Publication No. 2003/064014 (Kumar et al.) and U.S. Patent No. 8,940,263 (Golden, et al.) The Kumar et al. reference shows that it has been well known for over 20 years that a hopcalite catalyst removes hydrogen and carbon monoxide from air, and is particularly useful for removing both carbon monoxide and hydrogen from a feed air stream during pre-purification in cryogenic air separation units. Golden, et al. also discloses the use of a single layer of hopcalite for removal of substantially all of the hydrogen and carbon monoxide. The examples in Golden et al. confirm what is taught in Kumar et al. that hydrogen is chemisorbed in the single layer of hopcalite material such that the use of a longer bed of hopcalite catalyst which translates to longer residence times of the dry gas in the hopcalite layer generally improves the hydrogen chemisorption process in the hopcalite material

(00013) While the above-identified prior art pre-purification systems and methods target removal of impurities such as hydrogen, carbon monoxide, water, and carbon dioxide from feed air streams, the relative costs associated with pre-purification systems and methods remain high. Accordingly, there is a continuing need to improve such pre-purification systems and processes, particularly to reduce the costs of such pre-purification without sacrificing performance. In other words, there is a need for improved systems and methods for pre-purification of an incoming feed air stream to a cryogenic air separation unit, including substantial removal of hydrogen, carbon monoxide, water and carbon dioxide in the production of high purity or ultra-high purity nitrogen that has cost advantages and performance advantages over prior art pre-purification systems and methods.

Summary of the Invention

(00014) A first aspect of ~~The~~ the present invention may broadly be characterized as a method of purifying a gas stream to remove the hydrogen and carbon monoxide impurities present in the gas stream, the method comprising: (a) passing the gas stream substantially free of carbon dioxide and water through a first catalyst layer comprising a mixture manganese and copper oxides configured to remove at least some of the carbon monoxide and

hydrogen from the gas stream and produce a first intermediate effluent; (b) passing the first intermediate effluent through an adsorbent layer disposed downstream of the first catalyst layer, the adsorbent layer configured to remove water and carbon dioxide from the intermediate effluent and produce a second intermediate effluent; and (c) passing the second intermediate effluent through a second catalyst layer disposed downstream of the adsorbent layer, the second catalyst layer configured to remove at least hydrogen from the second intermediate effluent to yield an intermediate purified stream. The method of purification is ideally suited for use in pre-purification of a feed air stream in an air separation unit. Optionally, a further step (d) may be included that involves passing the intermediate purified stream through a second adsorbent layer that is configured to remove water and carbon dioxide from the intermediate purified stream and produce a purified stream.

(00015) A second aspect of the~~The~~ present invention may also be characterized as a pre-purification vessel configured for use with an air-separation unit comprising: a pre-purification vessel having an inlet configured to receive a stream of compressed feed air and an outlet configured to direct a purified, dry air stream substantially free of water, carbon dioxide, carbon monoxide and hydrogen; ~~(i)~~ a first purification section disposed within the pre-purification vessel comprising at least one layer of adsorbent configured to remove water and carbon dioxide from the compressed feed air stream and yield a dry feed air stream substantially free of water and carbon dioxide; ~~(ii)~~ a second purification section disposed within the pre-purification vessel downstream of the first purification section, the second purification section comprising a first catalyst layer comprising a mixture manganese and copper oxides configured to remove at least some of the carbon monoxide and hydrogen from the dry feed air stream and produce a first intermediate effluent; an adsorbent layer disposed downstream of the first catalyst layer, the adsorbent layer configured to remove water and carbon dioxide from the first intermediate effluent and produce a second intermediate effluent; and a second catalyst layer disposed downstream of the adsorbent layer, the second catalyst layer configured to remove at least hydrogen from the second intermediate effluent to yield an intermediate purified air stream; and ~~(iii)~~ a third purification section disposed within the vessel downstream of the second purification section and comprising at least one other layer of adsorbent configured to remove water