Educating the chemical engineer of the future

***Edmond Byrne** argues that sustainability needs to quickly become the context for 21st century chemical engineering education to enable engineers be fit for purpose to address significant challenges ahead. He provides some suggestions for helping achieve this.*

The twenty first century promises to present humankind with an unprecedented confluence of global challenges, all emanating from an unsustainable societal construct. These include global energy, water and food scarcity, exacerbated by accelerated climate change; constituent elements for a *"perfect storm"* as described by Professor John Beddington, the UK government's chief scientific advisor last year. Social inequality and economic turmoil only promise to aggravate the situation.

'Sustainability' presents a myriad of definitions, but for its sheer eloquence and simplicity it's hard to beat that of MIT chemical engineering professor emeritus John Ehrenfeld, who suggests *"sustainability is the possibility that humans and other life will flourish on Earth forever."* Based on trends expressed through any of the metrics that abound regarding ecological, environmental, social and even economic measures, one would be hard pressed to argue that the current societal construct is currently sustainable by this definition.

a unique perspective

Chemical engineers, with their inherent understanding of material and energy balances and the second law of thermodynamics, can appreciate how any economic societal construct that does not consider the earth as a whole and materially closed system is ultimately doomed to failure. A world based on 'end of pipe mitigation', or for that matter, one which only strives for increased efficiencies while ignoring the reality of capacity limits, will not present a sustainable construct. As Ehrenfeld points out; *"reducing unsustainability, although critical, will not create sustainability."* Instead, the existing paradigm of ever increasing consumption of everything (material, energy, etc) must be replaced by one which recognises the earth's (physical resource) limits (see Figure 1). As we increasingly press against these limits, the call for such change is becoming ever more urgent in the context of our complex ecological, social and economic world; as the feted macroeconomist Rudiger Dornbusch observed, crises always take a lot longer to happen than expected but, once started, they move with frightening rapidity.

Thus, in common with other disciplines, but with a special responsibility and indeed opportunity to lead in this endeavour given our unique perspective, chemical engineering and its educational programmes must quickly be imbued with a sustainability informed paradigm. And as with all cultural practices, which obtain as complex evolving systems, a tipping point towards this new paradigm will not be attained through some single factor but due to a number of elements combined; informed and motivated educators, high level policies and initiatives of professional institutions, accreditation guidelines, aspirational students, industry expectations, regulatory requirements and evolving broader societal and cultural norms.

progress being made

Many of these factors are currently falling into place; at an institutional level for example, the IChemE has established a lead role among peer institutions globally through a number of initiatives, including the visionary 'Roadmap for 21st Century Chemical Engineering', a kind of strategic plan for the profession largely based on moving towards a sustainable future (Figure 2). Each of its six themes, which include 'sustainability and sustainable chemical technology', 'health, safety, environment and public perception of risk', 'energy', 'food and drink', 'water' and 'bioprocess & biosystems engineering' present both the major challenges we face and the makings of providing a sustainable future.

what shape a future curriculum?

Embedding a sustainability informed paradigm cannot be achieved by merely adding a module as an add-on to an already crowded curriculum. While such modules are useful (and perhaps necessary) in providing students with the necessary concepts, tools, language and framework around sustainability, it is imperative that a sustainability informed philosophy run perpendicularly through the programme, including and in particular from first year and any introductory chemical engineering modules.

The outcomes of a recent workshop at University College Cork on accreditation and sustainable engineering (as part of a broader Symposium, see: www.ucc.ie/isee2010) reveal a number of future potential directions. The chemical engineering groups involved suggested the development within programmes of a number of topics which in most cases could be integrated into the existing curriculum structure. These include integration of a sustainability paradigm into (process and product) design, 'chemistry for the future' (e.g. molecular transformation), complexity/systems thinking/uncertainty, life cycle analysis, including identifying system boundaries for material and energy balances, macroethics and moral leadership, post normal science, thermodynamics and its relationship with sustainability, sustainable energy, creativity and teamwork, communications and engineers as agents of social change.

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sample question; pipeline design

It is estimated that some 20% of the world's industrial electrical demand comes from pumping systems. Appropriate pump–pipeline design can therefore play a significant role in controlling energy costs. To demonstrate this, students might be asked to choose an appropriate design between two smooth long straight horizontal pipe options operating with some given flowrate, q (see Figure 3). The only difference between the two pipelines is that the second has a diameter twice as great as the first. Moreover the Reynold's number in one of them is just about laminar at 2000.

Doing the calculations using the usual equations, the students (and their lecturer!) might be surprised to find that the pressure drop (and hence power consumption) is some 40 times greater for the narrower pipe (afflicted by turbulent flow) than for the wider one. The lesson? In designing conventional pumping systems, select larger diameter pipes if and where possible. Notwithstanding any extra capital outlay, a potential operating cost reduction of up to 97.5% is not to be sniffed at!

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design project example

An example application of a sustainability embedded approach involves the traditional chemical engineering capstone design project, typically a group design of an industrial process to produce some given (chemical/pharmaceutical/food) product. As part of the design the group typically consider possible alternative processes to produce the product and then chooses and designs a suitable process having analysed and compared the available processes subject to a number of constraints, including economic, environmental, safety, availability, and so on.

A commonly quoted example is the production of the vinyl chlorine monomer (VCM), the precursor to the poly vinyl chloride (PVC) polymer. Here, as part of the design exercise, students may be required to investigate two options; one with an ethylene raw material, the other using acetylene. As part of this, a number of novel unit operations may be considered which lead to a reduction in volatile organic compound (VOC) emissions in one process compared with the other. The system can then be extended to incorporate raw materials and PVC production and a life cycle analysis can be undertaken. While these are interesting and in many ways innovative approaches, they remain firmly within the constraint driven paradigm of traditional chemical engineering practice. As a result of this the student is only challenged to compare one unsustainable system with another less unsustainable system.

A more appropriate question from a standpoint whereby sustainability is context might not be simply: *'What is the best way to produce vinyl chloride?'* but instead: *'Design a process to produce a material with the properties of PVC.'* This turns the design question on its head and opens up many potentially innovative possibilities while empowering the students' learning. It provokes follow-on questions among the design team, such as: *'Are there materials, and corresponding processes, other than VCM/PVC that can take their place, that are sustainable, or at least, less unsustainable?' 'Could for example, lactic acid, and the resultant biodegradable plastic polymeric lactic acid (PLA) take the place of PVC for many applications?' 'In general, how feasible is it to produce plastics from renewable materials as opposed to oil?' 'What are the technical and economic barriers preventing for example, the production of biodegradable polymeric materials to met the required specifications?'*

envisaging a broader role

These are questions which will arise if a much broader scope is envisaged. Questions too that will ignite the interest of curious undergraduate engineers and which can engender a sense of empowerment and responsibility to search for genuine alternative sustainable design options, and not only while carrying out and researching their project but throughout their future careers. This also allows the undergraduate engineer develop an appreciation and capacity for research whereby they investigate possibilities emanating from the cutting edge of scientific and engineering research, thereby encouraging greater innovation among aspiring chemical engineers. Some more examples from throughout the curriculum amid a broader discussion can be found in a recent paper published in *Education for Chemical Engineers*, 4 (2009) pp51-67.

Chemical engineering graduates who are required to seek out sustainable design solutions through their educational programmes will for example, be more likely to consider designing pharmaceutical plants using micro reactors and continuous micro-unit operations as opposed to at traditional batch/large scale and hence push process design boundaries, boundaries which are being increasingly recognised in the industry as being outdated in the context of industry overcapacity and reduced production requirements for more potent and tailored products. Such approaches also have the capacity to significantly reduce energy, material and waste consumption/production while also side stepping scale up problems.

leading positive change

Graduates with a sustainability informed education would also better understand the need for multi and inter-disciplinarily approaches to solving the 'wicked' ill-defined real problems they are likely to encounter through their professional careers, across areas such as those outlined in the Roadmap. This results in improved communication and team working skills. It would also enable graduates envisage a wider, more normative role for chemical engineering, where they can influence key production decisions and directions, as well as better engage in the conversation on broader societal issues including policy development and formulation. Engineering is not, never has been, nor cannot ever be 'value neutral'. Plastics companies who hire chemical engineers who see their role as merely 'paid hands' to produce plastics more efficiently may find themselves without a market over time, and the chemical engineer they hired without a job. Chemical engineers who join plastic manufacturers, and who see their role as one which produces or develops a product which meets a required specification for a given function, may help lead their organisation to continued success through innovation and new product lines. The same applies to those working in pharmaceuticals, energy, food, water, biotechnology, consultancy, and so on.

recruitment; an enticing prospect

A chemical engineering profession which views sustainability as context for all professional practice is also a hugely enticing prospect for the bright idealistic school leaving teenagers considering their career options. While a recent Royal Academy of Engineering/Engineering and Technology Board publication on *Public Attitudes to and Perceptions of Engineering and Engineers* (2007) found that the public viewed engineering as *'part of a type of commercialism that acted in the interests of money and progress rather than the good of people'* and that engineers are *'responsible for key problems in society, such as climate change'*, another study of engineering students at Imperial College London found that *'making a difference to the world'* was among the top three inspirations behind choosing engineering among all students and the number one among females.

A sustainability informed paradigm throughout the profession can thus facilitate the establishment of an improved public image, while the propagation of an expanded self-image can help attract a broader profile of potential entrants to the profession. Is it any wonder therefore, that the progressive approach adopted by the IChemE, as epitomised by the Roadmap and other initiatives, has coincided with year-on-year increases in enrolments over the past decade to reach record levels across the UK? While more can be done by professional institutions, in particular via evolving accreditation guidelines, and while there is plenty scope among universities in further developing fit for purpose programmes, nevertheless a strong foundation has been laid for further progress.

the future is here

While Beddington's dateline of around 2030 for *"perfect storm"* conditions was designed more to focus minds than as a concrete forecast, it is a sobering fact that today's undergraduate intake will still be early career thirty-somethings by then. It is therefore imperative that both academic programmes quickly adopt to this new reality and that organisations employing them provide an attractive work ethos to enable such engineers display this broader range of skills; otherwise each may find their demise even more quickly than the society they inhabit.

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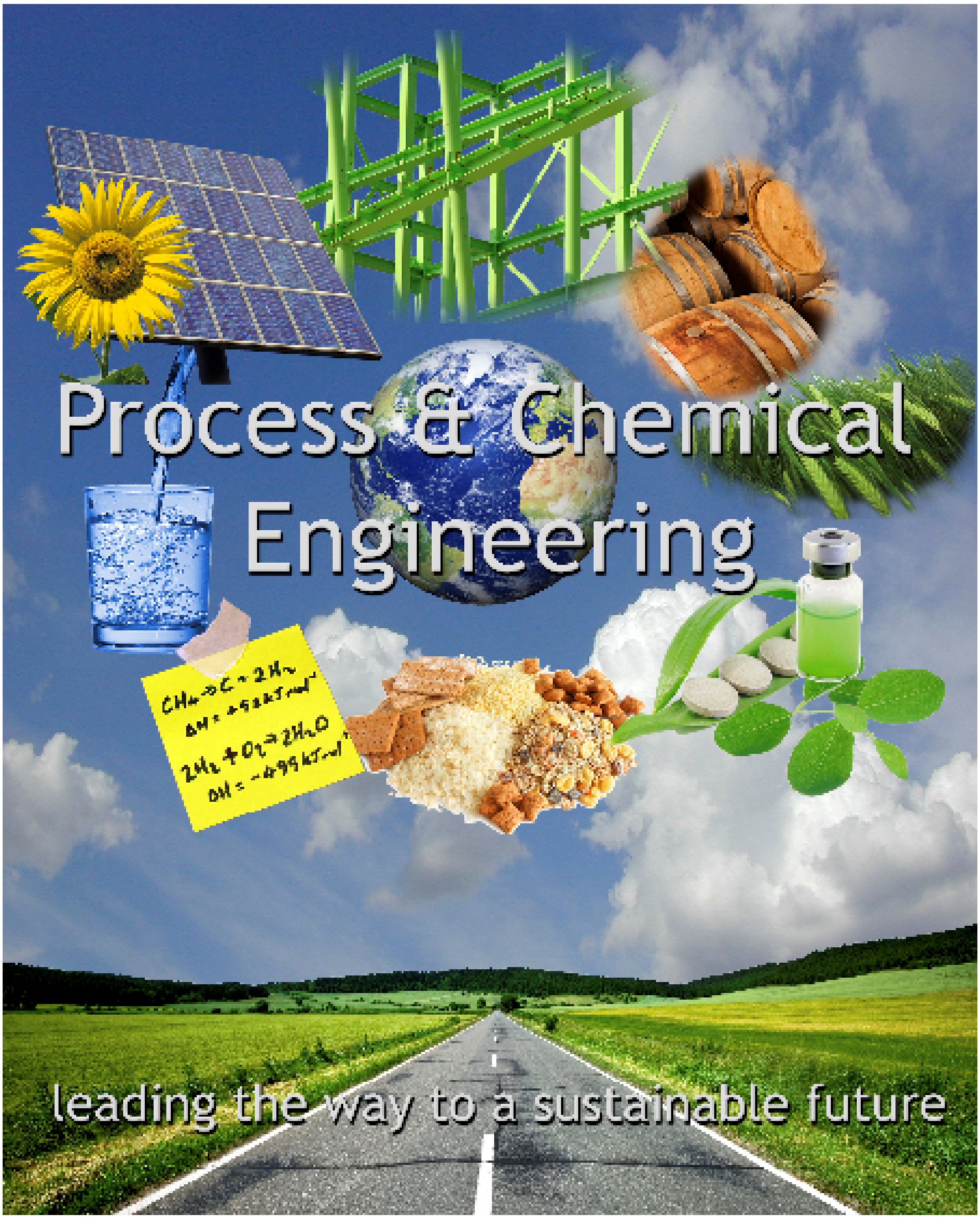
List of Figures below with potential captions:



A vision of Chemical Engineering (www.ucc.ie/processeng)

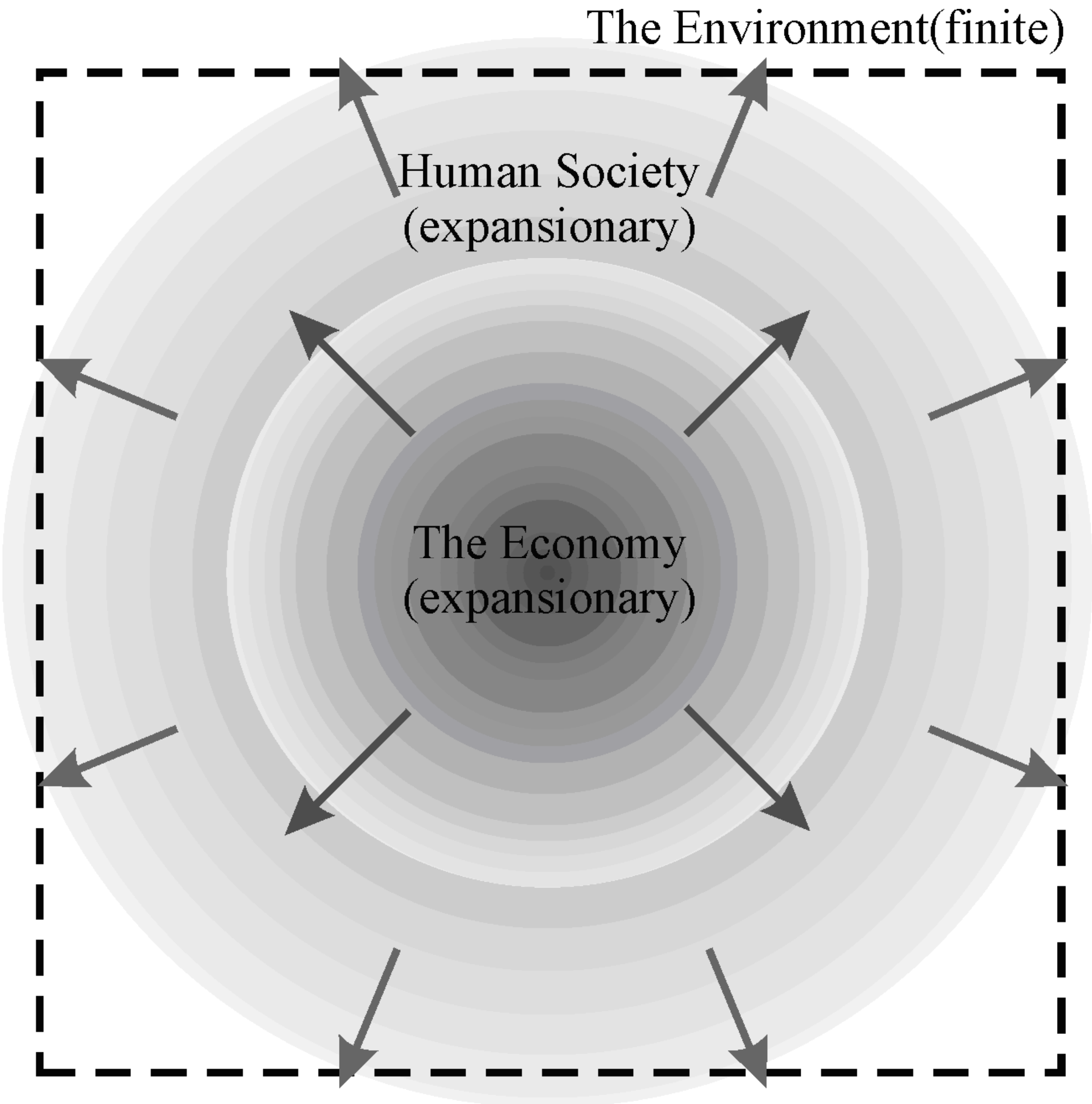


Figure 1 The three sphere model; recognises limits to economic and societal expansion within the materially closed system that we inhabit.

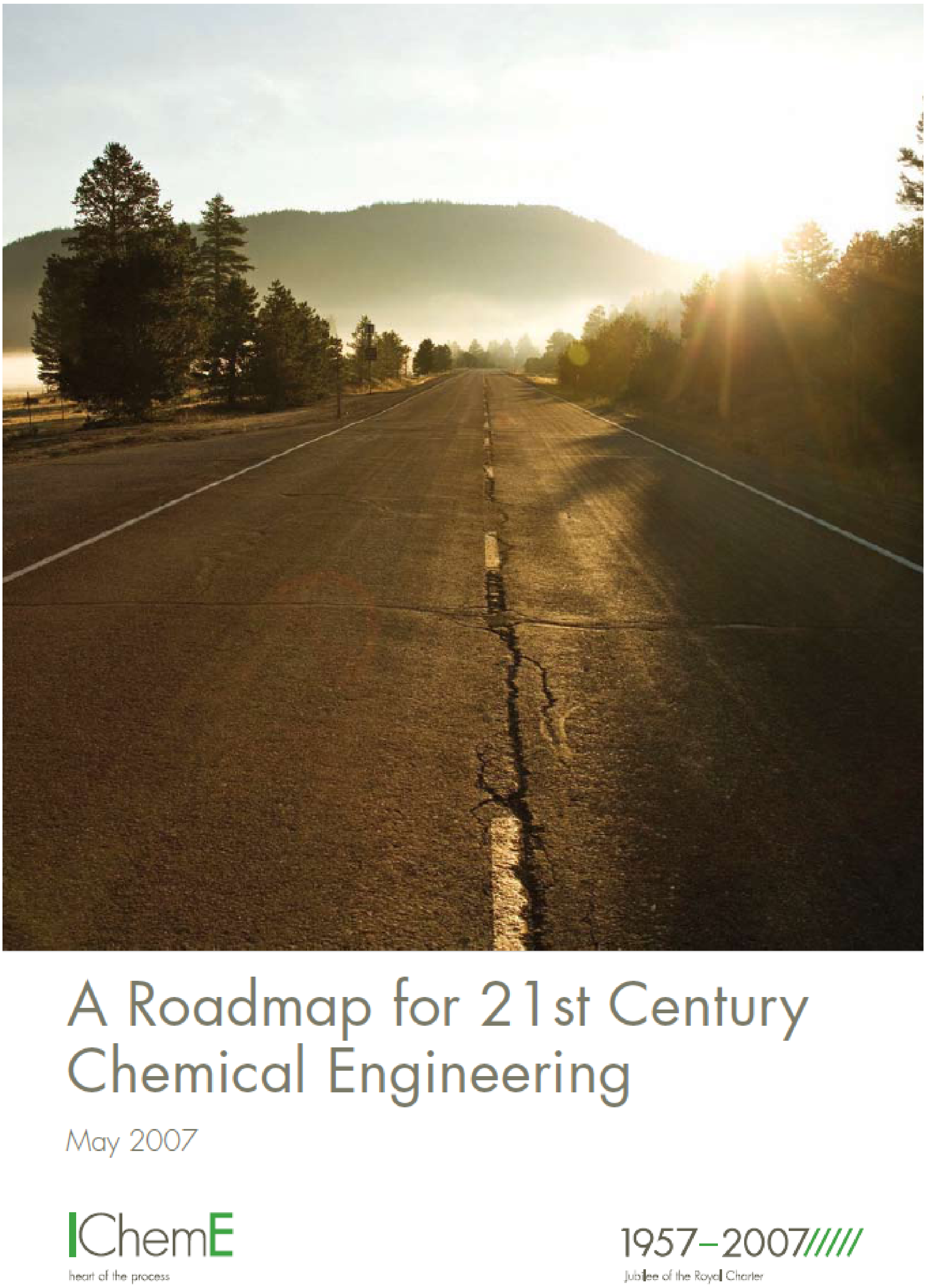


Figure 2 IChemE Roadmap; strategic plan for the profession

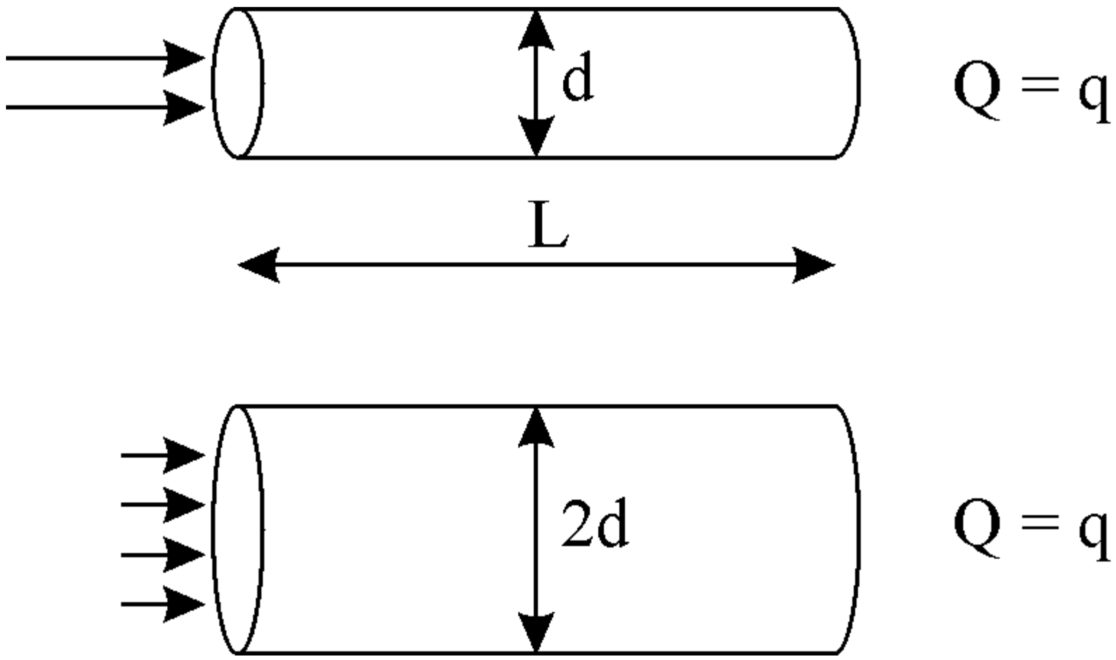


Figure 3 Pipeline diameter significantly affects pumping costs