Low Carbon Energy Solutions: Data Centres as Anchors for SOFC and Green Ammonia Deployment

Author: Himanshu Majeethia, Regional Director – Global Energy

Commitment to net-zero emissions by 2050 necessitates innovative solutions across all sectors, and data centres, as significant energy consumers, are a crucial area of focus. While previously reliant on grid electricity largely powered by natural gas, data centres can become anchors for deploying Solid Oxide Fuel Cells (SOFCs) and green ammonia, paving the way for a sustainable energy ecosystem.

The Energy Intensity of Data Centres: A Call for Decarbonisation

Data centres, the backbone of the digital economy, are energy-intensive facilities that require a continuous and reliable power supply. The increasing demand for cloud computing, streaming services, and data analytics is driving a surge in data centre energy consumption, making their decarbonisation a priority.

SOFCs: Enabling Efficient and Resilient On-Site Power

Solid Oxide Fuel Cells have revealed their potential, for electricity generation compared to other fuel cell technologies due to their high electrical efficiency, fuel flexibility, integration possibilities with combined heat and power (CHP) setups and relatively low upgrade costs.

SOFCs are composed of four key components:

- Anode: The site where fuel oxidation occurs, releasing electrons.
- Cathode: The site where oxygen reduction occurs, gaining electrons.
- Electrolyte: The solid oxide material that conducts oxygen ions between the anode and cathode.
- Interconnect: The material that electrically connects individual fuel cells in a stack.

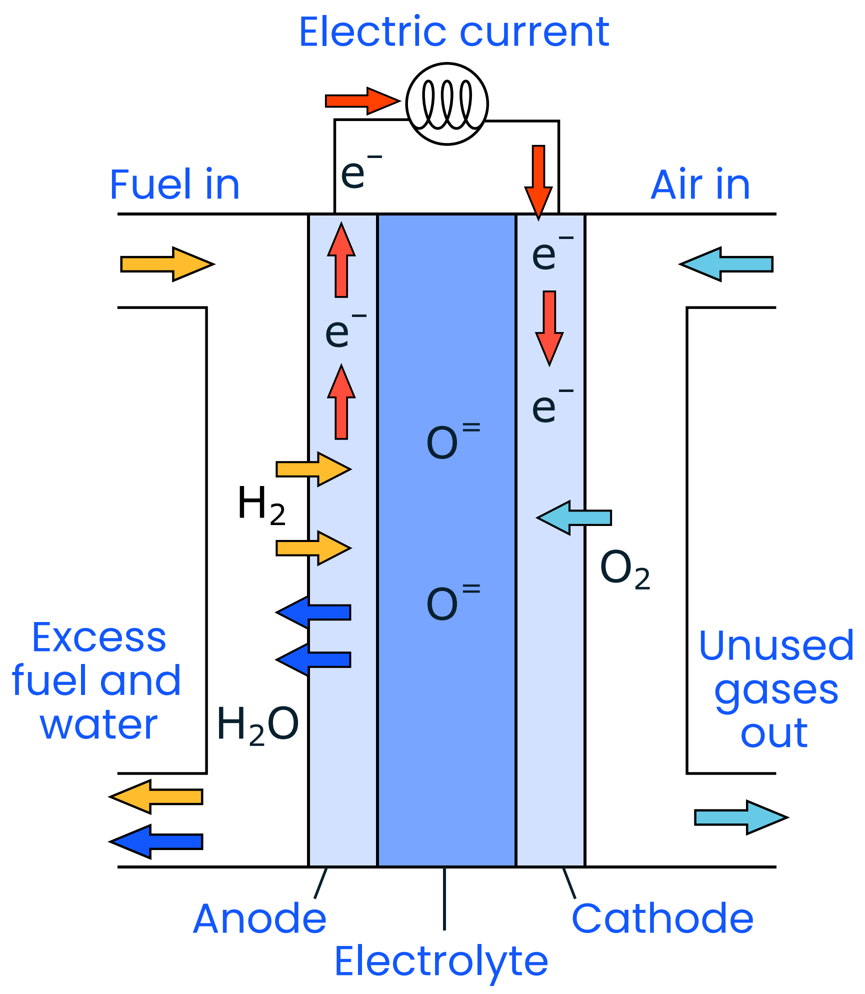

Figure 1: Schematic of solid oxide fuel cell

Source: Solid oxide fuel cell - Wikipedia

A SOFC is an electrochemical conversion device that produces electricity by oxidising a fuel. SOFCs are characterised by their use of a solid oxide material as the electrolyte. This solid electrolyte, typically a ceramic material such as yttria-stabilised zirconia (YSZ), allows oxygen ions to flow through it at high temperatures (typically 600°C to 1,000°C).

Oxygen from the air gains electrons at the cathode, forming oxygen ions. These ions migrate through the electrolyte to the anode, where they react with the fuel (hydrogen or methane), releasing electrons and generating electricity. The half-cell reactions are as follows:

Cathode: $O_2 + 4e^- \rightarrow 2O^{2-}$

Anode: $H_2 + O^{2-} \rightarrow H_2O + 2e^-$ (for H_2 fuel) or $CH_4 + 4O^{2-} \rightarrow 2H_2O + CO_2 + 8e^-$ (for methane)

SOFCs offer a compelling solution for on-site power generation in data centres, offering several key advantages:

- **High Electrical Efficiency:** SOFCs achieve typical electrical efficiencies of 60-65% that can be enhanced to 90% through heat integration, significantly higher than traditional power plants. This translates to reduced fuel consumption and lower emissions.
- **Fuel Flexibility:** SOFCs can operate on various fuels, including natural gas, biogas, and green hydrogen, providing flexibility in transitioning to cleaner energy sources.
- **Enhanced Resilience:** On-site SOFC systems provide a more resilient power source, reducing dependence on the grid and mitigating the risk of costly power outages.
- **Scalability:** SOFCs are modular and scalable, allowing data centres to tailor their power generation capacity to meet their specific needs.

Case Study

SOFC-Powered Data Centre for Enhanced Resilience and Sustainability

Consider a data centre aiming to reduce its carbon footprint and enhance power resilience by implementing a 100 MW SOFC system powered by a blend of natural gas and hydrogen.

This system not only significantly reduces the data centre's reliance on the grid, boosting its energy independence, but also lowers emissions by partially using zero- or low-carbon fuels such as ammonia, hydrogen, hydrogen-blended natural gas, and biogas. Additionally, the SOFC's exhaust heat is captured and utilised to power an absorption chiller for cooling, further improving energy efficiency, reducing operating costs, and minimising environmental impact.

From a technical design perspective, the SOFC system's integration requires careful consideration of fuel processing, air management, thermal management, and power conditioning. Advanced control systems are necessary to optimise performance and ensure reliable operation.

Integrating SOFCs and Green Ammonia: A Synergistic Approach

Green ammonia is produced by synthesising ammonia using hydrogen generated exclusively from renewable energy sources, making the process carbon-neutral and sustainable and presents a viable pathway to further decarbonise data centre operations.

Ammonia (NH3) is an efficient carrier of hydrogen. Liquified ammonia (-33°C) has a higher volumetric energy density than compressed hydrogen gas (350 bar), allowing renewable energy to be transported over long distances and it can be cracked back into nitrogen and hydrogen, and the hydrogen used in the SOFC.

The production begins with water electrolysis powered by renewable electricity - such as solar, wind, or hydro - to split water into green hydrogen and oxygen. This green hydrogen is then combined with nitrogen extracted from the air through the Haber-Bosch process, which involves reacting hydrogen and nitrogen at high pressure and temperature in the presence of a catalyst to form ammonia.

Ammonia serves as an efficient hydrogen carrier due to its easier liquefaction and transport compared to pure hydrogen, enabling energy storage and global distribution.

When the liquid NH3 shipment is received at the NH3 receiving terminal, the ammonia is first regasified before undergoing ammonia cracking to produce hydrogen. This hydrogen is then utilised in Solid Oxide Fuel Cells (SOFCs) for highly efficient, near-zero-emission power generation for the data centre usage. This synergy maximises efficiency, reduces emissions, and enhances energy security.

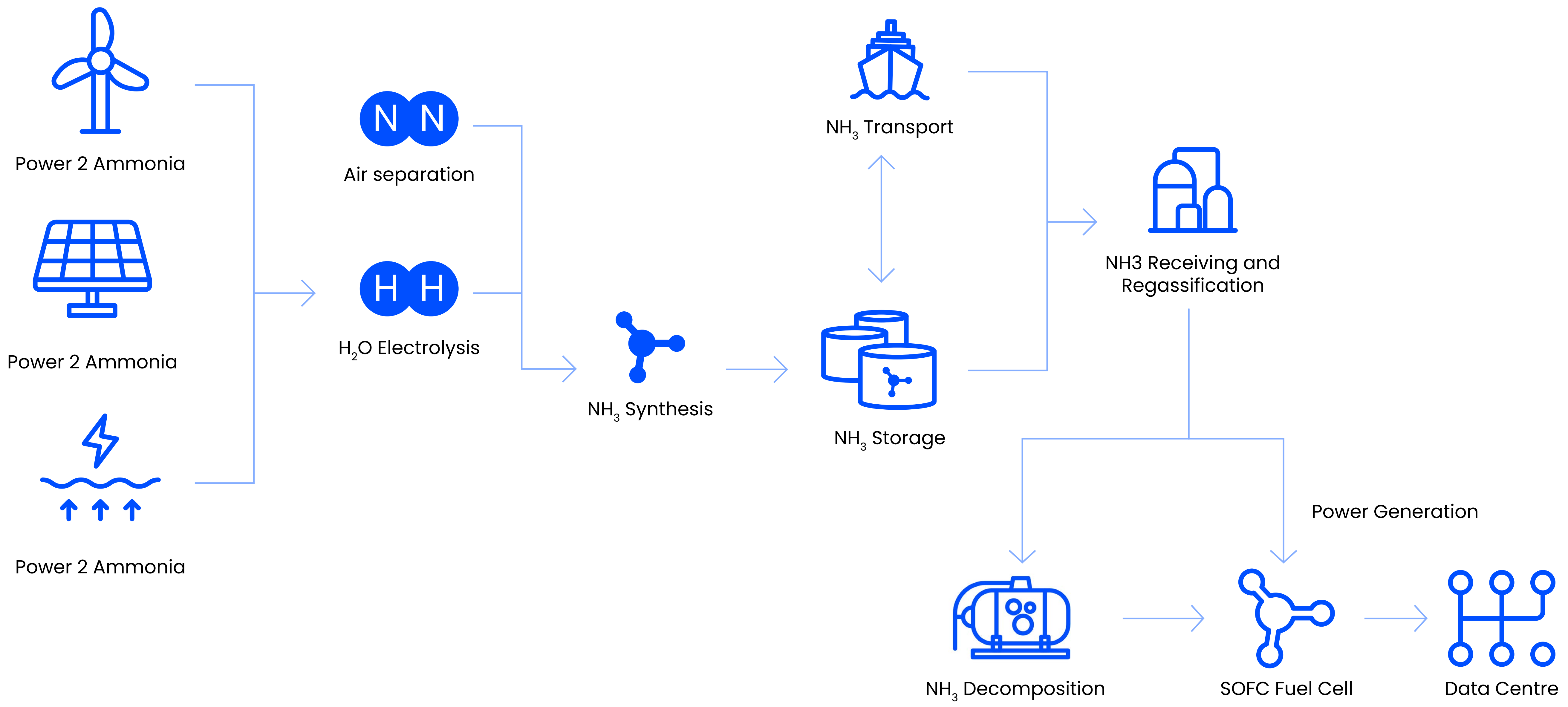

Figure 2: Green ammonia and SOFC value chain

There are however technical considerations for ammonia integration to be considered, including the catalytic cracking process, where ammonia is converted into hydrogen using catalysts such as Ni/Al_2O_3 at temperatures ranging from 600 to 800°C, achieving approximately 85% conversion efficiency.

Additionally, controlling NOx emissions is critical, as burning ammonia produces nitrogen oxides; therefore, post-combustion treatment involves Selective Catalytic Reduction (SCR) using catalysts like V_2O_5-WO_3/TiO_2 to effectively reduce NOx emissions to acceptable levels.

To support this integration, data centres also need to build in spatial considerations and allocate space for SOFC systems, ammonia storage, and cracking units. A conceptual rendering suggests that a 100MW SOFC system, with the plot space required for CO2 capture, would require approximately 4 hectares in addition to the space required for the data centre itself.

Figure 3: SOFC 100 MW Conceptual Rendering

Implementation Barriers to SOFC and Green Ammonia Adoption in Data Centres: A Multi-Faceted Challenge

While SOFCs and green ammonia offer a promising path to decarbonise data centres, several key challenges must be addressed.

Safety and Regulation: Stringent safety protocols are vital for toxic ammonia, requiring comprehensive training and risk mitigation. A clear regulatory framework, including ammonia-specific standards for power generation application, is currently lacking.

Infrastructure and Supply Chain: Significant investment is needed for specialised ammonia storage, cracking units (to produce hydrogen), and reliable green ammonia supply chains. Space constraints can pose a challenge for infrastructure development.

Economic Viability: High upfront costs for SOFC and ammonia infrastructure need to be addressed. Green ammonia and SOFCs must become competitive with conventional fuels through carbon pricing, subsidies, and financial incentives.

Technological Maturity: Further R&D is needed to improve SOFC durability, reduce maintenance, and enhance ammonia cracking efficiency. Waste heat recovery systems must also be cost-effective and easily integrated.

Public Acceptance: Addressing public concerns about ammonia safety through transparency and education is crucial. Greater awareness is needed regarding the benefits of SOFCs and green ammonia.

Overcoming these barriers requires a collaborative effort from government, industry, and research institutions through targeted policies, incentives, and public engagement.

Conclusion: Data Centres Leading the Way

In conclusion, the pursuit of a sustainable energy future hinges on the strategic integration of SOFCs and green ammonia, especially within energy-intensive sectors like data centres.

While these technologies offer significant advantages in terms of efficiency, resilience, and emissions reduction, their successful deployment requires a concerted effort to overcome implementation barriers.

These include addressing safety concerns with robust regulations, developing the necessary infrastructure and supply chains, ensuring economic viability through incentives and carbon pricing, promoting technological maturity through further R&D, and fostering public acceptance through education and transparent communication.

By proactively tackling these challenges, we can unlock the transformative potential of SOFCs and green ammonia and secure a more sustainable future.

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