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## COVER PHOTO

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# TAKING BIO-R&D TO COMMERCIALIZATION THROUGH PARTNERING

**DAVID SUDOLSKY**, Anellotech, Pearl River, NY, USA, **JEAN-PIERRE BURZYNSKI**, IFPEN, Rueil-Malmaison, France  
**JEAN-LUC NOCCA**, Axens, Rueil-Malmaison, France

Process development in the hydrocarbon processing industry (HPI) is not for the faint-of-heart or the quick fix crowd. The inherent risks of high investment in large-scale plants, typical for the HPI, present significant hurdles for a first-of-a-kind technology. Most successful new substantial technology breakthroughs (i.e., not incremental improvements) take time and resources to develop and implement commercially due to a combination of both technical and commercial requirements.

This article discusses a green innovation and technology start-up company, Anellotech, and how challenges along the path towards commercialization of its thermal catalytic process for converting non-food biomass into aromatics (BTX) have been addressed via the close collaboration of complementary partners. The alliances set a goal of realizing this previously elusive aspiration of producing bio-BTX by leveraging the innovation of fresh thought and advanced R&D with decades of industrial and institutional knowledge and experience with fluidized bed reactors and associated catalyst formulations. The company's founders knew that only a team built upon, and balanced by, practical learnings and visionary development could succeed in taking the fledgling technology from the lab bench to the competitive world market.

Understanding this, and with the effort being led by its own internal team with R&D and industry expertise, the company has sought out and attracted a coalition of highly involved and motivated technical, commercial and operational partners. These partners bring additional expertise in process development, catalysis, plant operations, commercial licensing and product market applications for the technology.

## THE BEGINNING

The path began eight years ago in the labs of Professor George Huber at the University of Massachusetts. With a

bench-scale unit and the assistance of his UMass R&D team, Prof. Huber created the early basis for what is perhaps the best chance for the HPI to make the leap from fossil-driven basic chemicals to bio-based building blocks for mainstream chemical intermediates and plastics: the Bio-TCat™ Process. This technology became the foundational asset for the formation of Anellotech. **FIG. 1** illustrates the sequence from concept through commercialization.

Since that starting point in 2008, the company significantly advanced the technology in corporate R&D facilities, and grew its staff to 22. These scientists and engineers have worked to resolve early development hurdles and to design a proprietary catalyst with a major catalyst development partner, specifically for required reactor conversions. The next step, however—and a major one—is the scale-up to pilot level testing to create a data platform for the design of a commercial demonstration plant. A fully integrated development and testing facility will be operational in 2016. This 25-meter-tall unit, jointly designed with a process development partner, will confirm the viability and suitability of the process for scale-up, plus generate the data needed to design commercial plants planned for first commercial operations by the end of this decade. This development partner has extensive experience in scaling up pilot designs to world-scale production facilities. Their input helped ensure that the development and test unit is sufficiently instrumented and flexible enough to capture the required data and accommodate learnings along the way.

## THE PARTNERSHIPS IN BRIEF

Experience shows that one of the keys to accelerate a commercialization timeline for new technology in the HPI is aggressive partnering to leverage the application of critical resources at the point of innovation and problem solving. Anellotech has assembled resources that

complement its own experienced R&D team. These partners are experts in process development, catalysis, engineering design and licensing, working in close cooperation with Anellotech to accelerate development and drive cost-competitiveness. Here is the role of each partner:

- **Johnson Matthey (JM)** will co-develop and provide catalysts for the development program and will manufacture catalysts for commercial use.
- **IFP Energies nouvelles (IFPEN)** will collaborate with Anellotech throughout the process development with a focus on process scale-up and hydrodynamic studies, including work at its site in Lyon, France.
- **Axens** will finalize development and basic plant design and prepare the technology for commercialization.

Strategic partners in the BTX supply chain have also invested in the effort. In January, Suntory and Anellotech announced they have been engaged in an alliance since 2012 to help realize a 100% bio-based polyethylene terephthalate (PET) bottle. These alliances provide essential expertise and market presence to foster the successful commercialization, broad licensing and servicing of commercial plants.

Just naming the players and describing their interests and capabilities does not adequately capture the nature of these relationships. Let's take a closer look at what truly makes this alliance strong.

## WHY THE ALLIANCES ARE WORKING

**Catalyst partner.** At the heart of the Bio-TCat Process is a fluidized bed reactor utilizing a catalyst that must address both the physical and performance requirements of the process. It was paramount for Anellotech that it work with a catalyst supplier committed not only to providing development and manufacturing



TABLE 1. Technology alliances

Research and development		Technology demonstration	Technology licensing	Proprietary products
Catalyst research	Process development	Technology demonstration and product development	Process licensing, basic engineering design and technical services	Proprietary equipment and catalyst sales
Technology development			Technology development	

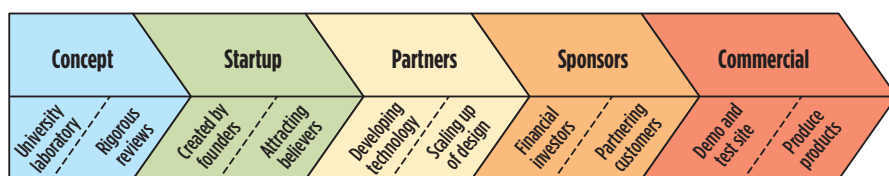


FIG. 1. Sequence from concept through commercialization.

capability, but also investing time and resources to the commercialization effort. JM has supplied all jointly-developed catalysts since its involvement began in 2014, and JM will provide catalyst for subsequent development, demonstration and commercial units, including the TCat-8 development unit being installed and commissioned in Texas later in 2016.

JM has provided technical and project management personnel at its Savannah R&D center to work on tailored catalysts, and respond to alternative process conditions developed by the Anellotech process engineers. JM is also providing expertise on catalyst systems; catalyst characterization; fingerprinting the finished catalyst with physical, chemical and other special tests; catalyst processing within the Bio-TCat Process; and catalyst equilibration. Once the development program is complete, JM will provide manufacturing scale-up and commercial manufacturing capability, plus participate in the provision of extensive technical services to licensees as the technology becomes more widely adopted.

**Process partner.** Although Anellotech had considerable process expertise of its own, there was a need to buttress its basic knowledge in fluidized bed reaction systems and catalyst regeneration with greater depth in scale-up and commercial plant behavior. It needed a process partner with its own scientists, labs and pilot plants to magnify the total critical mass dedicated to the Bio-TCat development effort. Also, there was a need for a process partner with a presence in licensing to broad sectors of the HPI. IFPEN and subsidiary Axens were an extraordinary fit with this profile.

As the development program unfolded, IFPEN and Anellotech became an integrated team functioning under an alliance

management committee, along with a technical committee, for guiding the development effort. IFPEN has made significant contributions working alongside Anellotech on process design, HAZOP studies, control systems, experimental planning and developing chemical analysis methods. This collaboration will continue while IFPEN also begins conducting advanced modeling and cold-flow hydrodynamic studies to support reaction engineering and scale-up. IFPEN's advanced computational modeling capabilities are essential to bringing Anellotech's technology beyond the bench and to scales appropriate for larger scale testing and development and, eventually, commercialization.

In total, it took approximately nine months for IFPEN, Axens and Anellotech to develop their alliance structure and agree to terms for an initial memorandum of understanding (MoU). IFPEN, Axens and Anellotech intentionally sought to spend more time on the MoU to get the full operations development and licensing teams involved in defining the objectives and the mechanics of the alliance, both for near-term development and for future commercial operations as a licensing business alliance. Countless hours were spent exploring the capabilities and resources of both parties, understanding the current state of the technology and what, in very real and practical terms, would be needed to bring it to commercialization. During this MoU development period, they also confirmed the alliance's long-term business vision, which aligned the interests of all three entities while slowly building a strong partner working relationship.

Another key ingredient of commercialization success is early and patient investment by an aligned partner. While

only recently announced, Suntory provided significant funding to Anellotech from 2012 onward, prior to the initial discussions between the technical partners, which began in earnest in early 2014. This funding enabled Anellotech to continue to make significant strides at its Pearl River R&D facilities while negotiations with the technology development partners progressed without undue pressure to prematurely finalize the development alliance. TABLE 1 illustrates these parallel processes. Suntory valued and fully supported the deliberate and detailed approach that these three eventual technical development and commercialization partners were taking, realizing that the new alliance was also crucial to achieving the Suntory goals. Suntory, too, was intensely focused on fostering the development of a real solution for its primary goal of a 100% bio-based PET bottle. The full and uncompromised alignment of all these partners around making cost-competitive "drop-in" bio chemicals a reality is perhaps the most powerful aspect of their collaboration. This funding not only sustained the Bio-TCat program through this alliance-building phase but also continues today as the parties are preparing to start up the TCat-8 test unit.

In summary, the Anellotech development and commercialization team is extraordinarily well aligned to lead the Bio-TCat Process into the market and to support the needs of its licensees for the foreseeable future. Its four partners (Suntory, JM, IFPEN and Axens) have specific complementary skills and businesses that ideally fit the expected implementation and growth of this technology entry into the production of bio-based core chemicals.

### ENABLING ANELLOTECH'S LICENSING VISION VIA STRONG TECHNICAL PARTNERS

A technology can only be declared a success if it can survive the test of time in the field under real market and operating conditions. Anellotech understood early on that its best operating model would need to be based on licensing to



companies that have the wherewithal to build and operate plants, utilizing the technology. Thus, it has chosen a complete technology licensing business model that supplies not only the intellectual property under license but that also designs the commercial plants, supplies proprietary catalysts and provides ongoing technology improvements, as well as technical services to its licensees. In addition, the partners will offer technical services to licensees to keep the plants updated and running efficiently over their lifetimes. To that end, Anellotech's partners were also selected due to the alignment of their businesses with Anellotech's long-term operating and service commitments to its licensees. In this way, licensed plants will be fully supported and the technology continuously enhanced by a coalition of process, catalysis and operations experts.

It is evident that a key contributor to the steady and continued progress toward commercialization of the Bio-TCat Process has been the formation of a team of capable and complementary partners. However, a list of impressive names in an

alliance does not guarantee true innovation or real progress. Essential to successful development is the fully invested thought each partner has made in understanding where the technology stands; agreeing how it will be introduced to, and supported in, the marketplace; and what each collaborator must contribute along the path from one milestone to another.

The in-place alliance members understood that even a functionally complete team could benefit immensely from additional partners to critically augment efforts and accelerate the team toward its shared goals. Thus, there has been an ongoing search for additional collaborators to join the commitment. Anellotech also found that existing alliances often provide synergies that lower the barriers of entry for additional interested parties. For example, the Suntory interest in bio-paraxylene creates an excellent opportunity for other entities looking to source bio-benzene from the overall production of a plant co-producing both aromatic chemicals. Also, the mandate of the existing partners that Bio-

TCat produce "drop-in" aromatic chemical products will attract the interests of downstream processors that are interested in obtaining early access to a highly sought feed material, identical to what they already process, but with renewables sourcing. Another Anellotech goal is to provide a technology that delivers cost and environmental benefits to refiners with aromatics processing capability or interest in aromatics as high-octane, non-oxygenated blend stock for gasoline.

Anellotech has benefitted immensely from its highly functional alliances. Its core collaboration strategy has enabled this startup to truly establish a path, whereby, the efforts inside its own organization can be effectively and reliably leveraged to bring its technology to commercial-scale operation. Rather than solely filling discrete gaps, truly effective alliances should provide a continuum of capabilities required for success where the collective team of partners operates seamlessly to reach its goals. Together, Anellotech and its partners have entered the race to develop a cost-competitive, drop-in bio-BTX. **HP**

## THE AUTHORS



**David Sudolsky**, who co-founded Anellotech with George Huber, secured the initial funding for the company, recruited the management team and scientific advisory board, and is leading the expansion of the company. Prior to joining Anellotech, Mr. Sudolsky was a business officer or CEO of five biotechnology, specialty pharmaceutical and bioprocessing startups, one of which (Dura Pharmaceuticals) was sold for \$1.8 B. He has hands-on chemical engineering experience in process design and refinery plant startups with Union Carbide, and work at Booz, Allen & Hamilton. Mr. Sudolsky attended Columbia University and earned an MBA degree in marketing and finance and a BS degree in chemical engineering.



**Jean-Pierre Burzynski** is the IFPEN process business unit director. He is in charge of R&D programs in the fields of refining, petrochemicals, biofuels and bioproducts. He has over 30 years of experience in refining and petrochemicals R&D working in process development as project manager, department head and director of the process engineering division in Solaize, France. Mr. Burzynski is the author of several technical papers and patents in the fields of refining, petrochemicals and clean fuels production. He holds an engineering degree from the École Centrale de Lyon and a post-graduate research degree (DEA) in fluid mechanics from the University of Lyon.

Since 2008, he has been a member of the IFPEN executive committee and a member of the Axens and Eurecat board of directors.



**Jean-Luc Nocca** is CTO of Axens and executive vice president in charge of the technology development and innovation division. During his carrier, he has carried out several technical, commercial and management assignments in North America for Axens (Houston and Princeton) as well as in IFPEN's headquarters in Rueil-Malmaison, France. Mr. Nocca has spent over 23 years in the US holding the positions of CEO and, formerly, vice president of technology sales and marketing. He has over 35 years of experience in the refining and petrochemical industry. He is also the author of several technical papers and patents in the field of petrochemicals and clean fuels production.

Mr. Nocca holds BS degrees from Ecole Supérieure des Industries Chimiques in Nancy, France and the Ecole Supérieure des Pétroles et Moteurs in Rueil-Malmaison, France.