Project 2: The Complete sets of technology development for bio-based polyamide 56 industrial chain

1. An executive summary (maximum 1 page) with a description of the achievement, including approach, objective, methodology, and (expected) results.

Polyamide materials have a wide range of applications in engineering plastics, synthetic fibers, films and other fields, mainly because of high strength, eminent toughness, excellent abrasion-resistant, strong impact resistance and chemical resistance and other excellent properties. Compared to polyamides traditionally sourced from petroleum resulting in high carbon emissions, bio-based polyamides based on renewable resources are an important development direction of the current polyamide industry.

Bio-based PA56 is produced by polycondensation of bio-based pentamethylene diamine (PDA) and petroleum-based adipic acid, and PDA is prepared by microbial fermentation with plant sugar as raw material. The gene editing and key enzyme directed evolution technology were applied for obtaining high-yielding pentamethylene diamine-producing strains. A green and efficient purification integration process was developed for PDA. Meanwhile, the key technologies were developed such as continuous polymerization and direct melt spinning of bio-based PA56, fabric dyeing and finishing. Finally, the project designed and integrated a complete set of equipment for fermentation, purification, polymerization and spinning. It was the first time that the industrialization of bio-based 1,5-pentanediamine, PA56 fiber and fabrics was implemented in the world. At present, a production capacity of 50 kt/a bio-based 1,5-pentanediamine, 100 kt/a PA56 and 30 kt/a staple fiber production capacity has been completed.

Bio-based PA56 fiber could be widely used in clothing, home textiles, luggage, tire cord and other fields, which has the characteristics of excellent moisture absorption, comfortable softness and low temperature dye ability. Compared with petroleum-based PA66 fiber, each ton of PA56 will reduce carbon dioxide emissions by 4.3 tons, making an important contribution to the reduction of carbon dioxide emissions. PA56 is expected to become a major commercial fiber after polyester and nylon 6/66.

2. A short biography of the participants including, i.e., the applicant's

contact data, career achievements and history, education, list of publications, etc.

Donghua University (DHU): is one of the National Key Universities directly under the Ministry of Education (MoE) of China and enlisted in China's Project 211 (the top 100 universities selected by the MoE in 1995 as national priority universities for the 21st century) and “Double First-Class University Plan” (most recently announced by the Chinese Government in October 2017, to develop a group of elite Chinese universities and individual university departments to world standard disciplinary, high-level institution with a focus on textile, material, as well as design. DHU is surging towards the goal of building “a high-level research university with domestic first-class, international influence and characteristics.” Located in Shanghai, DHU has three campuses: Sonqjiang Campus, Yan'an Road Campus and Xinhua Road Campus, covering an area of nearly 2,000 mu (approximately 1,333,333 m^2) with an overall floorage of over 830,000 m^2.

Donghua University possesses one of the top colleges of textiles in China. Seven disciplines of chemistry, engineering, mathematics, materials science, computer science, environmental science and ecology, and biology and biochemistry are among the top 1% of the ESI world. There are one first-level national key discipline and 5 second-level national key disciplines. It has 1 national key laboratory, 1 national engineering technology research center, and 20 provincial and ministerial scientific research platforms.

Cathay Biotech Inc.: is a listed company on the Shanghai stock exchange’s STAR market (symbol: 688065.SH). Cathay Biotech was founded in 2000 and engages in the research, development, production and sales of new bio-based materials based on synthetic biology and other disciplines and utilizes bio-manufacturing technology. Pentamethylene diamine (PDA), produced from sustainable resources through Cathay’s proprietary process, can be widely used as an epoxy curing agent, an ingredient in hot melt adhesive formulations, diisocyanates and in other related applications. The substitution of hexamethylene diamine (HMDA) by Cathay’s PDA in the field of polyamides can solve the main bottleneck of the development of the polyamide industry. Based on its own bio-based polyamide products, Cathay launched the high-performance textile material TERRYL® for broad applications in clothing, carpets, industrial yarns and other textile fields. Industrial and consumer goods and other engineering material fields, and provides solutions for the sustainable development of our society.

Cathay currently owns a bio-based polyamide production facility with a capacity of 100 KT/a and is investing multi-billion USD for a bio-material industry park in the middle of China mainly for bio-based polyamide at a scale of million tons/a and its downstream productions.

Corresponding participant:

Dr. Xiucai Liu

Dr. Xiucai Liu is the founder, chairman and CEO of Cathay Biotech Inc (2000-present; Shanghai, China). He currently also serves as a professor at the Eastern China University of Science and Technology.

Unistone Pharmaceuticals Research Center (joint venture with Beijing University) (1994-1997), founder and CEO.

Sandoz Research Institute (New Jersey) (1991-1994), Senior Scientist;

Universities of Yale and Columbia (1989-1991), post-doctoral research scientist

University of Wisconsin-Milwaukee (1986-1989) , Ph.D, Biochemistry;

University of Science and Technology of China (1985-1986), Ph.D. student, Chemistry;

Institute of Soil Science, Chinese Academy of Science (1982-1984), Master, Soil Biology;

University of Science and Technology of China (1978-1981), B.A, Chemistry;

Under Dr. Liu's leadership, Cathay Biotech Inc. has become a world leading industrial biotechnology company listed on the Shanghai STAR stock market with a multi-billion USD valuation. He has led his team complete the development and commercialization of a series of bio-based first-kind compounds and polymers, such as bio-produced long-chain dicarboxylic acids (C9-18), bio-butanol, bio-based pentanediamine and polyamides 5X. The company is now establishing the world's largest bio-industry park in central China.

Cathay Biotech Inc. has developed key technologies of bio-based PDA and PA56 industrialization. Donghua University and Cathay Biotech maintain a close collaboration in the development of bio-based textile studies. 42 Chinese invention patents, 11 PCT patents and 16 related papers were published.

3. A description of the exceptional achievements (maximum two-pages) containing the following information:

a. Which aspects of textile manufacturing does the achievement focus on?

Bio-based materials were applied to fabricate fabrics, which could reduce dependence on petrochemical resources, lower emissions of carbon dioxide, and thus facilitate sustainable development of textile industry.

b. Which challenges were taken on, what was the pursued aim?

The challenging problems of the project mainly include: how to realize the low-cost, high-purity biological preparation of 1,5-pentanediamine, as well as the preparation of high-quality bio-based PA56, and realize the direct melt spinning of PA56. The goal pursued by the project is that the bio-based PA56 industry chain can greatly reduce carbon dioxide emissions. The performance of bio-based PA56 fiber fabrics can be comparable even better to other polyamide fiber fabrics, such as PA6 and PA66, and have competitive production cost in the market.

c. Which was the methodical approach? Is the achievement related to a process or product? What were the key steps to success?

High-quality, low-cost 1,5-pentanediamine is prepared from plant resources by biological methods, and PA56 resin, PA56 fiber and fabric products have been developed. The key steps for success are the construction of the micro-organism trains that can produce 1,5-pentanediamine with high-efficiency, develop an efficient separation and purification technology of 1,5-pentanediamine and commercialize combined technology at large-scale; the efficient mass transfer and heat transfer continuous polymerization technology of bio-based PA56; bio-based PA56 melt transport and direct spinning technology and the whole process application technology. of weaving, dyeing and finishing technology.

d. Quantify the benefit of your approach leading to the achievement.

1,5-pentanediamine is made from renewable plant raw materials. The manufacture process doesn’t use fossil raw materials, and therefore reduces carbon emissions significantly. The biobased PA56 is synthesized by replacing 1,6-Hexanediamine with 1,5-pentanediamine and its environmental benefits and the sustainable nature are not only reflected in its renewable source of raw materials, but also in the Live Cycle Analysis (LCA) of these products. The LCA, especially the reduced Global Warming Potential of these products, demonstrate the environmental benefit of PA56.

Compared with Nylon from fossil resources such as petroleum (e.g. PA6 or PA66), the PA56 carbon Footprint Assessment results are as follows:

PARAMETER	UNIT	Applied Database （Ecoinvent3.6）		Products	
		Nylon 6	Nylon 66	1,5-pentanediamine	PA56
Global warming potential-Fossil (GWP-fossil)	kg CO_2 eq.	9.90E+00	8.66E+00	7.31E+00	7.28E+00
Global warming potential-	kg CO_2 eq.	1.20E-02	3.11E-02	-5.95E+00	-2.90E+00

Biogenic (GWP- Biogenic)					
Global warming potential-Land use and Land transformation (GWP- luluc)	kg CO_2 eq.	1.95E-05	1.73E-05	1.12E-03	1.20E-03
Global warming potential-Total	kg CO_2 eq.	9.91E+00	8.69E+00	1.36E+00	4.38E+00

Cathay Biotech has invested multibillion USD and is building a new industry complex for a million-ton bio-based PA56 and its application industrial chain. In comparation to petroleum-based PA66, each ton of PA56 will reduce carbon dioxide by 4.3 tons. Therefore, one million tons scale of PA56 is expected to reduce carbon dioxide emissions by 4.3 million tons/a, making an important contribution to the reduction of carbon dioxide emissions in the world.

e. Describe how your experience will promote further advances in your respective field or beyond.

1,5-pentanediamine is derived from corn, potatoes, straw and others, playing a positive role in promoting agricultural development, especially in the third world. The successful experience of bio-based PA56 industrial chain development will greatly facilitate the promotion and application of other fibers prepared from bio-based raw materials in the textile industry, which could make important contributions to the sustainable development of the world textile industry.