
ACADEMIA–INDUSTRY COOPERATION IN RESEARCH AND DEVELOPMENT

A Framework for Science-Based Innovation, Cost-Effective Technology
Transfer, and Advanced Drying and Dewatering

Perspectives of Professor Arun S. Mujumdar

Technical Report

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A practical framework for connecting fundamental science, engineering research,
industrial implementation, and technical workforce development.

Executive summary

Academia–industry cooperation is an essential mechanism for converting scientific knowledge into practical technologies, competitive industrial processes, and economic and societal benefits. Its importance is particularly evident in engineering and technology, where scientific discoveries must be translated into equipment, operating procedures, process designs, control strategies, and commercially viable products.

The central proposition of this report is that scientific excellence and industrial relevance should reinforce one another rather than compete for attention. Universities contribute fundamental understanding, analytical and computational tools, experimental facilities, independent evaluation, and highly trained researchers. Industry contributes practical problems, process and product knowledge, realistic operating constraints, engineering resources, scale-up expertise, and routes to implementation. Effective cooperation brings these complementary capabilities together early enough to influence both the research questions and the resulting technology.

This report synthesizes perspectives associated with Professor Arun S. Mujumdar’s published writings on university–industry interaction, engineering research, and drying science and technology. It develops those perspectives into a practical framework emphasizing science-based innovation; faster, more economical development; interdisciplinary and international collaboration; workforce development; and a systematic path from industrial need to pilot-scale validation and implementation.

Collaboration does not automatically produce innovation. Poorly defined objectives, conflicting incentives, intellectual-property disputes, administrative burdens, and inadequate scale-up resources can make joint projects slower and more expensive than anticipated. The proposed methodology therefore combines scientific ambition with explicit industrial objectives, disciplined project management, measurable outcomes, and long-term partnerships.

1. Intellectual foundations and evolution of the perspective

1.1 From academic excellence to useful technological impact

A recurring concern in Mujumdar’s writings is the gap between the generation of scientific knowledge and its adoption in industrial practice. Research can be technically sophisticated, mathematically elegant, and widely published without necessarily producing a useful industrial innovation.

His 2004 review, “Research and Development in Drying: Recent Trends and Future Prospects,” identifies stronger industry–academia interaction and industrial participation in academic research as important conditions for successful technology transfer. It also questions a closed-loop research culture in which academics primarily conduct research for other academics, potentially placing publication prestige ahead of technological impact.

Scientific output includes papers, models, experimental data, algorithms, and new theoretical understanding. Engineering output includes validated designs, operating procedures, control strategies, and equipment improvements. Industrial impact includes measurable improvements in productivity, energy use, product quality, reliability, safety, resource efficiency, and commercial performance. These outputs are connected but not interchangeable; an effective R&D system should recognize their respective contributions and create pathways between them.

1.2 The complementary roles of academia and industry

Partner	Core contributions
Academia	Fundamental science; transport phenomena; thermodynamics; materials science; mathematical modelling; computational fluid dynamics; experimental methods; AI; independent evaluation; and training.
Industry	Real production problems; product and process specifications; operating data; equipment; pilot plants; manufacturing expertise; capital investment; commercial constraints; and implementation capability.
Joint effort	Relevant research questions, shared facilities, complementary skills, experimentally validated solutions, industrial demonstration, trained personnel, and adoption of improved technologies.

The ideal partnership is not one in which a university simply performs tests requested by a company, nor one in which industry passively receives academic results. It is a co-creative relationship: industrial challenges stimulate new science, while scientific understanding enables more effective industrial solutions.

1.3 Publications informing this synthesis

Publication or contribution	Relevance
Mujumdar (2004), "Research and Development in Drying: Recent Trends and Future Prospects"	Industry participation, technology transfer, and the relationship between fundamental and applied research.
Mujumdar (2010), "Editorial on Industry–Academia Collaboration in R&D;"	Practical challenges and importance of university–industry interaction.
Mujumdar (2017 presentation), "University-Industry R&D; Collaboration: A Personal Perspective"	Personal perspective on effective collaboration.
Mujumdar (2018), "Editorial: On Academia–Industry Collaboration in Drying Research"	Multidisciplinary and international cooperation, sustainability, and barriers to adoption.
Mujumdar (2018), "Role of Academia in Industrial Developments"	Contribution of academic knowledge to industrial development.

In his 2017 editorial, Mujumdar emphasized that promising drying innovations had not been adopted industrially at the level their potential might warrant. He identified scale-up difficulties, different academic and industrial timescales, intellectual-property concerns, and inadequate industrial financial support as barriers. He also advocated combining limited resources and diverse talent through international networks to address global energy and environmental challenges.

2. Why academia–industry cooperation accelerates innovation

2.1 Better definition of research problems

Industrial collaboration helps researchers distinguish between a scientifically interesting problem and one whose solution would materially improve an industrial process. A useful problem definition identifies the current process and its limitations; underlying physical, chemical, biological, or materials mechanisms; desired improvement and measurable acceptance criteria; technical, economic, safety, environmental, and regulatory constraints; and the evidence required before adoption.

2.2 Science-based innovation instead of trial and error

Industrial experience and empirical experimentation remain valuable, but combining them with fundamental science can improve efficiency and generalizability. In drying, an empirical approach might vary air temperature, velocity, and residence time. A science-based approach also investigates heat and mass transfer, moisture diffusion, shrinkage, phase changes, material structure, and links between operating conditions and product quality.

The strongest approach combines (1) mechanistic understanding, (2) experimental validation using representative materials and conditions, and (3) data-driven prediction and optimization where appropriate. AI and machine learning can improve prediction, fault detection, and control, but depend on representative data, physical constraints where needed, and validation under actual operating conditions.

2.3 Reducing time and cost

Cooperation can shorten development by providing access to expertise and facilities that would otherwise need to be developed independently. Industrial input clarifies commercially meaningful constraints; universities investigate mechanisms and alternatives; equipment manufacturers contribute design knowledge; and pilot facilities reveal problems before expensive plant modifications.

- Avoiding unnecessary duplication of experiments and equipment.
- Screening alternative technologies before capital-intensive scale-up.
- Reducing commissioning time and the risk of unsuccessful implementation.
- Improving energy and material efficiency.
- Identifying maintenance, control, and reliability issues early.
- Sharing the cost and risk of precompetitive research.

These benefits are conditional. Collaboration can become more expensive when responsibilities are unclear, projects are poorly scoped, or partners delay decisions.

2.4 Improving academic relevance and measuring success

Industry involvement broadens academic research by exposing researchers to practical challenges. Independent scientific scrutiny, in turn, helps industry challenge established assumptions, compare competing explanations, and investigate options that may lie outside its immediate product-development cycle.

Research performance should not be assessed exclusively through publication counts, citations, or patents, nor only by immediate revenue. A balanced evaluation includes scientific advancement, validated engineering outcomes, industrial adoption, economic and environmental benefits, and human-capital development. Measure both the knowledge created and the useful change enabled by that knowledge.

3. Advantages and disadvantages of joint R&D;

3.1 Principal advantages

- Complementary expertise: scientific, engineering, manufacturing, and commercial knowledge supports solutions that neither partner could develop as effectively alone.
- Cost and risk sharing: shared laboratories, pilot facilities, personnel, and funding reduce duplicated investment.
- Faster development and validation: industrial input prioritizes relevant questions while academic expertise supports mechanism-based analysis.
- Better scale-up and implementation: early involvement of process engineers, equipment manufacturers, and operators reveals practical issues before deployment.
- Stronger innovation: academic teams explore new concepts while industry evaluates manufacturability, reliability, economics, and market needs.
- Highly trained technical manpower: students and early-career researchers gain experience with industrial data, process constraints, pilot experiments, and implementation.

3.2 Principal disadvantages and mitigation

Challenge	Why it matters	Mitigation
Different objectives	Academia may seek generalizable knowledge; industry may need a near-term improvement.	Agree on scientific and industrial outcomes at initiation.
Different timescales	Rigorous experiments may take longer than industrial development cycles.	Use staged work packages, decision gates, and early deliverables.
Intellectual property	Ownership, licensing, confidentiality, and publication can be contentious.	Agree on background IP, foreground IP, licensing, and publication rules before work.
Confidentiality versus openness	Secrecy can limit dissemination; premature disclosure can compromise commercialization.	Define confidentiality periods and separate publishable findings from protected information.
Unequal contributions	Partners may perceive that costs and benefits are unfairly distributed.	Document responsibilities, in-kind contributions, deliverables, and benefit sharing.
Scale-up uncertainty	Laboratory performance may not persist at larger scale.	Include pilot-scale and industrial validation in the original plan.
Administrative burden	Contracts, procurement, and approvals can delay experiments.	Appoint a project manager and use standardized agreements.
Publication-driven incentives	Novelty may be favored over industrial relevance.	Recognize patents, prototypes, adoption, and training alongside publications.
Dependence on individuals	A project may lose momentum if a champion leaves.	Build institutional agreements, shared documentation, and succession plans.
Commercial failure	A technically successful invention may be too costly or difficult to maintain.	Evaluate techno-economics and adoption constraints from the beginning.

3.3 Collaborative R&D; versus contract testing

Contract testing answers a defined question using established methods. Consultancy applies existing expertise to a specific problem. Collaborative R&D; involves joint problem definition, investigation of uncertainty, new knowledge or capability, and shared responsibility for results. A strategic partnership establishes a continuing program of research, training, facilities development, and technology advancement. All can be useful, but complex problems involving novel drying mechanisms or difficult scale-up often benefit from genuine collaborative R&D.;

4. Why interdisciplinary collaboration is essential

Drying and dewatering are especially suitable for interdisciplinary R&D; because performance depends on coupled phenomena across several scientific and engineering domains. Food drying, for example, combines heat transfer and moisture transport with tissue structure, shrinkage, biochemical reactions, microbial stability, sensory quality, and consumer requirements. Pharmaceutical drying may require consideration of solvent removal, crystallinity, polymorphism, degradation, powder flowability, residual moisture, and regulatory requirements.

A team may include chemical and mechanical engineers; heat- and mass-transfer and fluid-mechanics specialists; materials and product scientists; computational modellers and control engineers; food, pharmaceutical, or bioprocess specialists; environmental and energy engineers; and economists, managers, and equipment manufacturers. Organize the team around the problem rather than around departmental boundaries.

4.1 Sector-specific opportunities

Sector	Collaborative R&D; opportunities
Food and agriculture	Couple drying kinetics and heat transfer with microstructure, nutrient retention, flavor, texture, shelf life, and energy optimization.
Pharmaceuticals and biologics	Integrate drying kinetics, formulation science, particle engineering, thermal sensitivity, residual solvent/moisture, process analytical technology, and quality-by-design.
Biomass and forest products	Combine mechanical dewatering, porous-material transport, fiber science, waste-heat recovery, renewable energy, and process integration.
Electrode materials	Study solvent evaporation, coating uniformity, particle/binder migration, pore structure, residual solvent, and final electrode performance.
Wastewater, minerals, and chemicals	Link particle characterization, filtration, centrifugation, thermal drying, water recovery, contaminant management, and life-cycle economics.

The research team and validation requirements differ by sector. A common principle is to investigate the material and the process together rather than optimizing the dryer independently of the product.

5. The additional value of international cooperation

5.1 Why cross national boundaries?

International cooperation expands access to specialized facilities, expertise, industrial experience, and alternative technological approaches. It is valuable when no single country or organization possesses all capabilities required for a complex engineering problem.

- Complementary specialization: one group may excel in modelling, another in material characterization, and another in industrial equipment.
- Shared infrastructure: partners can avoid duplicating expensive experimental and pilot facilities.
- Wider validation: technologies can be tested with different raw materials, climates, energy systems, and operating conditions.
- Broader innovation: alternative approaches challenge assumptions and stimulate new concepts.
- Human-capital development: researchers gain experience in international teamwork and diverse research environments.
- Greater dissemination: networks can spread validated methods to industries and countries unable to develop them independently.

5.2 Risks and mitigation

International projects introduce language and cultural differences, time-zone coordination, unequal access to funding and facilities, differing regulations and IP laws, material-transfer difficulties, and the risk of unequal participation. Address these through transparent governance, equitable authorship and credit, shared work plans, clear data-management procedures, appropriate IP arrangements, and regular technical reviews.

5.3 Illustrative network structure

Partner	Typical responsibility
Industrial problem owners	Define the production need, supply representative data/materials, set acceptance criteria, and lead adoption decisions.
Academic group A	Fundamental science, experiments, material characterization, and validation.
Academic group B	Modelling, AI, process optimization, and control.
Equipment/technology partner	Equipment design, integration, scale-up, and maintainability.
Energy partner	Renewables, heat recovery, utilities, and energy-system integration.
Joint pilot team	Demonstration, techno-economic assessment, workforce training, and technology transfer.

6. Developing highly trained technical manpower

A major benefit of collaborative R&D; is the development of engineers and scientists who understand how to translate scientific knowledge into industrial performance. Academic training builds depth in theory, experimental design, and scientific communication. Industrial exposure adds experience with uncertain data, competing requirements, budgets, safety, and decisions made with incomplete information.

Training element	Expected capability
Fundamental coursework	Transport phenomena, thermodynamics, materials science, numerical methods, and domain science.
Industrial problem definition	Translate operating symptoms into research questions and measurable objectives.
Experimental and analytical skills	Instrumentation, uncertainty analysis, data interpretation, and reproducible research.
Computational tools	Modelling, simulation, AI/ML, optimization, and digital-twin methods where appropriate.
Industrial placement	Equipment, process operation, safety, maintenance, and production constraints.
Pilot-scale research	Scale-up, equipment limitations, material variability, and process integration.
Techno-economic evaluation	Capital costs, operating expenses, payback, life-cycle costs, and implementation risk.
Communication and teamwork	Explain results to scientists, plant engineers, managers, and commercial decision-makers.

6.1 Recommended institutional mechanisms

- Co-supervised master's and doctoral projects.
- Industrial internships and research placements.
- Industry-supported doctoral fellowships and postdoctoral positions.
- Joint appointments and visiting researcher programs.
- Short courses for practicing engineers.
- Shared pilot facilities and demonstration laboratories.
- Industrial case studies integrated into university curricula.
- Continuing education in energy efficiency, advanced process control, AI, and sustainable manufacturing.

Students should have a clearly defined research contribution, appropriate academic supervision, and a reasonable opportunity to publish findings under agreed confidentiality rules. The long-term benefit is a workforce capable of leading innovation inside industry and identifying new research needs.

7. Proposed methodology for collaborative R&D; in drying and dewatering

Stage 1 — Establish the industrial need and quantify the baseline

Document the existing process, feed properties, moisture content, throughput, energy use, product quality, emissions, labor, downtime, and operating cost. Record initial and final moisture content on a stated wet or dry basis; water removed per unit time; thermal and electrical energy; drying time; quality and rejection rates; availability and maintenance; utility prices and emissions; and capital constraints. The baseline must be reliable enough to determine whether an apparent improvement is real.

Stage 2 — Formulate a joint research question

Agree on a question with the industrial sponsor, academic team, and technology partners. For example: “Can specific energy consumption of an existing dryer be reduced by 25% while maintaining throughput, product quality, safety, and reliability?” This is an illustrative target, not a prediction; the appropriate target must be based on process data and technical-economic assessment. Decompose the question into hypotheses, design choices, and acceptance criteria.

Stage 3 — Form a multidisciplinary team

Select participants according to project needs. A typical team includes a process engineer, transport-phenomena specialist, materials or product scientist, experimental researcher, modeller, controls specialist, and equipment engineer. Appoint an industrial sponsor, academic scientific lead, technical project manager, data/documentation lead, and commercialization contact.

Stage 4 — Conduct a critical technology assessment

Assess existing options before designing new equipment. Depending on the application, these may include improved hot-air drying, heat-pump-assisted drying, heat recovery, microwave/radio-frequency/infrared assistance, vacuum or freeze drying, superheated steam, hybrid systems, mechanical dewatering before thermal drying, solar/geothermal/waste-heat integration, and advanced control. Select based on material properties, production requirements, quality, utilities, safety, scale-up risk, and total cost of ownership.

Stage 5 — Develop the scientific and engineering basis

Investigate the mechanisms that govern performance. Work may include heat and mass transfer, fluid mechanics and airflow distribution, moisture diffusion and shrinkage, sorption, particle or porous-material characterization, CFD, spray-drying particle models, energy and exergy analysis, quality/degradation kinetics, process integration, and mechanistic/data-driven hybrid models. Develop sufficient model fidelity to guide design, predict relevant outcomes, and support scale-up.

Stage 6 — Design experiments and screen alternatives

Use systematic experimental design rather than relying only on one-factor-at-a-time trials. Variables may include temperature, humidity, velocity, pressure, particle size, feed rate, solids concentration, residence time, pretreatment, and heat-recovery configuration. Measure drying rate, energy consumption, final properties, reproducibility, and equipment performance. Where appropriate, use factorial experiments, response-surface methods, uncertainty quantification, and model-based optimization.

Stage 7 — Develop and validate a laboratory prototype

Demonstrate the proposed mechanism under controlled conditions. Assess repeatability, reproducibility, mass and energy balances, measurement uncertainty, product quality, model agreement, operational limitations, and comparison with baseline. Faster drying alone is insufficient if it causes unacceptable quality, higher downstream costs, or unstable operation.

Stage 8 — Scale up to pilot equipment

Treat scale-up as a distinct project stage. Examine geometry, airflow distribution, residence-time distribution, heat-transfer area, material handling, and variability. For continuous dryers, reproduce important hydrodynamic and thermal conditions as closely as practical. For pharmaceuticals and sensitive foods, establish meaningful evidence of product quality and consistency. Determine the operating window, scale-up rules, equipment requirements, and remaining uncertainties.

Stage 9 — Perform techno-economic and environmental assessment

Compare the proposed process with the baseline using consistent system boundaries. Assess specific energy per unit of water removed and saleable product; capital and installation costs; operating and maintenance costs; annual savings; net present value; greenhouse-gas emissions; water use; product yield and quality; reliability; and sensitivity to energy prices.

A simple first estimate of annual energy-cost savings is:

$$S_E = (e_0 - e_1) \times M_w \times C_E$$

Here S_E is annual energy-cost savings; e_0 and e_1 are baseline and improved specific energy consumption; M_w is annual water removal; and C_E is the applicable energy cost per unit. Units must be consistent. This simplified estimate must be supplemented by capital, maintenance, product-quality, production-capacity, and other relevant effects.

Stage 10 — Demonstrate the technology industrially

Plan and execute demonstration with the university, industrial sponsor, equipment supplier, and relevant partners. Test under representative feed variability, operating schedules, and production conditions. Include operator training, safety reviews, maintenance planning, and deviation-management procedures. A successful demonstration turns a promising research result into a credible investment decision.

Stage 11 — Transfer, commercialize, and disseminate

Technology transfer may involve licensing, joint equipment development, engineering consultancy, process redesign, spin-offs, or direct implementation. Agree on publication, confidentiality, inventorship, authorship, and ownership of future improvements. The appropriate model depends on novelty, ownership, commercial potential, and implementation requirements.

Stage 12 — Monitor performance and continue improving

After deployment, compare operating results with the baseline and acceptance criteria. Document deviations, maintenance, quality changes, and further optimization opportunities. Plant data can support model refinement, digital twins, predictive maintenance, and adaptive control. The desired outcome is a continuing improvement cycle rather than a project that ends at commissioning.

8. A practical implementation roadmap

Illustrative period	Phase and key actions
Months 0–3	Define and organize: select industrial problems, measure baseline, identify partners, agree objectives, IP, confidentiality, and governance.
Months 3–9	Investigate and screen: develop mechanistic understanding, model the process, characterize materials, experiment, and shortlist technologies.
Months 9–18	Validate and evaluate: pilot equipment, validate performance, assess quality and safety, and conduct preliminary techno-economic analysis.
Months 18–30	Demonstrate and decide: industrial trials, refine engineering designs, finalize investment assessment, and decide on implementation.

This is an illustrative schedule for a bounded project with an available pilot facility. Complex pharmaceutical, biologics, or major equipment-development projects may require substantially longer.

Recommended governance

Use a joint steering committee for periodic oversight and a technical team for more frequent work. Each work package should specify its responsible partner, deliverables, budget, schedule, and acceptance criteria. Release funding in stages where appropriate, with explicit decision gates to stop, redirect, or expand the project based on evidence.

9. Priority R&D; themes for drying and dewatering

Priority 1 — Energy-efficient and low-carbon drying

Investigate heat recovery, heat pumps, electrification, renewable energy, thermal storage, hybrid systems, and process integration. Evaluate whole-system performance rather than dryer efficiency alone.

Priority 2 — Mechanical dewatering before thermal drying

Improve filtration, pressing, centrifugation, and other mechanical separation operations to reduce the water load entering the dryer. Assess energy and cost for the complete dewatering–drying train.

Priority 3 — AI, process control, and digital twins

Develop hybrid physics–AI models for monitoring, optimization, fault detection, and control. Validate against plant data and assess robustness to changing feed properties and operating conditions.

Priority 4 — Drying mechanisms and product quality

Couple transport phenomena with material science, microstructure evolution, phase changes, and product-specific quality requirements. This is critical for foods, pharmaceuticals, electrode materials, and advanced biomaterials.

Priority 5 — Scale-up and industrial validation

Develop reliable scale-up methods, standardized performance metrics, modular pilot facilities, and shared industrial demonstration programs to bridge laboratory innovation and commercial deployment.

9.1 Precompetitive collaborative research

Many drying challenges are shared across companies even when products differ: heat-transfer limitations, moisture measurement, dryer modelling, energy recovery, airflow uniformity, and predictive control. A consortium can investigate these common challenges while companies retain control over proprietary formulations, process settings, and commercial strategies.

Clearly distinguish precompetitive knowledge—general mechanisms, validated methods, generic models, and shared metrics—from partner-specific developments such as proprietary product data, confidential operating conditions, specialized equipment designs, and company-specific improvements. Agreements can permit wider dissemination of the first category while protecting the second.

10. Illustrative project: energy-efficient drying of industrial biomass

Consider a biomass processor that incurs substantial costs drying wet feedstock before combustion, pelletization, or further conversion. The company seeks lower operating costs and forms a joint project with a university, equipment manufacturer, and energy-systems specialist.

- Baseline assessment: measure feed moisture and variability, dryer energy, production rate, and product requirements.
- Material characterization: determine particle-size distribution, moisture-binding behavior, permeability, and feed variability.
- Process analysis: examine heat and mass transfer, airflow, and mechanical-dewatering opportunities.
- Technology screening: compare conventional dryer optimization, heat recovery, heat-pump assistance, and suitable renewable-energy options.
- Modelling and experiments: predict performance, run targeted trials, and identify promising configurations.
- Pilot validation: test the preferred approach using representative biomass.
- Economic assessment: compare capital cost, operating savings, maintenance, emissions, and sensitivity to energy prices.
- Industrial demonstration: verify improvements at representative production rates.
- Workforce development: train researchers and plant engineers in modelling, instrumentation, optimization, and control.

The project may reveal that the largest savings arise not from a new dryer, but from combining better mechanical dewatering, reduced air leakage, exhaust heat recovery, and improved control. The industrial objective should determine the research strategy rather than the research strategy determining the industrial problem. No specific percentage saving should be assumed before measurement and validation.

11. Measuring success: a balanced performance framework

Dimension	Suggested indicators
Scientific advancement	Validated mechanisms, predictive models, methods, and peer-reviewed publications.
Engineering performance	Specific energy, throughput, process stability, product quality, and reliability.
Economic value	Capital requirements, operating savings, payback, net present value, and implementation costs.
Environmental performance	Greenhouse-gas emissions, water use, waste generation, and resource efficiency.
Technology transfer	Validated prototypes, pilot trials, licenses, equipment deployment, and industrial adoption.
Human-capital development	Graduate training, placements, interdisciplinary skills, and subsequent employment or leadership.
Partnership quality	Repeat projects, partner satisfaction, shared facilities, equitable contributions, and continuity.
Knowledge dissemination	Publications, conferences, technical guidance, training materials, and reusable nonproprietary data.

Targets should be project-specific. A fundamental study may prioritize scientific understanding and a validated model; a demonstration project may emphasize energy savings, reliability, and readiness for investment. A balanced scorecard avoids both undervaluing enabling science and overstating the industrial importance of unvalidated research.

12. Recommendations for universities, industry, and funding organizations

For universities

- Recognize industrially relevant research and validated technological outcomes in academic assessment.
- Provide incentives for faculty participation in collaborative R&D.;
- Establish accessible pilot facilities and professional support for industrial projects.

- Train researchers in project management, technology transfer, techno-economics, and IP management.
- Protect fundamental research and publication opportunities while honoring legitimate confidentiality.

For industry

- Involve academic partners during problem formulation rather than only after selecting a technology.
- Provide technical personnel, representative materials, process data, and equipment access.
- Contribute appropriate funding and recognize that rigorous R&D; entails uncertainty.
- Include scale-up, maintenance, and commercial implementation in project planning.
- Support long-term research relationships rather than relying only on short-term procurement or consultancy.

For governments and funding agencies

- Support projects that combine industrial contributions with public research funding.
- Fund pilot-scale validation and demonstration, where promising ideas often face a financing gap.
- Encourage interdisciplinary and international consortia with equitable participation.
- Support shared facilities and technology-transfer expertise, especially for small and medium-sized enterprises.
- Evaluate scientific, technological, economic, environmental, and workforce outcomes.
- Avoid structures that reward publications alone or demand immediate commercialization from long-term research.

13. Overall conclusions

The perspectives represented in Professor Arun S. Mujumdar's published work support a strong case for closer, more systematic cooperation between academia and industry in engineering and technology. The message is not that universities should become extensions of industrial R&D; departments, nor that industry should finance every academic activity. Rather, the two communities should recognize their complementary roles and build effective mechanisms to connect fundamental understanding with practical innovation.

- Relevance and excellence must coexist. Industrial problems can stimulate fundamental discoveries, while rigorous science can produce more reliable and generalizable engineering solutions.
- Technology transfer should be designed into the research process. Problem definition, scale-up, pilot validation, economics, IP, and implementation should be considered from the beginning.
- Interdisciplinary and international cooperation can increase returns on scarce resources through shared expertise, facilities, and diverse perspectives.
- Human-capital development is a central outcome. Researchers trained in scientific fundamentals and industrial practice strengthen long-term innovation capacity.
- Success requires continuing partnership and objective evaluation. Publications, patents, prototypes, adoption, energy savings, quality, and trained personnel are complementary indicators.

For drying and dewatering, a particularly promising strategy is to establish sustained, multidisciplinary collaborations around clearly defined industrial problems. These collaborations should combine transport phenomena, materials science, process modelling, experimental validation, advanced control, energy integration, and techno-economic assessment. They should engage manufacturers, equipment suppliers, and end users from the outset and include a credible path to pilot and industrial demonstration.

Ultimately, the most productive model of engineering R&D; is one in which science informs industrial practice, industrial challenges stimulate new science, and both contribute to better technologies, more competitive manufacturing, sustainable resource use, and a highly trained technical workforce.

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