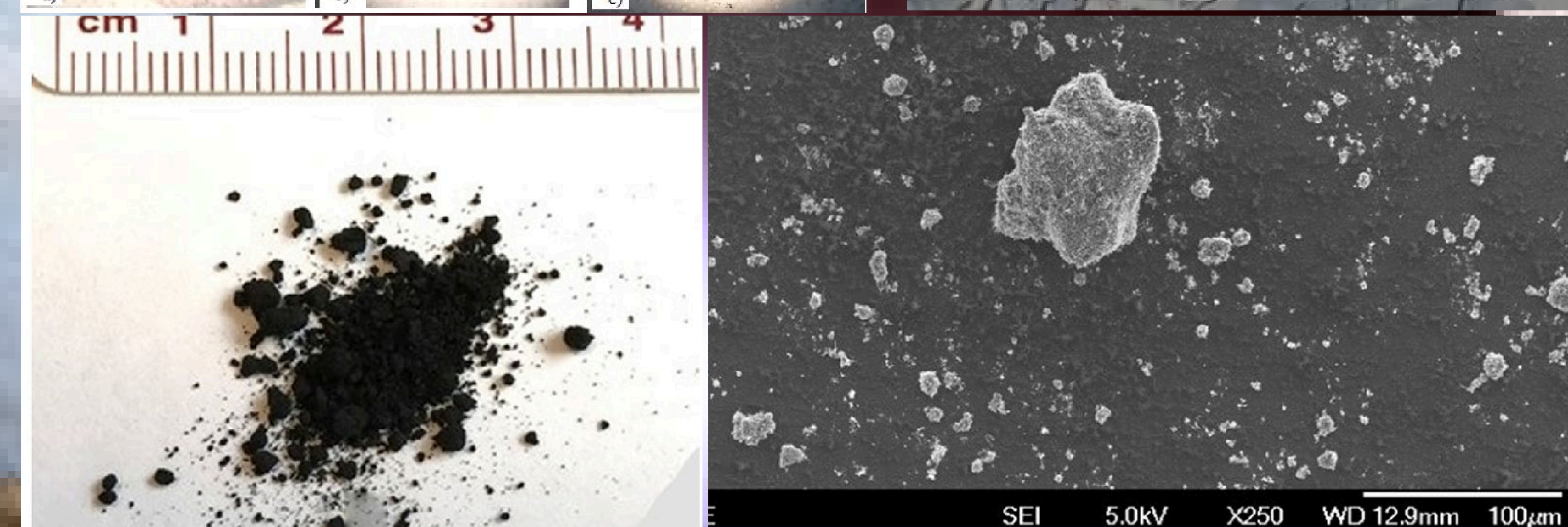


CORCaTS CFR (left) and Rotary Kiln CFR (right) use by ES62 for Bosch ECLSS studies.

Bosch carbon formed on metal foam pucks. Credit: M. B. Abney, et al., 2016.



Carbon formed in pH Matter CFR. Credit: Z. Greenwood, et al. 2018.



Bosch carbon from rotary kiln CFR. Credit: B. C. Stewart, et al. 2022.

Reaction Optimization and Carbon Buildup

The primary barrier for a Bosch-based O_2 recovery system is the solid C buildup produced in the reactions– it clogs pipes, fouls catalysts, and poses a high contamination risk for downstream systems. Thus, Bosch-based systems are considered high-maintenance system at the current state of the art. MSFC is exploring methods to deal with the solid C buildup and improve the overall efficiency of a Bosch-based process:

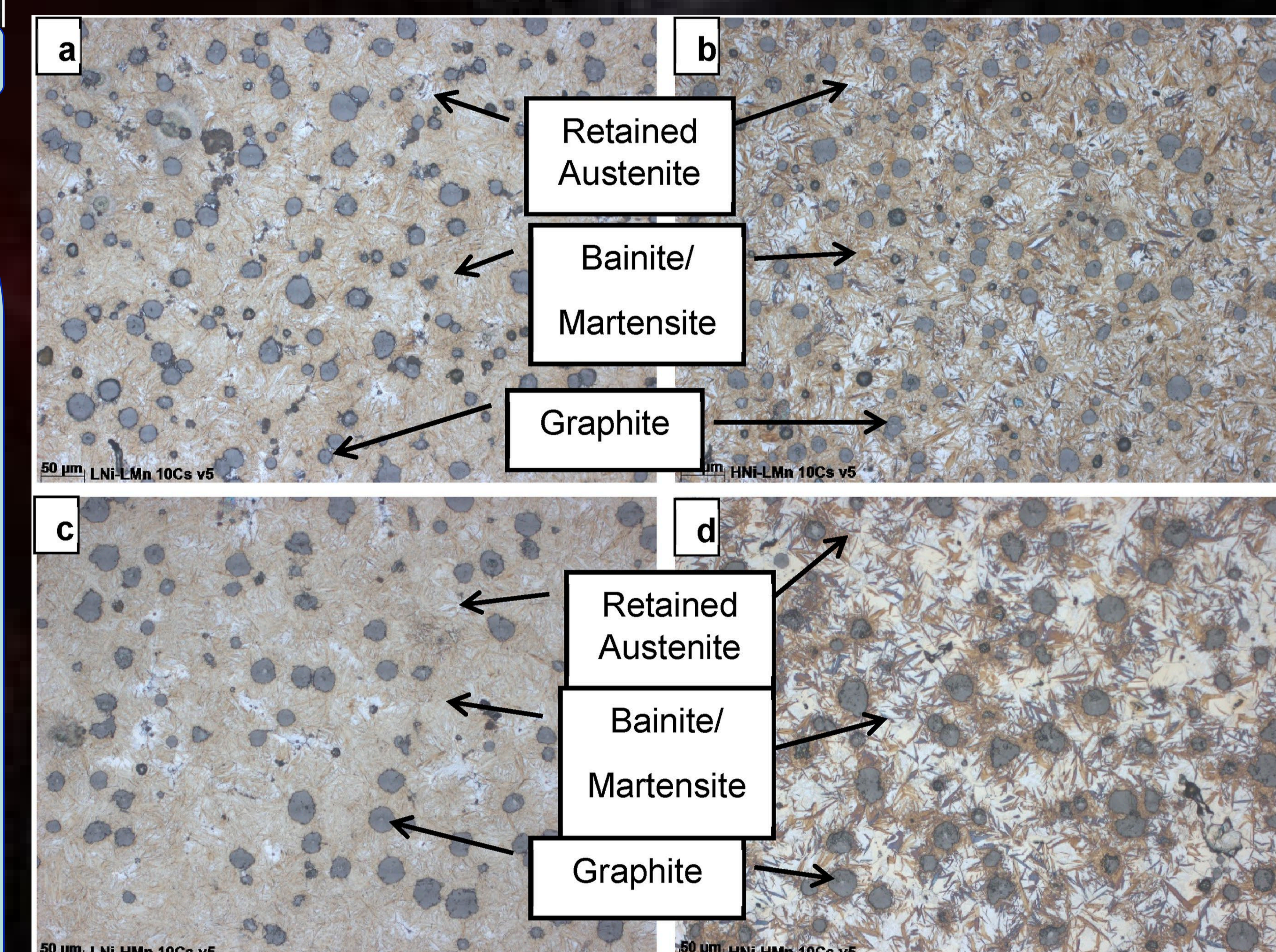
- **S-Bosch:** Split the RWGS and CF reactions into their own, independent reactors to better optimize catalyst makeup and contain C to one part of the assembly rather than one shared reactor.
- **SBIR and industry collaborations:** These have aimed to produce a reactor that continuously clears C to prevent blockages, downstream travel, and reaction quenching. (Coming to MSFC for testing soon!)
- **MSFC designed reactors and catalyst studies**– optimize catalyst for reaction activity, catalyst makeup, and C generation characteristics, including studies on using Martian soil as catalyst!
- **Mechanical reactor cleaning techniques**– Examines the use of components such as rock tumblers, concrete mixers, and augers to break the C loose.
- **Chemical reactor cleaning techniques**– Using chemical approaches such as ionic liquids and electroplating techniques to refresh in-reactor catalyst supplies after fouling occurs.

ISRU with Bosch Carbon

A crew of four generates roughly 8 lbm of C a day. As such, finding a use for the C collected in ECLSS air revitalization processes is key to smart and efficient resource allocation. C is an extremely useful and adaptable material, so several studies have been conducted on using it for the mission's benefit rather than treating it as a waste product. A notable approach is using it, along with Martian regolith, to create steel on Mars.

The regolith and atmosphere, in conjunction with metabolic CO_2, on Mars contains a relative abundance of the primary feedstocks for steel: Fe and C. Using Bosch-based systems for C sequestration and metallic harvesting systems, such as ionic liquids, ferrous alloys can be produced *in-situ*, allowing for infrastructure, tools, and components to be manufactured on the surface to reduce launch mass.

The chemistry-process-structure relationship can be used to our advantage by harvesting elements such as Ni and manganese (Mn) from regolith and meteorites to vary properties for different applications.



Ductile/Nodular Iron samples manufactured by Mississippi State University using ionic liquid harvested iron simulant and Bosch Carbon. 10°C/s cooling rate. Credit: B. C. Stewart, et al. 2022.

Future Work

Future work will continue to develop efficient methodology to apply the Bosch reaction to O_2 recycling. Additionally, uses for the byproduct C, effects of catalyst properties on reactivity, and C filtration methods are of critical importance for the future of Bosch technology.

Backup figs

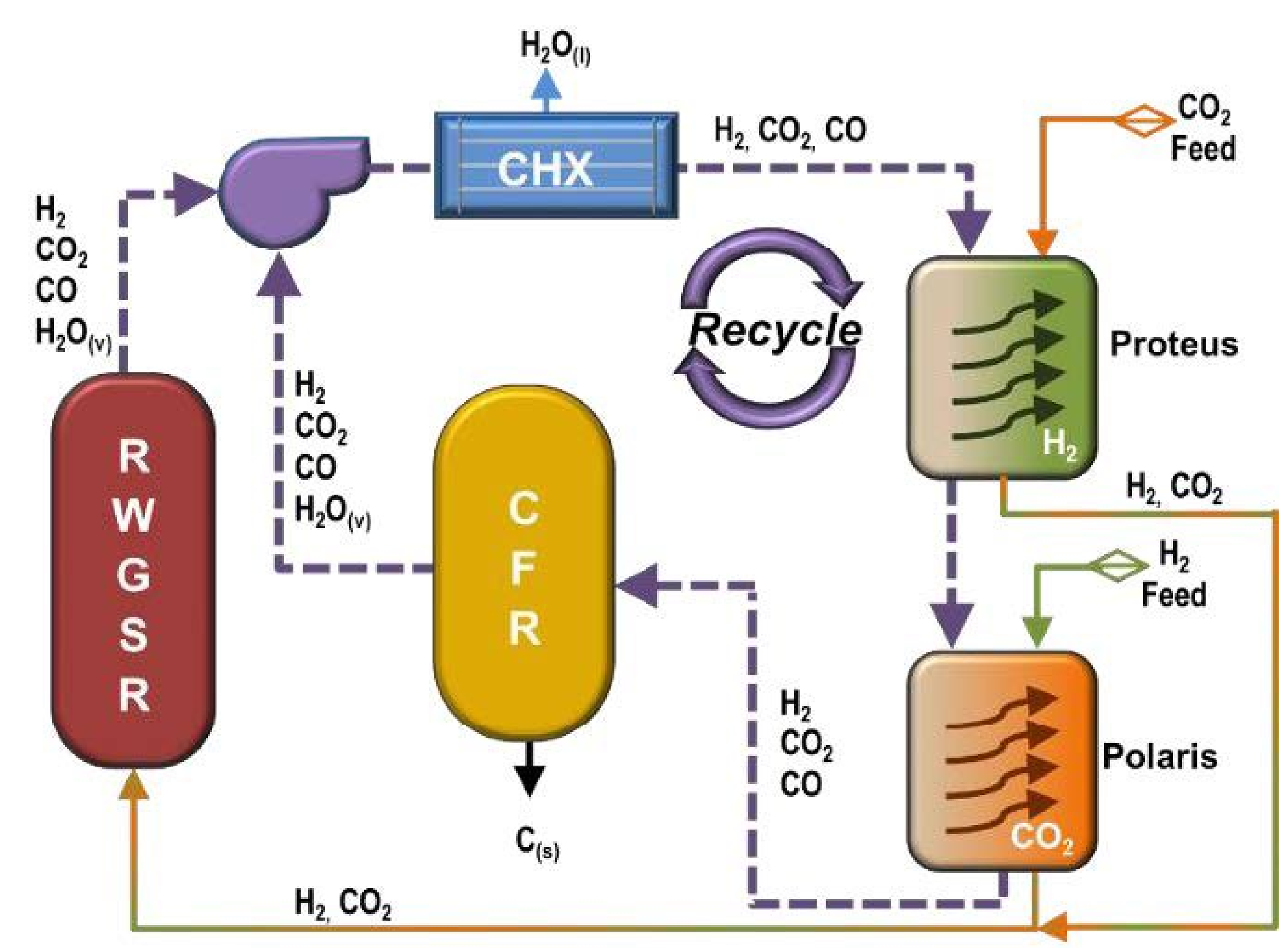


Illustration of S-Bosch system. Credit: Z. Greenwood, et al., 2018.