Green and large-scale production of ammonia: Laser-driven pyrolysis of nitrogen-enriched biomass

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Abstract

As a vital chemical, ammonia (NH₃) plays an irreplaceable role in many fields such as chemical synthesis and energy storage. Green renewable biomass can be converted into biofuels, but its nitrogen resources are underused throughout. Laser-driven pyrolysis is envisaged to debuts as a bridge to connect them to realize the direct conversion from nitrogen-rich biomass into ammonia. The pulsed laser-induced local-transient thermal effect recognized the biological nitrogen resources conversion, such as cheap and plentiful yeasts, to small gaseous molecules and achieved spectacular ammonia production rate up to 260.4 mg/h, an order of magnitude higher performance than thermochemical ammonia synthesis. Simultaneously, the tiny hot point generated by a low-energy laser (20 W) guarantees the whole ammonia synthesis reaction system is in a mild environment of low temperature and normal pressure. Additionally, the remaining solid residue after laser-driven pyrolysis also can be further exploited as a highly active catalyst for electrocatalytic nitrate reduction reaction (NIRR).

KEYWORDS
ammonia synthesis, laser pyrolysis, local temperature field, nitrogen-enriched biomass, wastes recycling

1 | INTRODUCTION

Ammonia (NH₃), as a vital chemical, runs through the production and living of the society and has shown irreplaceable application values in many fields such as chemical synthesis (e.g., agricultural fertilizer and pharmaceutical), energy storage, and hydrogen storage. Especially, NH₃ is an energy storage intermediate and a carbon-free energy
carrier, with high energy density and no CO₂ emissions from combustion, popping up as a candidate green energy vector. In view of this, to achieve highly efficient ammonia synthesis, researchers have invested a lot of attempts on technical routes such as thermocatalysis, photocatalysis, and electrocatalysis. The industrial Haber-Bosch process, converting the reaction mixture into ammonia, is considered the greatest chemical invention of the 20th century and is the main way to artificially fix nitrogen. However, Haber-Bosch process takes place under austere conditions (high temperatures over 400°C and high pressures of 200–300 bar), consuming large amounts of energy and produces large CO₂ emissions (1.6% of the global total). Although both photocatalytic and electrocatalytic synthesis of ammonia using N₂ as the nitrogen source can be carried out at ambient temperature and pressure, they are subjected to the high dissociation energy of N≡N bonds (945 KJ/mol), limited N₂ solubility in the aqueous phase, and competing hydrogen evolution reaction, triggering low activity and low ammonia selectivity. Consequently, it is imperative to explore a novel shortcut for highly efficient ammonia synthesis at mild conditions.

Facing the serious environmental issues (greenhouse effect) caused by fossil fuel depletion and the looming trend of low emission and carbon neutrality, biomass, as the green renewable resource with rich reserves, can be converted into high-value chemicals and biofuels with less greenhouse gas emissions to realize the effective recycling of resources, which is a promising development prospect. On this basis, ammonia synthesis from biomass would be more economical if the hydrogen and nitrogen gases were avoided. Yeasts (Saccharomyces cerevisiae), cheap and easily cultivated microorganisms with abundant biological nitrogen, are frequently employed in food fermentation and wine-making industries but also produce inevitable biological wastes that are difficult to reuse. It is noted that ammonia production from nitrogen-rich biomass offers an attractive alternative route. Currently, the primary pathways for the conversion and utilization of biological nitrogen are the production of nitrogen-rich bio oil and a relatively small amount of ammonia through thermochemical conversion process (pyrolysis and gasification), which is accompanied by high energy consumption.

Rapid pyrolysis by nonradiative heating methods, such as microwave and Joule heating, would significantly improve biomass pyrolysis. The reported microwave pyrolysis exhibited a higher percentage of gas phase and a lower percentage of liquid phase, while inhibiting the formation of tar compared to conventional pyrolysis. In addition, the catalyst-free pyrolysis of plastics to generate micromolecules through Joule heating with a heating rate of 103°C/s was achieved. As a booming technology, laser with high-energy density has been widely applied in the preparation of nanomaterials. A local high-temperature field can be created on the target by laser irradiation. What can be expected, laser-driven pyrolysis possibly provides a bridge to connect biomass resource utilization and ammonia synthesis.

In this work, cheap and available yeasts were used as nitrogen and hydrogen sources for the ammonia synthesis reaction by laser-driven pyrolysis. Pulsed laser interacted with the yeasts to achieve a local-transient thermal effect, resulting in extremely rapid pyrolysis to promote the conversion of nitrogenous macromolecules into small gaseous molecules. Profiting from the high-speed heating rate, ammonia rather than bio oil became the main bio-nitrogen product, which achieved high ammonia yield up to 260.4 mg/h. Additionally, the solid residue remaining after laser-driven pyrolysis was a nitrogen-doped porous carbon with cobalt phosphate nanoparticles, which was turned into treasure for further electrocatalytic nitrate reduction reaction (NIRR). In conclusion, the direct conversion from nitrogen-rich biomass into ammonia was achieved via laser-driven pyrolysis, which opens up a novel pathway for recycling biomass resources for large-scale ammonia synthesis.

2 EXPERIMENTAL SECTION

2.1 Preparation of metal yeast

The dry yeast powder (5 g) was added to 250 mL deionized water and incubated in a culture dish at 35°C for 24 h. Yeast cells were purified to remove possible impurities by centrifugation and washing with water. Subsequently, 1.55 g cobalt acetate ((CH₃COO)₂Co·4H₂O) was dissolved in the above solution and magnetically stirred at room temperature for 24 h. The resulting solution was centrifuged at 9000 rpm for 5 min and washed with deionized water to remove dissociated Co²⁺ and obtain Co-Yeast. In addition, following the above steps, yeast adsorbed a variety of metal ions (15 mM Cu²⁺, 10 mM Fe³⁺, and 15 mM Ni²⁺) to obtain Fe-Yeast, Cu-Yeast, and Ni-Yeast.

2.2 Laser-driven pyrolysis performance

The experiments were performed in a pulsed laser-driven pyrolytic system (Supporting Information Figure S1). The system was composed of a gas feeding unit, quartz reactor, condensing unit, cleaning unit, and gas detection or collection unit. A total of 100 mg of biomass (Yeast or Co-Yeast) was pressed into a biomass tablet (diameter 13 mm) by a tablet press at a pressure of 100 bar, which was placed in a
Figure 1. (A) Schematic diagram and (B) photograph of products obtained from laser-driven pyrolysis of yeasts.

Figure S3. First, Co^{2+} ions were captured by the organic macromolecules with a negative charge on the surface of yeasts and Co-Yeast powder was obtained by centrifugal and drying treatment. Subsequently, the resulting Co-Yeast powder was pressed into the tablets, which served as biomass hydrogen and nitrogen sources to achieve ammonia synthesis by laser-driven pyrolysis. After the laser-driven pyrolysis of yeasts, the solid (bio-char, 13.4 wt.%), liquid (bio-oil, 6.0 wt. %), and gases (80.6 wt. %, composed of NH_3, H_2, CO, CH_4, and CO_2) were obtained. Specifically, the dominant gas of NH_3 as a high value-added product was collected as NH_4Cl (Figure 1B).

2.3 Determination of products

The laser-driven pyrolysis products were carried by carrier gas at a rate of 150 mL/min from the reactor outlet through the condensing unit in an ice bath (Supporting Information Figure S1). An organic filter membrane intercepted the biochar particles in the carrier gas with a 0.22 μm pore size. Then, NH_3 in the noncondensable gas was absorbed by H_2SO_4 (0.01 M) solution in the double absorption cell, and the remaining gases of H_2, CO, CH_4, and CO_2 were dried and passed to gas chromatography (GC-7900, CEULIGHT) for analysis. The ammonia yield was spectrophotometrically detected using the conventional indophenol blue method. In detail, the reaction gas was absorbed using 2 mL NaOH solution (1 M) containing 5 wt.% salicylic acid and 5 wt.% sodium citrate, and then 1 mL 0.05 M NaClO and 0.2 mL 1 wt.% sodium nitroferricyanide (C_5FeN_6Na_2O) solution were added. After 1 h, the absorbance at a wavelength of ~675 nm of the mixed solution was detected with a UV-Vis spectrophotometer. The concentration of NH_3 was determined from the standard curve fitted with NH_4^+ of known concentration in 0.01 M H_2SO_4 solutions (Supporting Information Figure S2).

3 RESULTS AND DISCUSSION

The laser-driven pyrolysis of yeast after metal ion adsorption is shown in Figure 1A and Supporting Information Figure S3. First, Co^{2+} ions were captured by the organic macromolecules with a negative charge on the surface of yeasts and Co-Yeast powder was obtained by centrifugal and drying treatment. Subsequently, the resulting Co-Yeast powder was pressed into the tablets, which served as biomass hydrogen and nitrogen sources to achieve ammonia synthesis by laser-driven pyrolysis. After the laser-driven pyrolysis of yeasts, the solid (bio-char, 13.4 wt.%), liquid (bio-oil, 6.0 wt. %), and gases (80.6 wt. %, composed of NH_3, H_2, CO, CH_4, and CO_2) were obtained. Specifically, the dominant gas of NH_3 as a high value-added product was collected as NH_4Cl (Figure 1B).

3.1 Characterization of Metal-Yeast

The conglobate yeasts with smooth surfaces were observed by SEM in Figure 2A, and even-distributed signals of C, N, O, P elements were detected in Figure 2B. The N content of yeast cells was 11.8 wt.% determined by the high-temperature combustion method (Supporting Information Table S1), which as nitrogen-rich biomass was used in the laser-driven pyrolysis for ammonia synthesis. In addition, the N 1s XPS spectrum (Supporting Information Figure S4) confirmed that the protein-N was dominating nitrogen in the yeast. The surface of yeast possessed abundant functional groups, such as –OH and –COOH, which exhibited a negative potential of \(-38 \text{ mV}\), as shown in Figure 2C. After adsorption of various metal ions, such as Cu^{2+}, Co^{3+}, Fe^{3+}, Ni^{3+}, the Zeta potentials were changed into \(-23.0, -25.8, -11.3, \text{ and } -19.2 \text{ mV}\), respectively. With the increase of Co^{2+} concentration, the Zeta potential of yeasts gradually increased from \(-38\) to \(-12 \text{ mV}\). It was inclined to be stable due to the saturation when the Co^{2+} concentration exceeded 15 mM (Supporting Information Figure S5). As shown in Figure 2D, the clear solutions were obtained via the adsorption of metal ions by yeast. In addition, the tables pressed by Yeast, Cu-Yeast, Co-Yeast, Fe-Yeast, and Ni-Yeast showed the appropriate color of metal ions.

Take Co-Yeast as an example, the SEM image in Figure 2E shows basically the same morphology with Yeast. The appearance of Co signals confirmed the...
successful synthesis of Co-Yeast by EDS mapping in Figure 2F. The Fourier Transform Infrared spectrum (Supporting Information Figure S6) of yeast before and after cobalt ion adsorption also confirmed the successful adsorption of cobalt ions. The characteristic peaks of the oxygen-containing functional groups (-OH, C=O, -COOH) and the vibration peak of the aromatic and heterocyclic compounds were weakened significantly, indicating the bonding of Co$^{2+}$ with yeast. 

3.2 Thermal effect of laser-driven pyrolysis

Laser, as a kind of high-energy light with the short pulse width and high peak power, can produce ultrafast heating rate and the local thermal effect during the interaction with materials. The thermal effect induced by laser endowed laser-driven pyrolysis with an unrivaled preponderance in performance, which is a far cry from the heating mechanism in the conventional pyrolysis process (Figure 3A). As shown in Figure 3B, extremely rapid heating of 245°C/s could be achieved based on the laser acting on yeasts, and a local high temperature of 900°C was obtained in merely 4 s. During the process of laser pyrolysis, the incident laser energy was absorbed by yeasts, and converted into heat energy directly. In contrast, yeasts were heated by tubular furnace through heat radiation, which would lead to unavoidable energy dissipation originating from heat transfer, resulting in a slow heating rate of 20°C/min.

As portrayed in Figure 3C, the equally good infrared light absorption capacity of Yeast and Co-Yeast was confirmed by UV-Vis-NIR absorption spectra. When the laser acted on Yeast and Co-Yeast tablets, it would trigger a local high temperature, leading to the achievement of extremely rapid pyrolysis to directly convert nitrogen-containing organic matter into NH$_3$ (Figure 3D). As shown in Figure 3E, since the laser action region was extremely small, the localized high temperature was generated. The temperature of the entire reaction reactor was only 34.1°C, and the heat preservation was avoided. As a contrast, the traditional thermochemical system, such as tube furnace, required the insulation materials to maintain high heating temperatures. The laser-induced local high temperatures of 987°C (Yeast, Figure 3F) and 975°C (Co-Yeast, Figure 3G) were detected by the infrared camera. The appropriate sizes of the temperature zone were about 500 and 700 μm, respectively, which were consistent with the sizes of laser etching holes in tablets (Supporting Information Figure S7). In addition, the thermal effect produced by the laser was regarded as basically stable for 600 s in the pyrolysis process (Figure 3H), suggesting the continuous pyrolysis of biomass. In addition, the laser-induced temperatures of Yeast and Co-Yeast showed little difference, consistent with the UV-Vis-NIR absorption spectra, which confirmed the introduction of Co had no significant effect on the laser-induced temperature.
3.3 Laser-driven pyrolysis for ammonia production

Laser interacted with the yeasts to achieve a local-transient thermal effect, resulting in extremely rapid pyrolysis under room temperature and atmospheric pressure to promote the conversion of nitrogenous macromolecules into small gaseous molecules. Profiting from the high-speed heating rate, ammonia rather than bio oil becomes the main bio-nitrogen product. As shown in Figure 4A, for either Yeast or Co-Yeast, the mainstream products of laser-driven pyrolysis were gases (67.0 and 80.6 wt.%) rather than those (44.0 and 54.2 wt.%) of traditional pyrolysis, implying the higher cracking degree of yeast by laser-driven pyrolysis with the transient high temperature. Furthermore, the gas composition was composed of NH₃, H₂, CO, CH₄, and CO₂, in which the primary products of NH₃ were 18.6% (Yeast) and 31.8% (Co-Yeast), respectively (Supporting Information Figures S8 and S9). Under the action of the laser, the ammonia yields showed a linear increase trend with time, and the ammonia production rates of Co-Yeast and Yeast were 260.4 and 143.4 mg/h, as shown in Figure 4B and Supporting Information Figure S10. It was worth noting that the laser-driven pyrolysis of Co-Yeast to synthesize ammonia was very fast, which only need 5 min to obtain the 21.5 mg NH₃. Due to too high ammonia concentration, which needs to be diluted 80-fold before it can be used for spectroscopic detection (inset of Figure 4B). As a contrast, the traditional pyrolysis of yeasts required more 40 min to reach the optimal ammonia production temperature. In 5 min, no ammonia was detected during the traditional pyrolysis.

In addition to the advantage of laser pyrolysis for rapid ammonia synthesis, the ammonia amount produced per unit mass of biomass is also an important evaluation parameter. As shown in Figure 4C, the ammonia yield of the Co-Yeast pyrolyzed by laser was up to 99.34 mg/g<sub>yeast</sub>, outperforming its competitors of Yeast pyrolyzed by laser (52.16 mg/g<sub>yeast</sub>), Co-Yeast by traditional pyrolysis (35.01 mg/g<sub>yeast</sub>), and Yeast by traditional
The ammonia production (21.88 mg/g_{yeast}). The results confirmed that adding Co and laser with a rapid heating rate synergistically promoted sufficient pyrolysis of biomass to produce more ammonia. Ar as a carrier gas is useful for accurate assessment of ammonia production activity, but lower-cost carrier gases need to be used for production. Therefore, the NH₃ yields of Co-Yeast by laser-driven pyrolysis in different atmospheres were measured (Supporting Information Figure S11). The ammonia yields under inert atmospheres of N₂ and Ar were similar (94.9 mg/g_{yeast} /257.9 mg/h and 108.9 mg/g_{yeast} /296.0 mg/h). In addition, the air as a carrier gas produced a slightly lower ammonia yield of 83.5 mg/g_{yeast} /226.9 mg/h due to the oxidizing atmosphere, which consumed H₂ and inhibited NH₃ production. Interestingly, the use of water vapor as a carrier gas improved the ammonia production to 111.7 mg/g_{yeast}/303.6 mg/h because an external hydrogen source was provided by the vapor. The NH₃ yield increased with the increase of water content, implying that more hydrogen supply was conducive to the formation of NH₃ (Supporting Information Figure S12).

The sustainability of laser-driven pyrolytic synthesis of ammonia was demonstrated, as shown in Figure 4D. A total of 282.3 mg of ammonia was obtained by laser-driven pyrolysis of 3 g Co-Yeast in 48 min, which was collected by passing through a hydrochloric acid solution, and finally formed high-purity NH₄Cl (s) powder (834.5 mg, Supporting Information Figure S13).³³

To investigate the mechanism of laser-driven pyrolysis, the yeast-derived biochar products were characterized by...
XRD, XPS, and Raman spectrum. At first, the XRD pattern of biochar obtained by laser-driven pyrolysis and conventional pyrolysis showed similar phase compositions, but the degree of graphitization was higher by laser-driven pyrolysis due to the more complete pyrolysis of yeasts (Supporting Information Figure S14). As depicted in Figure 4E and Supporting Information S15, the content of protein-N for laser-driven pyrolysis was smaller than that of traditional pyrolysis, indicating the promoted decomposition of organic nitrogen in yeasts by laser. Simultaneously, the quaternary-N content of laser-driven pyrolysis was higher than that of traditional pyrolysis because the ring condensation reaction provided more H radicals for the cracking of proteins to obtain the higher ammonia yield. Raman spectra in Supporting Information Figure S16 confirmed that the $I_G/I_D$ ratio of Char-Y-Co (biochar from laser-driven pyrolysis of Co-Yeast) was higher than that of Char-Y (biochar from laser-driven pyrolysis of Yeast), indicating that Co metal promoted the fracture of C-H, C-O, and C-N, and the most stable C-C was retained. In addition, all of the different metals can improve ammonia synthesis to varying degrees by laser-driven pyrolysis (Supporting Information Figure S17). The highest NH$_3$ yield of Co-Yeast by laser-driven pyrolysis implied that both the laser with the transient high temperature and Co metal with enhanced graphitization played the promoting roles in cracking yeasts to NH$_3$. Spirulina platensis was also a kind of nitrogen-rich biomass, and the ammonia production from laser-driven pyrolysis and traditional pyrolysis were also performed in Supporting Information Figure S18, demonstrating the universality of laser-driven pyrolysis for ammonia synthesis.

As is well-known, various technical routes, such as thermocatalysis and photocatalysis, were employed to achieve efficient ammonia synthesis. From a comprehensive perspective in Figure 4F, the ammonia production of 260.4 mg/h by laser-driven pyrolysis outperformed an order of magnitude than previous results, such as thermocatalysis (catalyst: Ni/CoN, NH$_3$ yield: 11.05 mg/h), photocatalysis (catalyst: F-Vo-TiO$_2$, NH$_3$ yield: 1.75 mg/h). In addition, laser-driven pyrolysis only needed a 20 W pulse laser, which consumed one to two orders of magnitude less energy ($2.4 \times 10^{11}$ J/m$^2$/NH$_3$) than the reported ammonia synthesis methods (Figure 4G). Most importantly, the laser-driven pyrolysis of biomass for ammonia synthesis effectively utilized the green and renewable sources of hydrogen and nitrogen, avoiding the consumption of high-value H$_2$. Meanwhile, the generation of laser-induced local high temperatures does not require heat preservation, avoiding heat radiation loss. Therefore, the laser-driven pyrolysis of nitrogen-rich biomass achieved rapid and low-energy ammonia production under mild conditions.

### 3.4 | Electrochemical nitrate reduction reaction to ammonia

Except for gas products, liquid and solid products were also collected. However, the components of liquid products were complex and difficult to be analyzed. It has been confirmed that biochar has the opportunity to become a highly active electrocatalyst. Therefore, the remaining solid residues were collected to be employed as an electrocatalyst to realize electrochemical NIRR (biochar generation and collection, Figure 5A). The incident laser was absorbed within the skin depth of the yeast tablets and was converted into heat in subnanoseconds time. With an organic filter membrane interception, the Char-Y-Co powder synthesized by laser-driven pyrolysis was collected. The laser spot moved at a breakneck speed (500 mm/s) and quickly covered the whole tablet, which pyrolyzed the yeast tablet into powder by transient high temperature (Figure 5B).

The XRD pattern of Char-Y-Co exhibited peaks at 40.72°, 43.30°, 48.71°, 52.03°, and 56.20°, corresponding to the (121), (211), (031), (002), and (320) crystal planes of Co$_2$P, which corroborated the successful formation of Co$_2$P NPs on the carbon matrix (Figure 5C). In the XRD pattern of Char-Y, the amorphous carbon with a broad peak at 25° was only detected, corresponding to (002) of graphite carbon. Compared with Char-Y (Figure 5D), abundant Co$_2$P nanoparticles embedded in the porous carbon framework were observed in Figure 5E. The crystal lattice image in Figure 5F demonstrated the lattice constants of 0.176 and 0.34 nm, assigned to the (002) plane of Co$_2$P and the (002) plane of crystalline carbon, respectively. Due to a porous framework, the Char-Y-Co possessed a large BET surface area of 18.5 m$^2$/g (Supporting Information Figure S19). The EDS mapping showed that the Co and P elements were distributed as points, and the C element was distributed on the whole carbon material. It was worth noting that the signal of N element was very weak, indicating that the original N element in the yeast was almost converted into NH$_3$ by laser-driven pyrolysis. The measured N contents in different samples by the high-temperature combustion method also confirmed this conclusion (Supporting Information Table S2).

The obtained Char-Y-Co was employed as an electrocatalyst for NIRR. As shown in Figure 5G, the increased current densities from $-0.2$ to $-0.8$ V versus RHE in the presence of NO$_3^-$ confirmed the occurrence of NIRR. In Figure 5H and Supporting Information Figure S20, Char-Y-Co exhibited ideal NIRR catalytic performance from $-0.1$ to $-0.5$ V versus RHE, and the electrochemical reduction rate of NO$_3^-$ showed an increasing trend. While the FE of NH$_3$ exhibited a volcano type trend and exhibited ultra-high FE of 97.1% with NH$_3$ yield rate of...
FIGURE 5 (A) Diagram of biochar collection during laser-driven pyrolysis. (B) SEM image and the according photograph of Co-Yeast tablet by laser-driven pyrolysis. (C) XRD pattern of Char-Y and Char-Y-Co, SEM images of (D) Char-Y and (E) Char-Y-Co with according EDS mapping, and (F) HRTEM image of Char-Y-Co. (g) Polarization curves, (H) NH$_3$ yields and FE of Char-Y and Char-Y-Co. (I) The consecutive recycling testing of Char-Y-Co.

approximately 3.93 mg/h/mg$_{\text{cat}}$ at $-0.3$ V versus RHE. Due to the presence of Co$_2$P, the Char-Y-Co was more likely to produce hydrogen rather than reduce nitrate to ammonia at a high potential ($-0.5$ V), which caused the decrease of FE. In contrast, the Char-Y needed a much higher potential to obtain the efficient NIRR activity (NH$_3$ yield: 8.17 mg/h/mg$_{\text{cat}}$, FE: 83.6% at $-0.5$ V vs. RHE).

To demonstrate N in NH$_3$ from nitrate, isotopic labeling experiments were carried out using $^{15}$NO$_3^-$ and $^{14}$NO$_3^-$ as the reactants, respectively. Only the classic $^{15}$NH$_3$ signal was detected by the $^{1}$H nuclear magnetic resonance spectrum of either Char-Y-Co or Char-Y as the catalyst in the electrolyte made of $^{15}$NO$_3^-$, which verified that the N in NH$_3$ from nitrate (Supporting Information Figure S21). Additionally, when the electrolyte did not contain NO$_3^-$, no NH$_3$ signal was detected after the electrocatalytic reaction, which proved that trace amounts of N in the catalyst were not involved in NH$_3$ synthesis (Supporting Information Figure S22).

In Figure 5I, no significant attenuation of the NH$_3$ yield and FE was detected during the first eight cycles and the subsequent four cycles after 2 months, implying the high catalytic stability of Char-Y-Co for NIRR. The polarization curves before and after the cycle testing showed the nearly invariable current density, confirming the ideal stability of Char-Y-Co for electrocatalytic NIRR (Supporting Information Figure S23). Meanwhile, as shown in Supporting Information Figures S24 and S25, the XRD and SEM characterization displayed that the catalyst maintained its original phase and morphology after recycle testing, confirming the structure stability of Char-Y-Co. In all, the efficient NIRR activity and stability of Char-Y-Co was better or close to the reported results, which is summarized in Supporting Information Table S3. Therefore, the solid char
from laser-driven pyrolysis of Co-Yeast can be utilized as an efficient electrocatalyst for NIRR.

4 | CONCLUSIONS

In summary, laser-driven pyrolysis debuts as a bridge to connect biomass resource utilization and ammonia synthesis to realize the direct conversion from nitrogen-rich biomass into ammonia. Specifically, Co-Yeast as biomass nitrogen and hydrogen sources achieved the green laser-driven pyrolytic ammonia synthesis under mild reaction conditions (ordinary pressure and room temperature). The pulsed laser-induced local-transient thermal effect (more than 950°C with 245°C/s of heating rate) in collaboration with Co metal enhanced graphitization realized the spectacular and stable ammonia production up to 260.4 mg/h, providing a promising strategy for large-scale ammonia synthesis. In addition, the biochar of Char-Y-Co exhibited high catalytic activity in electrocatalytic NIRR with Faraday efficiency exceeding 97.1% and approximately 3.93 mg/h/mgcat at −0.3 V versus RHE. Consequently, the proposed laser-driven pyrolysis strategy was of great significance in broadening the research ideas of biomass nitrogen resource utilization.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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REFERENCES


SUPPORTING INFORMATION
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