A Circular Economy for Niobium

The Potential for Closed-loop Recycling

INTRODUCTION

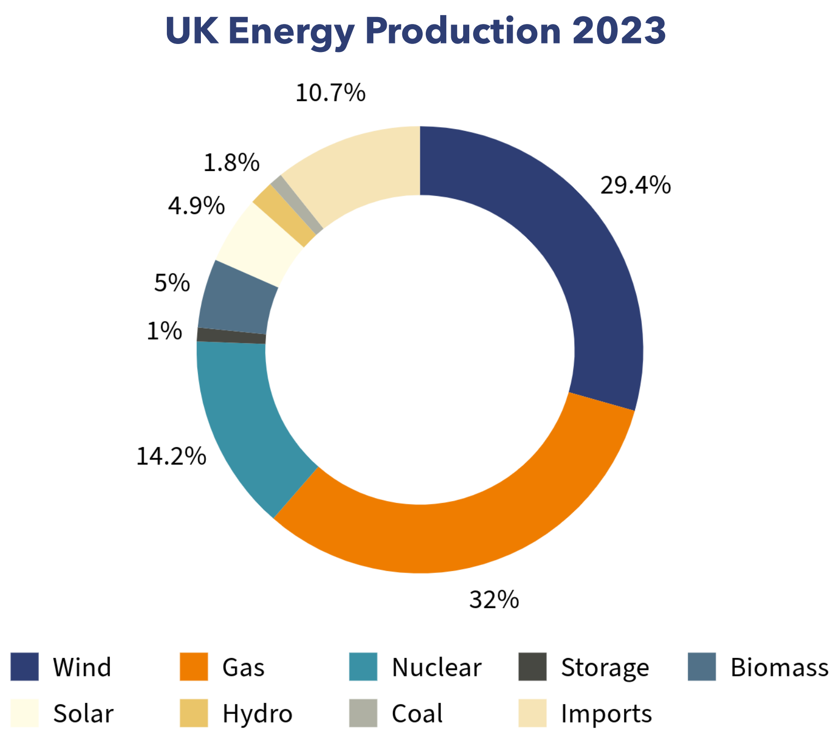
The recovery of niobium in its elemental form as a metal is challenging and when used in low concentrations it is economically difficult to justify. However, where there are known sources of potential end-of-life scrap that can be readily isolated, functional recycling within alloy systems becomes a real possibility. This article looks at the opportunity that offshore wind turbine towers may provide as a discreet source of niobium (Nb) for functional recycling in alloy steels rather than seeking to extract the niobium.

BACKGROUND

The first commercially available steels containing niobium were produced in the 1950's and in the subsequent decades high-strength, low-alloy (HSLA) steels gained wide acceptance owing to their superior performance characteristics. Today, the single largest use of niobium is as an alloy addition in HSLA steels where levels of around 0.03% - 0.04% are conventionally used to increase strength and toughness. HSLA steels are used in a wide range of applications where high strength, toughness and fatigue performance is required. Their ability to develop high strengths also makes them valuable in lightweighting for fuel efficiency in the automotive sector where material thickness can be reduced without compromising vehicle safety.

WIND ENERGY

Another important and growing application where HSLA steels are finding favour is wind power. Renewables are important to the future of the net-zero economy and wind power is a leading source of energy in that regard: in 2023, wind power accounted for 29.4% UK energy capacity[1] around 50% of which was located offshore. The UK is aiming to install a further 50GW of new offshore wind capacity by 2030 from the current level of 28GW. To support this aspiration new facilities for the manufacture of wind turbine components and their subsequent deployment are currently being developed by SeAH Wind at Teesside and Haventus at Ardersier Port, Moray Firth.



The average power output of an individual wind turbine has approximately doubled from 6MW to around 12MW in the last 10 years. This increase has been accommodated by better nacelle design and larger rotor diameters which now require steel towers of 100m or more in height. Increased tower heights allow turbines to access higher wind speeds and provide for a greater swept area of the rotors. A steel tower of this type is typically manufactured in conical sections fabricated from steel plate of progressively thinner sections and may weigh of the order of 600 tonnes.

WIND TOWER DESIGN & HSLA STEELS

The demand for taller wind towers has created new challenges for architects, civil engineers, fabricators, and designers. The well understood ferrous metallurgy of HSLA steels allows for the optimisation of static and dynamic properties of tubular structures hence taller, lightweight fabrications with excellent weldability, fatigue and fracture strength and low temperature toughness are possible to meet the demanding environmental conditions of wind farm locations such as the North Sea. Niobium treated S355, S420 and S460 with up to 0.05% Nb can meet the demands of high strength, toughness and fatigue performance.

Niobium containing steels have advantages not just over traditional steels but also competing materials such as concrete. Chief among the advantages of steel over concrete is its recyclability; concrete is very difficult to recycle and efforts to do so almost invariably default to low-grade applications such as crushed aggregate.

END-OF LIFE OPPORTUNITY

The average lifespan of a wind turbine is 20 to 25 years. Decommissioning can be delayed through life extension and repowering but ultimately the most likely outcome for an offshore wind tower at end-of-life is to be brought ashore and scrapped. Although steel is the most recycled material in the world, niobium is generally dissipative as a result of being diluted by the presence of low alloy steels in the scrap recovery process. However, where scrap containing niobium is collected and reused in the steelmaking process, its functional role can be restored with further additions of primary material.

CLOSED-LOOP RECYCLING

Electric arc furnace (EAF) steelmaking utilises scrap steel as feedstock rather than iron ore. The EAF process reduces CO_2 emissions to around 20% of those compared to blast furnace (BF) steelmaking. With increasing use of renewables this gap will widen as grid supply is further decarbonised. Ferrous materials make up an estimated 80-90% of a wind turbine's mass and approximately 50% of its total lifecycle emissions. Working with steel giant ArcelorMittal, Vestas claim to have achieved a 66% reduction in emission intensity per kg of steel by utilising EAF steel from Mittal's Industeel Charleroi plant in Belgium.

The carbon footprint of steel made by the blast furnace route is approximately 2 tonnes of CO_2 per tonne of steel. By utilising the EAF process Siemens Gamesa aims to reduce the CO_2 associated with the steel plates for its wind turbine towers by 63%. The Greener Tower concept will reduce CO_2-equivalent emissions whilst maintaining steel properties and quality.

There is currently no manufacturer of offshore wind turbine towers in the UK. However, the UK has a long history of EAF steel production with existing facilities at Liberty (Rotherham), Celsa (Cardiff), Sheffield Forgemasters, and Marcegaglia (Sheffield); new capacity to replace existing blast furnace steelmaking is planned at TATA Port Talbot and British Steel Scunthorpe.

IMPACT

The lower CO_2 potential of EAF steelmaking has led to what some analysts are referring to as the 'dash for scrap' to provide the necessary feedstock. In addition, however, when HSLA steels are recovered for remelting, critical minerals such as niobium may be functionally recycled. There may be some losses requiring compensation with new material but the niobium will be largely retained and will contribute to further alloying performance in new casts. In 2023 there were 2695 wind turbines installed in UK offshore waters (predominantly in the North Sea) equating to around 1.6m tonnes of steel or enough to run a typical EAF plant for a year. Owing to different installation and decommissioning dates only a fraction will become available in any one year but with a typical heat size of around 150 tonnes there is clearly scope for batches of Nb-bearing steel to be processed without significant dilution and thus largely preserve the role of niobium as an alloying element.

CONCLUSION

Circularity from low carbon energy production through low carbon steelmaking to end-of-life functional recycling of critical materials requires strategic scrap management. This necessarily includes traceability, separation and transportation as well as quality control. Moreover, installed wind turbines nearing the end of their useful life should be considered strategic inventory by EAF steelmakers looking to promote circular economy for critical minerals as well as minimising their CO_2 footprint. To facilitate this, information flows need to be made visible between scrap supplier and steel maker engaging any intermediaries such as metal recycling companies where towers can be dismantled, composition verified and broken down for ease of handling.

Further R&D will doubtless be necessary to ensure maximum recovery of niobium's functional role from scrap steel via the EAF process. This may include the examination of casting behaviour, rolling conditions and controlled cooling.

References

[1} National Grid ESO, 2024. *Britain's Electricity Explained: 2023 Review.* [Online]
Available at: https://www.nationalgrideso.com/news/britains-electricity-explained-2023-review

For further information visit:

https://www.betatechnology.co.uk/about-niobium/

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