

High-Temperature Chemistry in Future Industrial Processes – Daniel Lindberg

"Honorable Chancellor, Rector, Deputy Rector, Vice-Rectors, and distinguished practitioners and friends of science:

It has been exactly 30 years since I began my studies at Åbo Akademi. Had anyone asked my classmates at Pargas Svenska Gymnasium—or my parents—what they thought I would be doing in 2026, many would likely have guessed that I would be working as a professor of chemistry or physics at a university, possibly at Åbo Akademi. This has sometimes been a source of frustration; for instance, I haven't been able to surprise my old classmates with my career choice—most recently at my 30-year class reunion this past summer—because the usual reaction is simply that this was exactly what was expected. Perhaps I should have become what I wanted to be as a child instead: a mail carrier who only delivers the mail in the middle of the day.

It is perhaps not so surprising that I began my studies and have subsequently spent a large part of my research career at Åbo Akademi. Both my parents were educated at Åbo Akademi, and both spent the majority of their professional lives there. Just as I have always felt that Turku is a suburb of Pargas, Åbo Akademi felt like an extension of my home—specifically the two buildings by the Cathedral Square: Geologicum and the FÄ building (Administration building).

A side effect of my parents' careers at Åbo Akademi was that, through dinner-table conversations at home, I formed quite a vivid impression of various rectors, directors, managers, and professors long before I ever met them in real life.

I had originally set my sights on studying engineering geology or mining engineering at the Helsinki University of Technology in Espoo, but I ultimately decided to apply for geology and chemistry at Åbo Akademi University. I eventually chose geology—despite well-intentioned warnings from my father, himself a trained geologist,

given the rather bleak career prospects for geologists in the mid-1990s. Even during my studies, I developed a strong interest in high-temperature processes, particularly the formation of rocks from lava and magma. Throughout my subsequent research career, I have maintained a focus on the chemistry and properties of melts. After a successful exchange year at the University of Tromsø in Norway—where I melted rocks in the laboratory for my master's thesis—I planned to move back to Norway to pursue doctoral studies. However, obstacles arose: my prospective Norwegian supervisor took a sabbatical immediately after I finished my studies, delaying my plans, and subsequently died in an accident in the Norwegian mountains.

By that stage, however, I had already connected with the Laboratory of Inorganic Chemistry through Leena Hupa—then a lecturer, later a professor—serving first as a course assistant and subsequently as a doctoral student under Mikko Hupa. That path led me to become a researcher in chemistry and chemical engineering, focusing on high-temperature chemistry in combustion processes, specifically thermodynamics and ash melting.

In 2018, my career path eventually led me to the Helsinki University of Technology—by then Aalto University—where I became a professor of metallurgy and continued researching high-temperature metallurgical processes before returning to Åbo Akademi a year ago.

The actual theme of the day is high-temperature chemistry in future industrial processes. It is therefore useful to define what we mean by "high temperatures." We might consider 30 degrees on a fine summer day to be a high temperature, or think of baking something in an oven at 250 degrees as a high-temperature process. Clearly, then, it is not entirely obvious what is meant when we speak of high temperatures, high-temperature processes, or high-temperature chemistry. I can offer a couple of alternative explanations for what might be defined as a high temperature, based on some connection to physicochemical phenomena.

Throughout my career, the figure of 500 degrees has frequently come up. Why 500 degrees?

One explanation relates to how we visually perceive various materials that have reached a temperature of 500 degrees. Below 500 degrees, materials primarily emit infrared radiation; however, just above 500 degrees is the point where most solid materials begin to emit radiation in the visible spectrum—in other words, they start to glow.

I draw an alternative threshold for what constitutes a "high temperature" from the field of process metallurgy. A common distinction is made between hydrometallurgy and pyrometallurgy—that is, processes involving water versus processes involving fire, or high temperatures. If we take water as our starting point, most people know that its boiling point is 100 degrees. Many of you are likely also aware that the boiling point of water can be raised by increasing the pressure, but there is a limit to how much it can be raised. A point is reached where it is no longer possible to distinguish between liquid water and water vapor. This is called the critical point of water, and the highest boiling point of water is 374 degrees.

So, I leave it to you in the audience to define the lower limit for high-temperature processes, but these two options mark where I draw the line.

If one defines a minimum threshold for high-temperature processes, it is arguably possible to define a maximum limit as well.

When it comes to common industrial processes, practical limits are encountered:

For instance, in the steel industry or in coal- and gas-fired power plants, maximum temperatures remain below 2,000 degrees—typically around 1,600–1,800 degrees—because the materials used to construct the reactors and furnaces cannot withstand conditions beyond that.

Regarding high-temperature chemistry, we can also envision a theoretical upper limit. At sufficiently high temperatures, chemical compounds cease to exist;

instead, all matter dissociates into atoms and ions—a state known as plasma. At this point, high-temperature chemistry transitions into high-temperature physics—a subject best left for someone else to describe at a future professorial inauguration.

Finnish expertise has played a significant role in the development of industrial high-temperature processes. Finnish companies have held a world-leading position in developing technologies for the combustion of biomass and black liquor from the pulp and paper industry—such as fluidized-bed boilers and recovery boilers. Similarly, the company Outokumpu developed the flash smelting process, which is the leading technology for copper smelting. Today, Finnish companies such as Valmet and Metso are global leaders in their respective sectors. What, then, is driving the development of industrial high-temperature processes—such as those involved in the thermal conversion of solid fuels or pyrometallurgical operations? A key driver is the green transition: the need to develop processes with significantly lower carbon footprints than current state-of-the-art. This is particularly evident in iron and steel production, a major global source of CO₂ emissions. Centuries ago, biomass in the form of charcoal was used to reduce iron ore to pig iron; while this process might—by certain metrics—have been considered carbon-neutral, it was hardly sustainable. Later, the industry shifted to using coal and coke in various smelting processes. To move away from coke usage in the future, several alternatives exist, such as electrifying the smelting processes. This is already happening to some extent on an industrial scale in steel production from scrap, but there are also advanced plans to produce steel and other metals via molten oxide electrolysis—a process that uses electricity to split ore minerals into metal and oxygen. Such processes have been proposed for the simultaneous production of metals and oxygen at future bases on the Moon or Mars. Although the process is conceptually straightforward, significant challenges remain in identifying suitable materials—durable and cost-effective enough—to implement these methods on a large scale. Another option is

to replace coke with hydrogen—an approach that is already quite advanced, with several major projects underway in Northern Sweden and potentially in Finland in the near future. A third alternative is to replace coke with biochar or biocoke. However, the current challenge is that biocoke can be more expensive to produce and generally possesses inferior properties compared to metallurgical coke. Our research group, in collaboration with other Finnish universities, has been involved in projects investigating how to improve biocoke production methods—such as pyrolysis—and how to modify its properties (e.g., through various leaching techniques) to enhance quality and make it comparable to metallurgical coke.

Another potential future process our group is researching involves burning black liquor in oxygen-enriched environments within the pulp and paper industry's recovery boilers; this aims to concentrate—and potentially recirculate—CO₂, thereby improving the prospects for carbon capture. Challenges arise because the existing chemical processes within recovery boilers are highly complex, particularly regarding emissions control and chemical recovery. Encouragingly, Finnish recovery boiler manufacturers are showing interest in developing these next-generation processes in collaboration with Åbo Akademi.

In closing, I am delighted to have returned to Åbo Akademi. For a long time and in many situations, I have felt that I was suffering from so-called "imposter syndrome." I am a geologist who earned a doctorate in chemistry; I became a Doctor of Science in Technology without having an engineering degree, and I became a professor of metallurgy without having taken a single course in the subject—but now that I have become a professor of high-temperature chemistry and technology, I have finally found my true calling.

Thank you very much!