From Laboratory to Global Market

Dr. Mashelkar's ASSURED Framework, Scientific Commercialisation and Wealth Creation in Chemical Technology

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A Perspective Article for Doctoral Researchers in Chemical Technology

Abstract

Doctoral research in chemical technology is judged in the academy by novelty and rigour. It is judged in the market by something harsher: whether a molecule, catalyst or process can be made affordably, at scale, safely and repeatedly, and then sold to customers who have alternatives. This article argues that the gap between those two systems of judgement is not a law of nature but a design failure, and that it can be closed if researchers adopt commercial criteria at the bench rather than after the thesis is bound. The organising lens is the ASSURED framework of Dr. Raghunath Anant Mashelkar, which holds that successful innovation must be Affordable, Scalable, Sustainable, Universal, Rapid, Excellent and Distinctive (Mashelkar, 2026a). Drawing on Mashelkar's own transformation of India's National Chemical Laboratory (NCL), on the literature on the "valley of death" in chemical scale-up, and on three decades of practical experience in international chemical trading, the article translates each ASSURED attribute into questions a PhD student can answer in the laboratory notebook. It closes with a practical scorecard and a short agenda for converting knowledge into wealth.

Keywords: ASSURED innovation; technology commercialisation; chemical scale-up; intellectual property; affordable excellence; wealth creation; valley of death

1. Introduction: The Unfinished Journey

Every chemical technologist knows the satisfaction of a clean NMR spectrum or a catalyst that survives its hundredth cycle. Far fewer know the satisfaction of a customer's purchase order for the first tonne. This article is concerned with the territory between those two moments.

Dr. Mashelkar has described this territory with characteristic economy. Assured success in innovation, he told a graduating audience, "requires successful exploitation of a new invention in actual practice, in the field, in the market", and "the journey of mind to market place is a very difficult one" (Asian Community News, 2026). Note the word "exploitation". An invention that remains in a journal is, in commercial terms, an unexploited asset. It may be beautiful. It is not yet wealth.

The distinction matters especially in chemistry, which sits at the base of pharmaceuticals, agrochemicals, polymers, coatings, electronic materials and battery chemicals. A breakthrough that reaches the market multiplies its value through downstream industries; one that does not loses that leverage entirely.

Section 2 explains why laboratory success so often fails commercially. Section 3 introduces the ASSURED framework, Section 4 interprets its seven attributes for chemical technology, Section 5 examines the NCL case, and Section 6 offers a scorecard and recommendations.

2. The Valley of Death in Chemical Technology

The phrase "valley of death" is widely used for the gap between research funding and commercial investment. The Institution of Chemical Engineers, in evidence to the UK Parliament, located it precisely at Technology Readiness Levels five and six, the point at which promising technologies stall after laboratory proof but before pilot validation (IChemE, 2025). It listed the usual causes: weak entrepreneurship skills, shortage of skilled staff, lack of pilot facilities, and a cultural divide between academia, "who focus on publications and patent filing", and business, "who focus on sales and profit margin" (IChemE, 2025).

More recent analyses suggest there is not one valley but several. The Council on Foreign Relations, writing on mineral and materials technologies, identifies four in sequence: a technology valley between discovery and a reliable engineered process; a pilot-scale valley, where facilities are "capital intensive, technically risky, and too small to generate revenue"; a commercialisation valley, where investors demand evidence that only a commercial plant can generate; and a profitability valley, where even an operating plant struggles against depreciated incumbents (Council on Foreign Relations, 2026). The US Department of Energy similarly refers to multiple "valleys of death" across all readiness levels in sustainable chemistry (US Department of Energy, 2025).

Three features of these valleys matter to the PhD student.

First, many failures are technical but invisible at small scale. A recent framework for advanced materials notes that "synthesis routes that are cost-effective at milligram quantities become economically prohibitive" when scaled linearly, and that the specialised equipment used in the laboratory "frequently has no industrial analog" (Born-Qualified, 2026). Heat removal, mixing time, mass transfer, impurity

accumulation in recycle streams and solvent recovery rarely appear in a thesis, yet they decide plant economics.

Second, many failures are economic rather than technical. A review of industrial biomanufacturing observes that commodity chemicals produced via mature petrochemical routes typically sell at around US$1 to 5 per kilogram, while new facilities carry capital costs far higher than fully depreciated refineries (Beyond Petrochemicals, 2026). Brilliant chemistry that cannot meet that price point is not a product.

Third, the remedy is consistently described as earlier integration of commercial thinking. The same body of work recommends that techno-economic analysis and life-cycle assessment be built in "as design criteria from the early stages of research" (Beyond Petrochemicals, 2026). This is exactly where the ASSURED framework is most useful. It gives the researcher a compact, memorable set of design criteria to apply before the expensive mistakes are made.

3. The ASSURED Framework: Origins and Logic

3.1 From Gandhian Engineering to ASSURED

The ASSURED framework did not appear in isolation. In 2010, Mashelkar and the late C.K. Prahalad published "Innovation's Holy Grail" in the Harvard Business Review, arguing that "affordability and sustainability, not premium pricing and abundance, are the new tenets of effective innovation" (Prahalad and Mashelkar, 2010). They called this approach Gandhian innovation and summarised it as getting "more from less for more people", the MLM paradigm (Mashelkar, 2026b). One of their illustrations came from chemistry-based industry: Lupin's reversal of the usual drug development process to create an affordable treatment for psoriasis (Harvard Business Impact, 2010).

MLM described a philosophy. ASSURED operationalised it. Mashelkar and Ravi Pandit set the framework out in Leapfrogging to Pole-vaulting (Mashelkar and Pandit, 2018), a book whose central argument is the shift "from reactive leapfrogging to proactive pole-vaulting through radical transformation" (Penguin Random House India, 2018). Most recently, Borde and Mashelkar (2025) placed ASSURED at the core of More from Less for More, described by one reviewer as "a rigorous approach to designing solutions that are Affordable, Scalable, Sustainable, Universal, Rapid, Excellent and Distinctive" (Amazon India, 2025).

3.2 Three Structural Properties

Mashelkar insists on three properties that distinguish ASSURED from a simple checklist (Mashelkar, 2026a):

1. The seven factors are interdependent. "Better affordability can lead to bigger scalability."

2. The factors are time-variant. A process that is sustainable today may not be sustainable after a regulatory change tomorrow.
3. Each factor can be assigned a quantitative, semi-quantitative or qualitative value, and the weighting depends on the type of business.

The blunt conclusion follows: "Failure assured if ASSURED test fails" (Mashelkar, 2026a). Mashelkar has also explicitly recommended ASSURED as "a 'one word integrated strategy' for the chemical industry to implement sustainability" (Mashelkar, 2022), which makes it particularly relevant to the readers of this article.

4. Reading ASSURED Through a Chemical Technology Lens

What follows is my interpretation of each attribute for doctoral work in chemical technology. Mashelkar's own definitions are quoted first; the translation into bench-level questions is mine.

4.1 Affordable

Mashelkar states that "an affordable solution creates access for everyone across the economic pyramid", achieved through "extremely efficient operation, production and distribution systems" (Mashelkar, 2026a). In a lecture he went further: affordability "requires a genius", meaning not ten per cent cheaper but tenfold (Mashelkar, n.d.).

For the chemist, affordability is set early and is very hard to fix later. The choice of starting material, catalyst metal, solvent system and number of steps fixes most of the eventual cost of goods. A route that uses a palladium catalyst at five mole per cent, a cryogenic step and chromatographic purification is a fine academic achievement and a poor commercial proposition. The practical question is simple: what will one kilogram cost at one hundred tonnes per year, and how does that compare with today's market price? Students who can answer that question in their second year, even roughly, will make better research choices in their third.

In my trading experience, buyers in Japan, Europe and the United States never ask how elegant a synthesis is. They ask for price, consistency and delivery.

4.2 Scalable

"Scaling the solution to largest number of addressable beneficiaries makes the largest impact," writes Mashelkar, adding that "in depth understanding of the market addressability" matters as much as finding a Blue Ocean (Mashelkar, 2026a). In his IISER Pune lecture he observed that innovators can often satisfy

most attributes, but that scalability and sustainability "actually determine whether you are successful or not" (Mashelkar, n.d.).

In chemical technology, scalability has two meanings and the PhD student must hold both. The first is engineering scalability: does the reaction remain controllable when the surface-to-volume ratio falls by orders of magnitude? Are exotherms manageable, are filtration times acceptable, does the crystal form stay the same? The second is market scalability: is there a market large enough to justify a plant? A biomanufacturing review recommends a phased approach, entering high-value niches such as pharmaceuticals, cosmetics and food ingredients first before attacking commodity volumes (KAIST summary, 2026). That is market scalability designed deliberately rather than hoped for.

4.3 Sustainable

Mashelkar defines sustainability in three dimensions: solutions must be "environmentally sustainable, economically feasible (with robust business and revenue models), socially acceptable and also adaptable to sudden or radical policy changes" (Mashelkar, 2026a). He warns specifically against innovations that survive only on subsidies: "just depending on government subsidies and props will not work" (Mashelkar, 2026c). He also recommends PESTEL analysis, covering political, economic, social, technological, environmental and legal factors.

For our discipline, environmental sustainability means atom economy, E-factor, solvent selection, energy intensity and end-of-life fate. Legal sustainability means anticipating registration requirements under regimes such as REACH and similar national chemical-control laws, and watching substances of concern. A PhD process that relies on a solvent likely to be restricted in five years has a built-in expiry date. Economic sustainability means the process must earn its own way. Social acceptability, frequently overlooked by technologists, determines whether a community will accept a plant at all.

4.4 Universal

"Universal means user-friendly, simple and maintenance free products and services," with standardisation of design, inputs and processes and principles such as "tolerance for error and equitable use" (Mashelkar, 2026a). Mashelkar's favourite illustration is George Whitesides' paper-based diagnostics, which need no electronics at all (Mashelkar, n.d.). That is, notably, a chemistry innovation.

In process terms, universality is robustness. Can the process tolerate the normal variability of commercial raw materials, rather than requiring reagent-grade inputs? Can an operator in a mid-sized plant in Gujarat, Jiangsu or Ohio run it without a PhD chemist standing beside the reactor? Can it be made in standard glass-lined or stainless-steel equipment? Processes with narrow operating windows may work

beautifully in a fume hood and fail repeatedly at a toll manufacturer. A universal process is one that forgives.

4.5 Rapid

"The journey from mind to marketplace has to be rapid," says Mashelkar, and so must be adaptability after market entry, including "speed of competitive response" and "decision making speed" (Mashelkar, 2026a). Elsewhere he puts it memorably: "the speed of our action matching the speed of our innovative thoughts" (Mashelkar, 2026c).

Speed matters in chemistry because patent clocks run and competitors read the same journals. The International Finance Corporation notes that one way to survive the valley of death "is to cross it faster", and that new commercialisation models run activities in parallel that were once performed in sequence (IFC, n.d.). For the doctoral researcher, this argues for running preliminary techno-economic models, freedom-to-operate searches and customer conversations alongside experimental work, not after it. High-throughput experimentation, design of experiments, flow chemistry and machine-learning-guided optimisation are all tools of rapidity.

4.6 Excellent

Excellence means "state of the art technological or novel non-technological solutions", but Mashelkar adds immediately: "that is not enough. We need business excellence", covering leadership, strategy, customer focus, information management, people and processes (Mashelkar, 2026a). He rejects the assumption that affordable and excellent are opposites, arguing that India "has mastered an art of doing affordable excellence" (Mashelkar, n.d.).

In chemistry, excellence is ultimately specification. A customer for an electronic-grade chemical or a pharmaceutical intermediate does not want "high purity"; they want a defined assay, defined limits on named impurities, defined metal content, and a consistent impurity profile batch after batch. Excellence also means documentation, analytical method validation and quality systems. Researchers who learn to think in specifications, certificates of analysis and change-control procedures become far more valuable to industry than those who think only in yields.

4.7 Distinctive

"Innovation and not imitation is the key. There is no use creating 'me too' products and services. Solutions must be protected by robust intellectual property portfolio" (Mashelkar, 2026a). Mashelkar adds a demanding corollary: "you have to displace your product yourself; if you don't do that, your competitors

will do it" (Mashelkar, n.d.). In one essay he raises the ambition further, suggesting D might stand for disruptive (Mashelkar, 2026d).

Distinctiveness is where doctoral research has a natural advantage, because a PhD is by definition a contribution to new knowledge. The commercial discipline lies in converting novelty into defensible position: filing before publishing, drafting claims that cover the commercially relevant embodiments, and building know-how that competitors cannot easily replicate. A distinctive process with weak protection simply teaches competitors how to compete.

4.8 The Interplay

Mashelkar repeatedly emphasises that "it is the combination that has always to work" (Mashelkar, n.d.). In chemical technology the linkages are concrete. Fewer synthetic steps improve affordability, which widens the addressable market and so improves scalability. Aqueous or solvent-free processing improves sustainability and often universality, because it simplifies equipment and safety. Strong intellectual property enables distinctiveness, which protects the margins that fund excellence. The framework is not seven separate tests but one integrated design problem.

5. Case Study: NCL and the Export of Knowledge

The most persuasive evidence for these ideas comes from Mashelkar's own leadership of the National Chemical Laboratory in Pune between 1989 and 1995. When he became director, NCL had been in existence for thirty-nine years and "had not been able to secure even one single patent in the USA" (Mashelkar, 2016). Its role was largely import substitution for Indian industry.

Mashelkar redefined the business. "Knowledge is my product and it has a world market," he said, and NCL would become an "International Chemical Laboratory" (Mashelkar, 2026e). Two consequences followed, both instructive for PhD students. First, the research benchmark rose, because NCL could not sell technology to General Electric or DuPont if it had merely copied them. Second, patenting became essential, because multinationals would not license unprotected knowledge for fear of infringement (Mashelkar, 2026e).

The results were historic. In 1990 NCL licensed its hydrodewaxing technology patents to Akzo in Europe, described as the first reverse transfer of technology from an Indian national laboratory to an advanced nation. This was followed by licensing an engineering-plastics process to General Electric, and within five years NCL's clients included DuPont, Cargill and Polaroid (Mashelkar, 2016). The polycarbonate work rested on a breakthrough in solid-state polycondensation which, Mashelkar recalls, "we did not publish ... but patented ... in the US", which he called "putting a flag on GE's territory" (Mashelkar, 2026e). A related

intermediate, THPE, went on to become a business of roughly Rs 50 crore for an Indian manufacturer, creating jobs and wealth in India (Mashelkar, 2026e). One of the scientists involved later recorded more than twenty-five US patents in polycondensation chemistry and over US$10 million of income to NCL from licensing, royalties and research fees (Sivaram, 2011).

The cultural shift was summed up in a slogan every PhD student should remember: not "publish or perish" but "patent, publish and prosper", in that order (Mashelkar, 2016). Note that publishing was not abandoned. Mashelkar reports that NCL's scientific output grew alongside its business, with breakthroughs appearing in leading journals (Mashelkar, 2026f). Commercial discipline and scientific excellence proved complementary, not competing.

As Director General of CSIR from 1995 to 2006, Mashelkar scaled this model across some forty laboratories. Under his leadership CSIR held around 60 to 70 per cent of US patents granted to India during his tenure (Mitragotri, 2017). Crucially, incentives were aligned: scientists received "a handsome share" of royalties and licensing fees, and laboratories could build a corpus from net surpluses (Mashelkar, 2025). Wealth creation was rewarded, not merely encouraged.

The NCL story also illustrates ASSURED in retrospect. The technologies were Distinctive and protected; Excellent enough to sell to the world's most demanding chemical companies; Scalable because they were licensed to firms with global manufacturing capacity; and Rapid because licensing let NCL reach markets without building its own plants. The lesson for doctoral researchers is that a laboratory, or even an individual researcher, does not need to own a factory to create wealth. It needs knowledge that is distinctive, protected and relevant to someone who does.

6. Applying ASSURED in Doctoral Research

6.1 A Practical Scorecard

Because Mashelkar holds that each factor can be given a quantitative or semi-quantitative value (Mashelkar, 2026a), I propose the following simple scorecard for PhD students. Score each attribute from 1 (weak) to 5 (strong) at the end of each research year, and record the reasoning.

Attribute	Question for the chemical technologist	Evidence to collect
Affordable	What is the estimated cost per kilogram at commercial scale versus the current market price?	Raw-material costing, step count, catalyst loading, preliminary techno-economic model
Scalable	Do heat, mass transfer and safety hold at 100 to 1,000 times scale, and is the market large enough?	Calorimetry, kinetic data, market sizing, target customer list

Sustainable	Is the process green, self-financing, legally durable and socially acceptable?	E-factor, solvent guide ranking, life-cycle screening, regulatory watch list
Universal	Will it run in standard equipment with commercial-grade inputs and ordinary operators?	Robustness studies, impurity tolerance, equipment compatibility
Rapid	How quickly can it reach pilot and market, and what would slow it?	Readiness level, parallel work plan, critical-path timeline
Excellent	Can it meet a customer's full specification batch after batch?	Impurity profile, validated analytics, batch-to-batch reproducibility
Distinctive	Is it novel, protectable and hard to copy?	Prior-art and freedom-to-operate search, invention disclosure, know-how list

A low score is not a failure; it is information. A thesis with a score of 2 on affordability in year one has time to change route. A thesis that discovers the problem only at the viva has not.

6.2 Recommendations for PhD Students

Drawing on the framework and the NCL experience, I offer six recommendations.

1. Disclose before you publish. Speak to your institution's technology transfer office before submitting a paper or conference abstract. NCL's polycarbonate breakthrough became wealth precisely because it was patented first.

2. Learn to read patents as well as papers. NCL scientists, Mashelkar notes, "learnt to read patents, write patents, break patents" (Mashelkar, 2016). Patent literature often reveals what industry actually cares about.

3. Build a rough cost model in year one. It need not be precise. Its purpose is to direct curiosity toward routes that could succeed.

4. Talk to a customer. A thirty-minute conversation with a buyer, formulator or plant manager will frequently change the research question. In international chemical trade, the specification sheet a buyer hands you is often worth more than a literature review.

5. Design for the plant, not the fume hood. Ask early which unit operations your process will need and whether they exist at contract manufacturers.

6. Think in the plural. Mashelkar's MLM paradigm asks for "more from less for more" people (Mashelkar, 2026b). Wealth creation in chemistry is most durable when it also serves wide social need: clean water, affordable medicines, food security and energy transition.

6.3 Recommendations for Institutions

Mashelkar's CSIR model suggests three institutional priorities: reward commercial outcomes in promotion criteria, share royalties generously with inventors, and invest in shared pilot facilities, a recurring bottleneck at TRL five and six (IChemE, 2025). Mashelkar has also argued that a "suitably 'quantitised' ASSURED framework" should be used for "assessing, funding and monitoring everything from start-ups to government funded projects to in-house industry projects" (Mashelkar, 2025b). Doctoral programmes in chemical technology would be a natural place to start.

7. Limitations and Critical Reflections

ASSURED is a heuristic, not a predictive model; its weights are business-specific and its scores partly judgement. Attributes can also conflict in the short term, as when higher purity raises cost, which is why Mashelkar stresses interdependence and time variance (Mashelkar, 2026a). Nor should every thesis be commercial. The argument is only that a thesis with commercial potential should not waste it through avoidable choices.

8. Conclusion

The journey from laboratory to global market is long, expensive and uncertain. It is also learnable. Dr. Mashelkar's ASSURED framework gives chemical technologists a compact discipline for that journey: make it affordable, make it scalable, make it sustainable, make it universal, make it rapid, make it excellent, and make it distinctive. Apply all seven together, and apply them early.

The NCL story shows what follows when this discipline is combined with ambition. A laboratory that had never secured a US patent became an exporter of chemical knowledge to the world's leading multinationals within a few years, and created jobs and wealth in India in the process. Today's doctoral researchers have far better tools than NCL had in 1989. What they need above all is the mindset Mashelkar summarised in four words: patent, publish and prosper.

For the next generation of chemical technologists, the question is no longer only "Is it new?" It is also "Is it ASSURED?"

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