GC3 Green Chemistry & Commerce Council

Moving Business Toward Safer Alternatives

GC3 Webinar Series

September 17, 2013

Professor Kaichang Li: Successes and Lessons from a Serial Green Chemistry Innovator

Kaichang Li, Professor, Oregon State University

Webinar Discussion Instructions

- Due to the number of participants on the Webinar, all lines will be muted.
- If you wish to ask a question, please type your question in the Q&A box located in the drop down control panel at the top of the screen
- All questions will be answered at the end of the presentation.

Success and Lessons from a Serial Green Chemistry Innovator

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GC3 webinar, September 17, 2013

OVERVIEW

- My expertise
- Success and lessons from my research programs
  - Pulp and paper-related programs
  - Room temperature ionic liquids
  - Wood adhesives
  - Natural fiber-plastic composites
  - Pressure-sensitive adhesives
  - Styrene-free unsaturated polyester resins
- Acknowledgement

Expertise

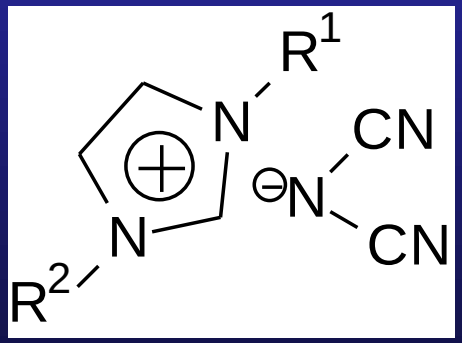
- Organic chemistry—organic synthesis and polymer synthesis
- Wood Chemistry — biosynthesis, chemical structures, biological and chemical degradation, and chemical and biological modifications of wood components
- Pulp and paper — pulping and bleaching chemistry, wet-end chemistry
- Wood Adhesives and wood composites
- Biochemistry, enzymology, and genetic engineering

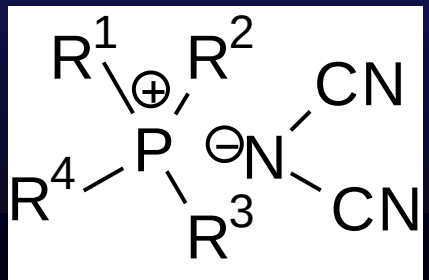
Pulp and Paper-related Research

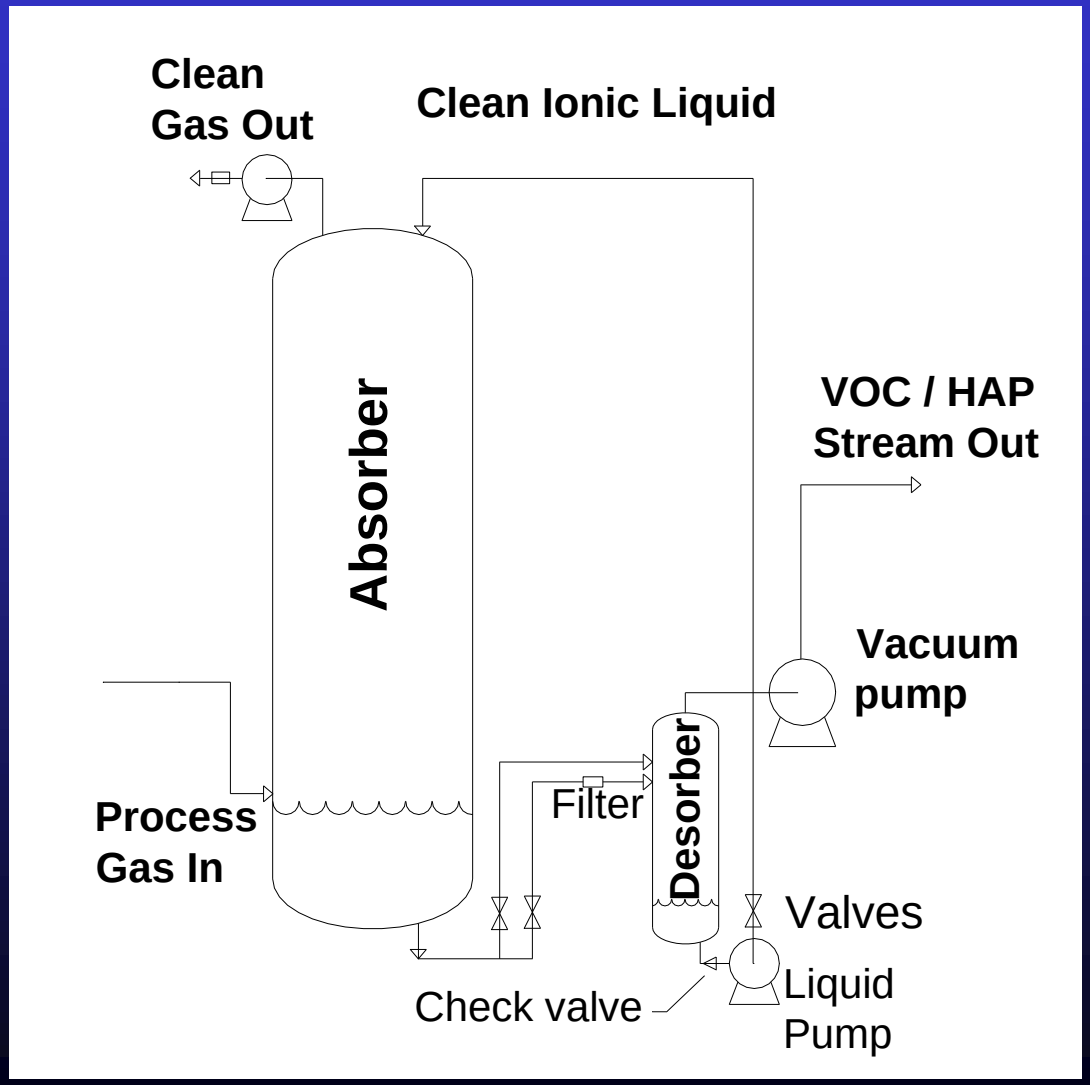
- Fungal degradation of lignin
- Development of environmentally friendly pulp bleaching techniques
- Enzymatic deinking of recycled mixed office paper
- Development of paper additives from renewable resources--Wet strength paper additives from wheat gluten

Projects Related to Room Temperature Ionic Liquids

- **Reduction of VOCs from wood composite manufacturing and various wood processing**







Lessons

- **Misperception: Everybody can use the technology and the society thus benefit more if a professor does not file a patent of a novel technology.**
- **Negotiate with the funding agency for preventing premature public disclosure of the technology**
- **Apply for a patent as soon as possible**

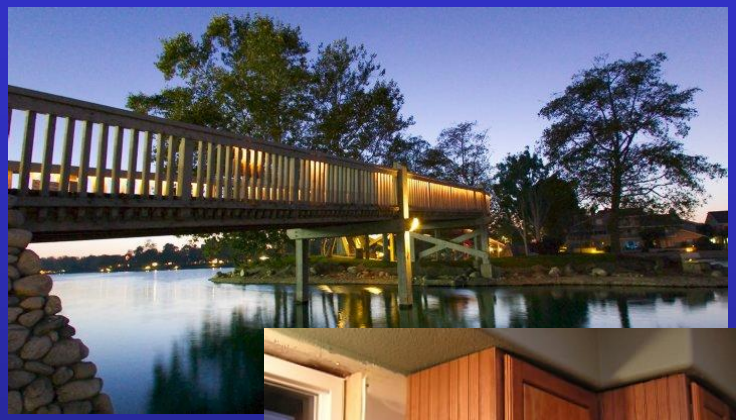
General introduction

Wood composites

- Consisting of woody materials and non-wood materials
- Traditional wood composites (woody materials and adhesives)
  - Plywood
  - Oriented strandboard (OSB)
  - Particleboard
  - Medium density fiberboard (MDF)
- Advanced hybrid composites
  - Wood-plastic composites (WPC)
  - Inorganic-bonded composites.

Wood composites cont.

- **Compared to solid wood:**
  - **better mechanical and chemical properties**
  - **various sizes and shapes**
  - **waste materials utilized**
  - **uniform properties at different directions**



- **Manufacture of furniture, flooring, kitchen cabinet, houses and bridges**

Wood adhesives

- Consume over 7 billion pounds of wood adhesives annually with the sale value of over 2 billion US dollars in the US and Canada in 2008
- Phenol-formaldehyde and urea-formaldehyde resins
- Issues in wood adhesives
  - Formaldehyde emission
  - Petroleum-based

Issues Associated with Currently Used Wood Adhesives

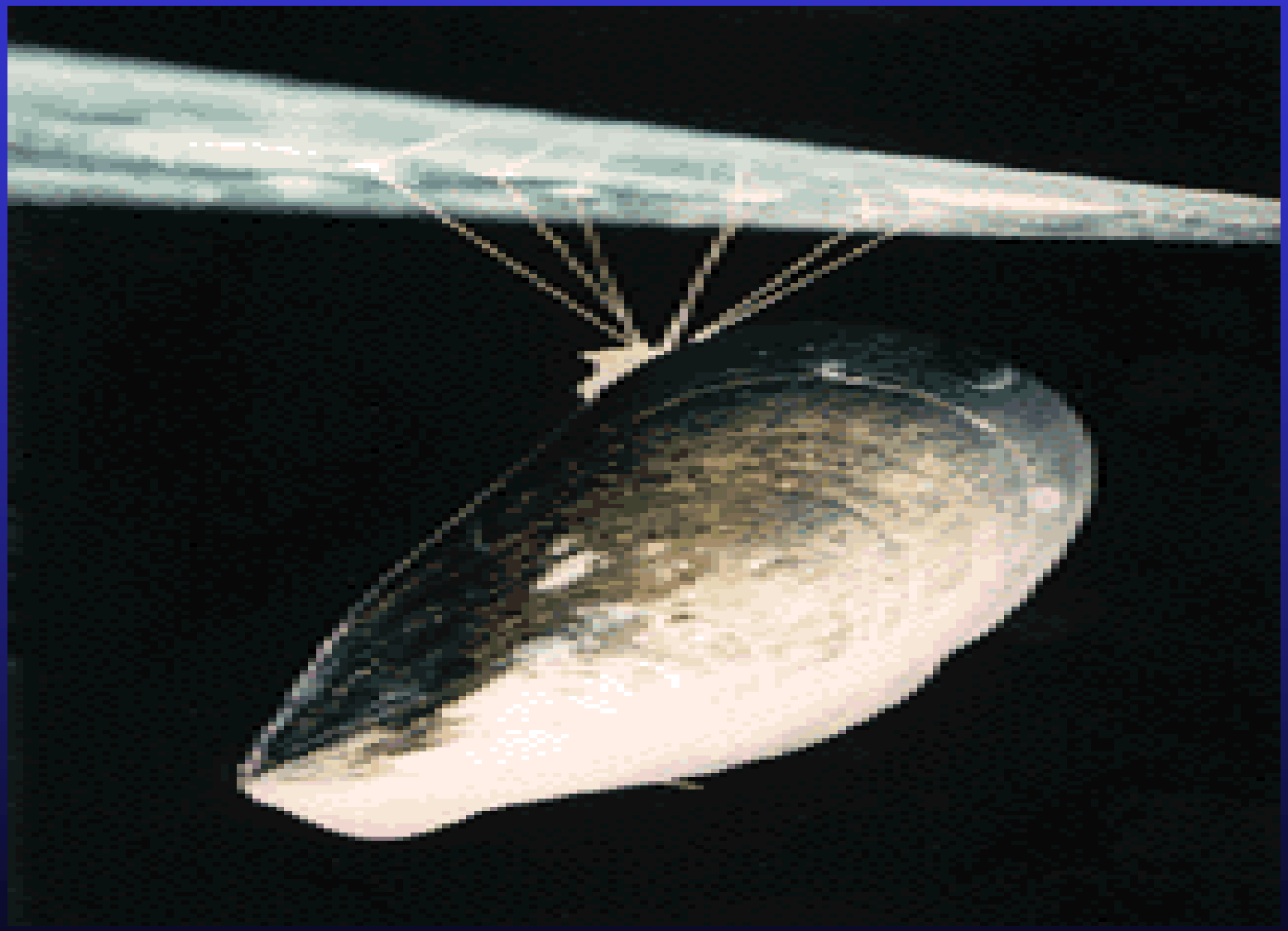
- **Formaldehyde emission**
  - **Formaldehyde is a human carcinogen**
  - **The U.S. Green Building Council is promoting the certification of green building practices, so called LEED certification (LEED: Leadership in Energy and Environmental Design)---no UF-bonded wood products**
  - **Formaldehyde is in the list of culprits for Sick Building Syndrome.**
  - **California Air Resource Board passed a regulation of setting low formaldehyde emission limit from wood products in April 26, 2007.**
  - **Toxic fumes from FEMA houses in New Orleans**
  - **A national regulation of limiting formaldehyde emission, "formaldehyde standards for composite wood products act," was signed into law on July 7, 2010.**

Green wood adhesives from renewable resources

- Our new wood adhesives
  - Formaldehyde-free
  - Environmentally friendly
  - From renewable natural resources
  - Adhesive properties comparable to PF and UF resins (narrow operation windows: long potlife at room temp, but have to be cured at 100-130 ºC in minutes, e.g. 6 min hot press time for making 11/16” panel)
  - Cost-competitive to PF and UF resins

Mussels glue

Mussels Stick



adopted from http://www.accessexcellence.org/WN/SUA11/collagen997.html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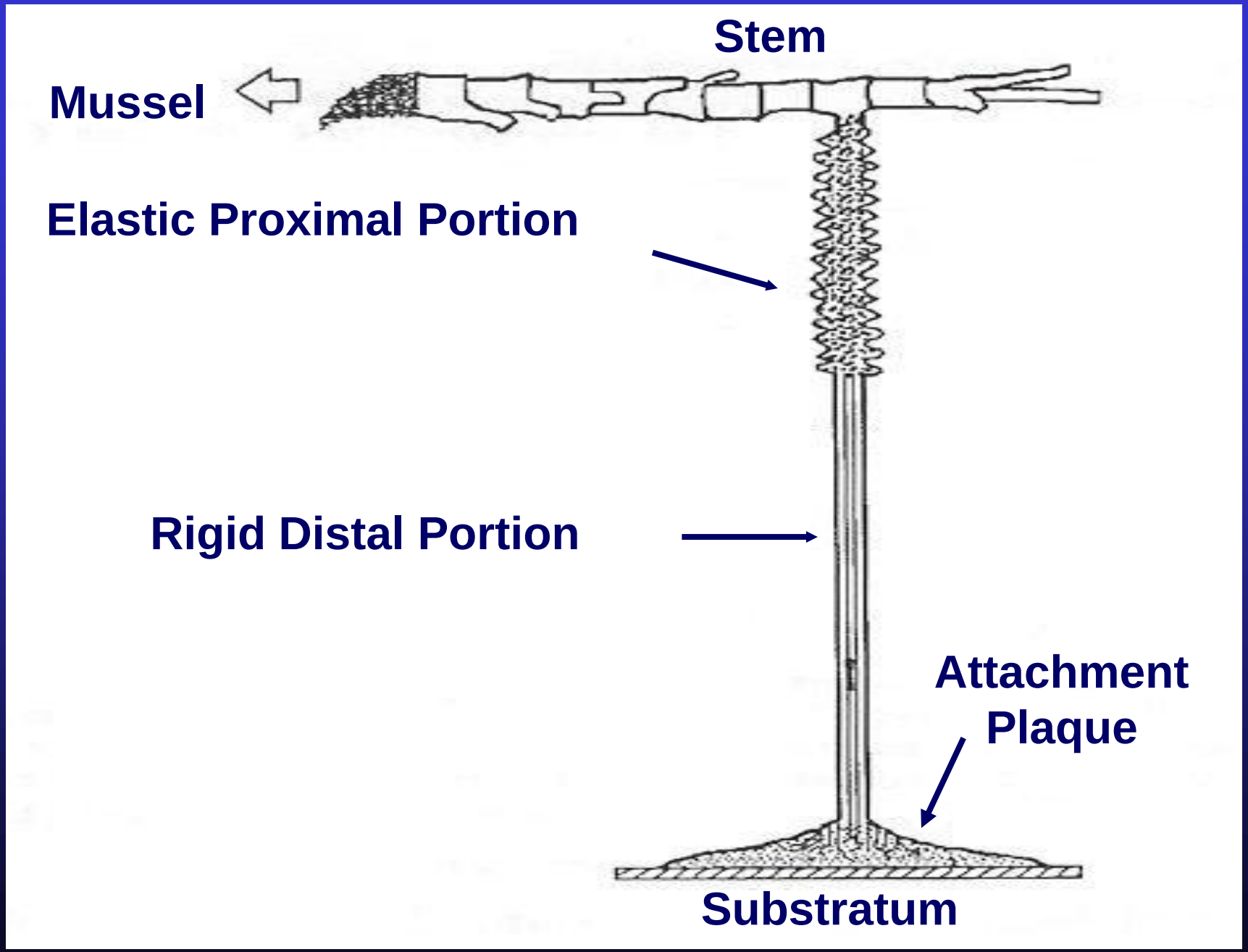


Qin, et al, JBC, 1997, 272, 32623.

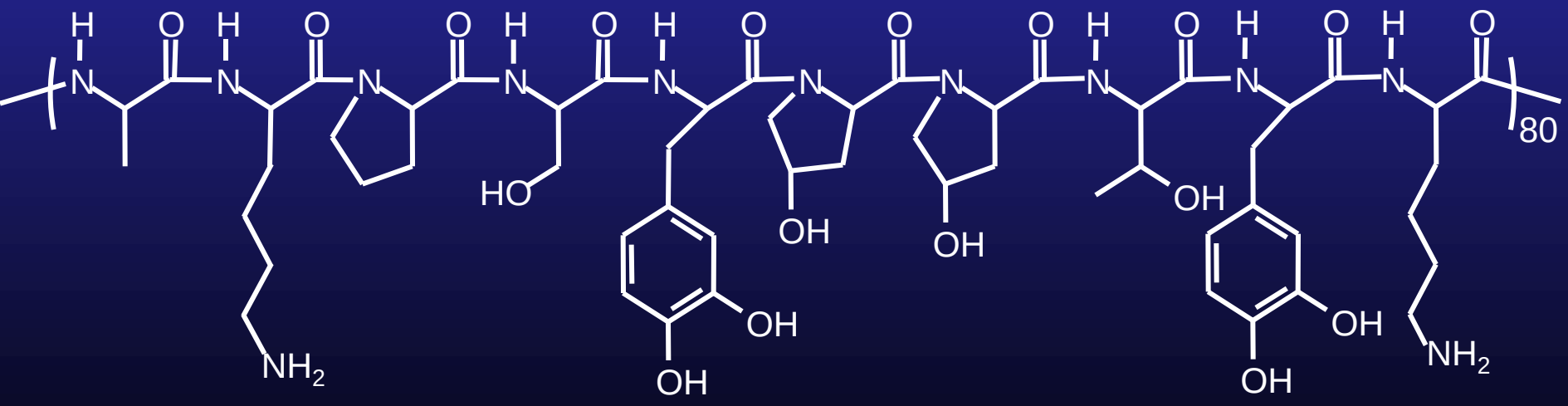
Marine adhesive protein (MAP)

MAP-1: rich in DOPA and lysine

MAP-2: rich in DOPA and cystine

MAP-3: small peptides

Ala-Lys-Pro-Ser-(Tyr/DOPA)-Hyp-Hyp-Thr-DOPA-Lys



Soy protein

- The soybean consists of about 40% protein, 21% fat, 34% carbohydrate, and 4.9% ash.
- Glutamic acid and aspartic acid account for about 1/3 of amino acids in soy protein

Timelines for development and commercialization of formaldehyde-free soy-based adhesives

- Provisional application filed on May 13, 2002 and a patent issued in 2006
- Presented the findings at Forest Products Society meeting in June 2003
- Began commercialization work from late 2003
- Full conversion of the first plywood plant in late 2004
- A provisional patent for the 100% renewable-material-based formaldehyde-free adhesives was filed in 2010
- The full conversion of the first plywood plant to use this adhesive is ongoing.

Economic Impacts

- Many plywood/particleboard plants are using our adhesive
- Huge quantity of the toxic UF resins are replaced every year.
- Millions of wood-based composite panels bonded with our adhesive are produced every year in the US.
- Foreign competitors took over 60% of the US wood-based composite panels market in 1990s. The market share of the US-made panels has been stabilized and started to grow since 2005. US-made panels are now exported to other countries.
- In the decorative plywood business alone, thousands of people in the US directly benefited from our formaldehyde-free adhesive technology.
- Our adhesive represents the biggest new use of soy flour outside of food applications. Soybean farmers and soybean processors greatly benefit from our research.

Environmental and Social Impacts

- **The replacement of the toxic UF resin with the soy-based adhesive reduces the emission of hazardous air pollutants from each plywood plant by up to 90%.**
- **Prompted the California Air Resources Board (CARB) to pass a regulation for setting formaldehyde emission limits on wood-based products used and sold in California in April 2007 (the main reason for stabilizing the market share of the US-made panels).**
- **A national regulation of "formaldehyde standards for composite wood products act" was signed into law on July 7, 2010 by President Obama.**
- **Our adhesive technology has dramatically improved indoor air quality in our working and living environments. Many people who are allergic to formaldehyde can now use wood-based composite panel products in their home and offices.**

Challenges in Commercialization of a Novel Technology

- The forest products industry lacks the spirit of innovation
- Most people want to be the second in use of a novel technology
- People tend to use their own experience to judge the merit of a new technology

Keys for the Success

- Strong support from open-minded industry leaders
- Willing to learn new things from outside talents.
- Be perseverant
- Don’t yield on internal and external pressures

Funding a research project at university vs. at private company

- Common misperception: I pay for the research, so I should own the resulting intellectual properties
- All IPs belong to the university if the research is done at the university
- The university won't negotiate licensing fees before the invention is made
- "The right of the first refusal" can be granted
- Great infrastructure and support at the university
- A private company is more flexible than the university regarding the ownership of the IPs

Natural fiber-reinforced polyester resins for automobile applications

- Wood-plastic composites
- Hemp, kenaf and bamboo fibers
- Novel coupling agents
- Novel surface modification methods for natural fibers

Research and development of pressure sensitive adhesives from renewable materials

- Uses of PSAs
  - Labels, post-it notes, stamp, package tapes
  - Issues: petrochemical-based, toxic organic solvents
- Published approaches for making PSAs from vegetable oils
  - Introduction of an acrylic functional group onto fatty esters/fatty acids/vegetable oils followed by free-radical polymerization
  - Cationic polymerization of epoxidized fatty esters
  - Direct polymerization of C=C double bonds

Pressure sensitive adhesives (PSAs) from renewable materials

- We have recently developed new PSAs from vegetable oils: less expensive, simple and green process, no organic solvents needed, and 100% renewable materials
- Four patents that contain three parallel PSA technologies have been filed
- One of the technologies has been licensed by a big company
  - The company refuses the participation of inventors in the commercialization work
- The other two technologies are still available for licensing

Styrene-free Unsaturated Polyester resins from renewable materials

- Existing unsaturated polyester resins
  - Used for boats, sink/shower tubs, automobiles, airplanes, water-cooling towers…
  - Issues: petrochemical-based, about 60% carcinogenic styrene
- Recent breakthrough: renewable-material-based replacement of styrene
- Challenges: no funding sources and lack industry support

The audio recording and slides shown during this presentation will be available to GC3 Members on the GC3 Website:
http://www.greenchemistryandcommerce.org

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Upcoming GC3 Webinars

Accelerating Commercialization of Green Chemistry Technologies at GreenCentre Canada

Rui Resendes, Executive Director, GreenCentre Canada
Tuesday, October 8, 2013
2pm Eastern/11am Pacific

InnoCentive: Using Crowdsourcing to Solve Green Chemistry Challenges & Create New Market Opportunities

Alph Bingham, Founder & Board Member, InnoCentive
Wednesday, October 23, 2013
2pm Eastern/11am Pacific