Roles of the Metallurgist in Impacting Industries: from atomic diffusion kinetics to structural analysis, from pico-liter soldering to micro-liter additive laser manufacturing, from jewelry investment casting to Tesla giga-casting, and from thermodynamic simulations to AI- and machine learning driven alloy formulation and implants design.

Boonrat Lohwongwatana
Department of Metallurgical Engineering, Faculty of Engineering, Chulalongkorn University

As an academic, I have faced continual challenges in career growth as a professor: fine-tuning research interests to match industry needs, balancing scientific curiosity with existing knowledge bases, applying for research grants amid shifting government priorities, and managing time while holding executive positions in research institutes. This talk explores those struggles and the many pivots that emerged as opportunities along the way.

The journey began with the development of a novel soldering technique, a supercooled viscous liquid capable of atomistically dissolving solid metals to form intimate contacts observed through HRTEM, which was later patented and licensed to Intel. This concept was later applied to solder-jet bonding of pico-liter solder balls in the hard disk drive industry. Work on shape memory alloys such as Nitinol, initially envisioned as a "self-healing" material, led to a deeper understanding and control of martensitic transformation, which was later applied to delayed cracking in heavily deformed stainless steel wires and incorrectly quenched (and delayly exploded) automotive axles. Research into bulk metallic glasses and rapid solidification provided insights into solder joint microstructures, solidification fronts in various alloy compositions, and the reliability of solder systems under cyclic thermal loading in semiconductor applications.

Subsequent projects in semicontuctor industry readily expanded into MgO coatings deposited by PVD and diamond-like carbon (DLC) films. The adoption of synchrotron and neutron techniques, such as 3D tomography, EXAFS, and in-situ solidification studies, opened new windows into phenomena such as magnetic anomalies in semiconductors, porosity formation in additive manufacturing, and microstructural evolution during aluminum alloy solidification.

A substantial part of the research was devoted to the jewelry industry, where investment casting remains the dominant process. This archaic yet intricate technique relies on numerous metallurgical concepts: vulcanization of rubber molds, viscous wax flow, stereolithography, phase transformations amongst α-quartz, β-quartz, tridymite, and cristobalite, alloy granulation, dendritic growth, and solidification dynamics. Some students ventured further by reducing the conventional thirteen investment casting steps to five, leveraging thermodynamic simulations to design novel alloys suitable for direct injection into molds made of copper, aluminum, or silicone.

Current projects extend these principles into Tesla's giga-casting of truck chassis, scaling die-casting concepts from toy cars such as Hot Wheels into full vehicle chassis production, eliminating hundreds of welds and assembled parts. This leap demands entirely new aluminum alloys and advanced mold technologies capable of rapid cooling, high throughput, and minimized shrinkage and porosity. Additive manufacturing now plays a central role in fabricating conformal cooling molds, combining laser powder bed fusion with new mold steel formulations designed for selective laser melting.

Different research teams focuses on churning out intellectual properties such as novel titanium alloys with antimicrobial properties, and the 3D printing of ultrathin and superelastic implants. Insights into phase transformations and evolution during Ti-6Al-4V laser melting and rapid solidification have led to the development of USFDA-approved craniomaxillofacial and orthopedic implants, now improving the lives of thousands of patients. AI and machine learning have been applied to implant design, image processing, alloy formulation, and large-scale manufacturing.

The common thread across these projects lies in the four pillars of materials science and metallurgical engineering: processing-structure-properties-performance, reinforced by advanced characterization and by the flexibility to pivot research directions. This openness has allowed teams to address real-world industrial problems through collaboration, innovation, and cross-disciplinary impact.