Neutral beam injection (NBI) is attractive as an actuator for non-inductive current drive in a steady-state DEMO or fusion power plant (FPP) due to its excellent current drive efficiency. Using NBI on a power producing device demands a high wall-plug efficiency in excess of 60% that in turn requires the use of negative ions and improved neutralizer concepts such as the laser neutralizer. Furthermore, very-long-pulse or continuous operation of an NBI beamline requires vacuum pumps which do not need cyclic regeneration of a kind that would release gas into the beamline volume. All of the mentioned technologies are at the development stage. On top of that, a steady state DEMO or FPP has to have a high level of availability, and so do its components. This probably makes some degree of redundancy inevitable for the NBI system and calls for failsafe designs in such critical areas as water cooled components.

Moving from pulsed (via long pulse) to continuous operation, also means moving from an operational regime where fatigue due to cyclic loads as a lifetime-limiting failure mechanism will be replaced by wear, predominantly due to mechanisms such as sputtering, redeposition, and material damage due to neutron irradiation. This applies for example to the ion source that is prone to sputter erosion due to backstreaming ions or the high-reflectivity mirrors of a laser neutralizer that are in danger of degrading as a result of plasma–surface interaction and neutron damage.

Apart from these technological needs, the major remaining challenge regarding the physics of negative ion NBI is the stable long pulse or steady state operation of the ion source itself. With the current technology negative ion production relies on the conversion of hydrogen neutrals and positive ions on caesiumated surfaces. While stable plasma generation in the rf source driver and a stable extracted negative ion current was demonstrated up to one hour at the ELISE test stand, the currents of co-extracted electrons increase steadily during long pulses. The detailed understanding of the underlying dynamics of Cs in the source and of possible solutions is, however, gradually improving.

In this paper we identify the technological and physical gaps and issues and give hints on possible solutions.