Analisis Tekno-Enviro-Ekonomi Produksi Amonia Hijau Melalui Elektrolisis Berbasis Pembangkit Listrik Tenaga Solar, Panas Bumi, dan Air = Techno-Enviro-Economic Analysis of Green Ammonia Production by Electrolysis Based on Solar Photovoltaic, Geothermal Power Plant, and Hydropower Plant

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Abstrak

Produksi amonia hijau dengan green hydrogen—elektrolisis air—dapat mempercepat penurunan emisi karbon sampai dengan 41% dari total produksi amonia global pada 2050. Namun, perbedaan penurunan nilai emisi berbagai skema sistem produksi dan rendahnya biaya produksi amonia hijau terhadap fossil-based ammonia mendorong penelitian aspek teknis sistem produksi amonia hijau dilakukan sebagai dasar analisis aspek lingkungan dan ekonomi dari variasi penggunaan sumber energi sistem produksi amonia hijau. Variasi sistem ditinjau dari tiga jenis sumber energi terbarukan, yaitu photovoltaic (PV)-baterai, pembangkit listrik tenaga panas bumi (PLTP), dan pembangkit listrik tenaga air (PLTA), sedangkan sistem secara keseluruhan terdiri atas unit elektrolisis air dengan teknologi alkaline electrolyser (AEL), unit separasi udara dengan metode distilasi kriogenik, dan unit sintesis amonia hijau dengan metode Haber-Bosch. Analisis aspek teknis dilakukan dengan simulasi proses ASPEN Plus, aspek lingkungan dengan metode life cycle assessment (LCA) serta ruang lingkup cradle-to-gate, dan aspek ekonomi dengan metode levelized cost untuk mendapatkan efisiensi energi sistem, nilai emisi CO2eq, dan levelized cost of ammonia (LCOA). Hasil penelitian menunjukkan bahwa efisiensi energi sistem pada konfigurasi sistem PLTA-AEL sebesar 39,16%, lebih tinggi secara signifikan dibandingkan PLTP-AEL (8,45%) dan PV-AEL (6,71%). Tinjauan aspek lingkungan menunjukkan bahwa PLTA-AEL dinilai paling menguntungkan dengan nilai emisi 0,84 kg CO2eq/kg NH3, diikuti oleh PLTP-AEL dan PV-AEL sebesar 0,87 kg CO2eq/kg NH3 dan 1,14 kg CO2eq/kg NH3 secara berurutan. Di sisi lain, PLTP-AEL menempati posisi teratas dari tinjauan aspek ekonomi dengan nilai LCOA 1.130 USD/ton NH3, diikuti oleh PLTP-AEL sebesar 1.179 USD/ton NH3 dan PV-AEL sebesar 1.356 USD/ton NH3. Aspek ekonomi pada ketiga konfigurasi sistem tersebut, yang belum mampu bersaing dengan grey ammonia, menjadi trade off atas keunggulan aspek lingkungan yang ditawarkan.

.....The production of green ammonia with green hydrogen—from water electrolysis— has the potential to accelerate the reduction of carbon emissions by up to 41% of the total global ammonia production by 2050. However, the differences in emission reduction values from various production system schemes and lower green ammonia production cost compared to fossil-based ammonia drive the research of technical aspects of green ammonia production systems. This serves as the basis for analyzing the environmental and economic aspects of the variations in energy sources used in green ammonia production systems. The variations in the system involve three types of renewable energy sources, namely photovoltaic (PV)-battery, geothermal power plant, and hydropower plant, while the overall system consists of an electrolysis unit using alkaline electrolyser technology (AEL), an air separation unit using cryogenic distillation methods, and a green ammonia synthesis unit using the Haber-Bosch method. Technical aspects are analyzed through process simulations using ASPEN Plus, environmental aspects through life cycle assessment (LCA) method with a

cradle to gate scope, and economic aspects through the levelized cost method so the system energy efficiency, CO2eq emission values, and the levelized cost of ammonia (LCOA) can be obtained. The research results indicate that the overall system energy efficiency of the PLTA-AEL system configuration is 39.16%, significantly higher compared to PLTP-AEL (8.45%) and PV-AEL (6.71%). From an environmental point of view, PLTA-AEL is considered the most advantageous with an emission value of 0.84 kg CO2eq/kg NH3, followed by PLTP-AEL and PV-AEL with 0.87 kg CO2eq/kg NH3 and 1.14 kg CO2eq/kg NH3, respectively. On the other hand, PLTP AEL ranks highest from an economic point of view with an LCOA value of 1,130 USD/ton NH3, followed by PLTP-AEL at 1,179 USD/ton NH3 and PV-AEL at 1,356 USD/ton NH3. The economic aspects of the three system configurations, which are not yet able to compete with grey ammonia, become a trade-off against the environmental advantages they offer.