Engineering Work in Canada:

Biotechnology
Software Development
Information Technology

Prepared for the
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Of the
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Executive Summary

Purpose of Study

The purpose of this study is to identify trends in engineering work in three rapidly growing and technology-intensive industries: **biotechnology, software development and information technology (IT).** This study is part of the *Engineering Work in Canada* research programme which is being undertaken by CERB. The *Engineering Work in Canada* Programme is a multi-year set of studies examining the current and future workplace conditions and utilization of professional engineers as well as their skill requirements.

The study was commissioned by the Canadian Engineering Resources Board (CERB). CERB is a standing committee of the Canadian Council of Professional Engineers (CCPE). CCPE is the national organization of the 12 provincial and territorial associations that govern the practice of engineering in Canada and license the country's 157,000 professional engineers.

Industry Definitions

Biotechnology:

- companies in the pharmaceuticals, agri-biology and aquaculture industries,
- companies developing or manufacturing advanced medical devices used in diagnostics or organ replacement,
- companies using biology-based technology for environmental remediation.
- among the key technologies that define the industry are cell fusion, recombinant DNA, the creation of new organic compounds and various proprietary processes involving biological processing.

Software Development:

- comprise companies or business units focussed exclusively on the design of software applications intended for sale in either consumer or specialized markets,
- excluded are companies that develop customized software solutions,
- included are companies that develop software that is integrated with hardware.

IT:

- manufacturers: producers of computer components or peripherals or communications equipment.
- non-manufacturers: communications utilities and custom-solution providers.

Methodology

This study is based on **interviews with human resource directors and engineering managers in 93 companies**. Interviews were conducted by telephone and in person. The sample of companies was drawn from a much larger roster that was prepared with the advice of Industry Canada, human resource councils, the CCPE and its affiliated provincial organi-zations. Companies were interviewed on the basis of their availability and within the overall constraint of maintaining reasonable representativeness in the interview sample.

The following table shows the distribution of interviews by industry and company size.

Figure No. 1
Distribution of Interviews by Industry and Size of Company

	< 50	51-250	251-500	> 500	Total
Biotechnology	3	12	8	3	26
Software Development	2	6	4	4	16
IT – Manufacturing	0	8	12	11	31
IT – Non-Manufacturing	0	3	7	10	20
Total	**5**	**29**	**31**	**28**	**93**

Regional factors are important for some purposes. However, the trends that constitute the central findings of this study are not regionally specific. In particular, **the organizational model, skill requirements and career paths that have emerged in the biotechnology, software and IT sectors are essentially the same in all regions**.

Figure No. 2:
Distribution of Interviews by Region and Industry

Industry	Bio-Technology	Software Development	Information Technology (Manufacturing)	Information Technology (Services)	Total
Atlantic	2	1	3	3	9
Quebec	7	4	5	3	19
Ontario	7	6	14	9	36
Prairies	8	2	5	3	18
B.C.	2	3	4	2	11
Total	**26**	**16**	**31**	**20**	**93**

The project team believes that the findings of this study warrant a high degree of confidence. In particular, we were impressed by **the conver-gence of findings across companies and across industries.** It is our view that additional interviews would have been largely confirmatory.

General Findings

This section reviews the findings that are applicable across all three industries.

1. Rapid Growth

In all three industries, rapid growth dominates all other factors in determining the demand for engineers. Growth rates in these industries have been approximately four times the economy-wide rate. In the past five years, growth rates have been accelerating.

The rapid growth of these industries has a number of implications:

1. the composition of the profession, by specialization, will change. In particular, electrical and electronic engineering is likely to increase more rapidly than other specializations;

2. *trends in specialization may have adverse implications for trends in professional registration;*

3. trends in specialization may also have implications for the role that engineers expect of their professional associations;

4. rapid growth in biotechnology, software development and IT will affect employers' expectations of engineers. *Employers in these industries expect graduate engineers to have a high level of theoretical knowledge, practical experience in designing applications and experience in working in multi-disciplinary teams.*

2. Engineering Work

Where is the Engineering Work in these Industries?

Figure No. 3 distinguishes seven business functions and reports the engineering intensiveness of these functions. It should be noted that these assessments are qualitative estimates based on the interviews.

Figure No. 3
Engineering Intensiveness of Business Functions
(based on Interview-Survey in Biotechnology, Software and IT, 1999)

Business Function	Engineering Intensiveness
Basic Science Research	Low to Very Low
Design of Product or Process	**Very High**
Management of a Production Process	Low to Moderate
Customer Support	Very Low
Trouble Shooting	Low
Specialized Solutions for Customers or Clients	Low to Moderate
General Management	Low to Moderate

The general findings that emerge from the interviews were as follows:

- In these industries, basic science research is generally done by individuals with advanced degrees. Although there are engineers involved in basic science research, this work is predominantly undertaken by other science-based professionals.

- **In all three industries, the essence of engineering work is in the design of a product or process, based on results developed in the basic science research stage.**

- Production management is not predominantly an engineering function.

- Engineers do not dominate general management, although a substantial number of general managers have an engineering background.

- There are **a minority of companies that have a pronounced engineering orientation and recruit engineers for the majority of general management functions**.

What does "Engineering Work" mean in these Industries?

- **Biotechnology:** Currently, there is a low utilization of engineers. There is significant scope for the profession to influence the conception of engineering work and the role of engineers.

- **Software Development:** The term "engineer" is widely used. This reflects the standing and credibility associated with the term. However, except in systems integration, the industry does not require an engineering degree.

- **IT-Manufacturing:** In general, design work is undertaken by engineers. Testing, production, trouble-shooting and customer relations are undertaken by technologists.

- **IT-Non-Manufacturing:** IT Solution Providers employ engineers when customer satisfaction requires an engineer or when there are systems integration issues that require engineering training. IT Transmission Services understand engineering work as responsibilities that require both an understanding of the relevant science and training in design principles.

3. Quality Control

In biotechnology and IT, there is a strong commitment to auditable quality standards and to quality control systems. In both of these industries, **understanding quality control theory and systems is regarded as a key skill requirement of engineers**.

4. Organizational Models

The predominant organizational model in all three industries is the multi-disciplinary team. **In recruiting engineers (as well as other science professionals), companies attach importance to non-technical skills that contribute to the productivity of multi-disciplinary project teams.**

Figure No. 4 summarizes the characteristics of the multi-disciplinary team. It should be noted that this model has been adopted, in various degrees, by companies in other industries. The sharpest contrast is between the multi-disciplinary team and the traditional engineering department.

Figure No. 4:

Characteristics of Multi-Disciplinary Teams

Characteristic	Description
Modus Operandi	Semi-autonomous team with a team leader whose leadership role is non-executive.
Composition	Teams are multi-disciplinary.
Analysis and Problem Solving	Emphasis on team-based approach rather than individual contribution.
Recognition	Team based.
Position Descriptions	Deliberately broad.
Stability	Life-span of the project.

5. Non-Technical Skills

Companies in the biotechnology, software development and IT industries attach considerable weight to a range of non-technical skills. These include:

- team-related skills
- general communications skills
- writing skills
- presentation skills
- business understanding
- leadership skills

Larger companies frequently undertake behavioural evaluation interviews to assess non-technical skills.

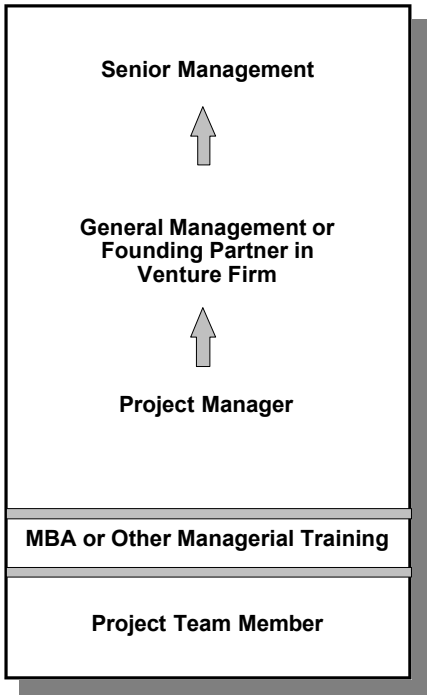
6. Project Management

Project management is an essential engineering skill in these industries. There is virtually no engineering work in biotechnology, software development or IT which does not involve project management.

7. Progression into Management

In biotechnology, software development and IT there is no natural progression for engineers into the ranks of general management. To advance into general management, engineers require additional training – either an MBA or company-specific managerial training. Figure No. 5 illustrates the predominant career path.

Figure No. 5:
Predominant Career Path in Biotechnology, Software Development and IT



8. No Dual Ladder

Advancement in the technical stream is limited to approximately a middle management level of remuneration. **There is no evidence of any trend towards instituting "dual ladders."**

9. Engineers and Technologists

In these industries, **there are no broadly accepted demarcation lines between engineers and technologists.** In some companies the distinction is pronounced. In these companies, design and project management are engineering responsibilities. In other companies, formal qualifications are significantly less important.

Companies generally praise the college and CGEP system for graduating well trained technologists with a practical orientation. University graduates are valued for their greater understanding of theoretical principles. For this reason, design functions, which require theoretical understanding typically are undertaken by engineers while production and trouble-shooting functions are more often assigned to technologists. Cost pressures, are a factor in substituting technologists for engineers.

10. Maintaining Skills

A significant proportion of companies regard the maintenance of skill currency as an individual responsibility. High rates of employee turnover in these industries militate against significant employer investment in generic skills. Virtually all companies will support training that is directly related to company requirements. However, **there is a strong philosophical view that generic skill development is primarily an individual responsibility.**

Company size is the single most important factor in determining the degree to which a business regards human resource development as a strategic variable. Large companies attempt to anticipate their human resource needs and to train employees to meet those needs. These companies typically have human resource development strategies that involve skill development plans for most employees. For non-technical skills, large companies often develop internal training programmes. Indeed, large companies are increasingly establishing internal training for management. The best known of these programmes is the GE Six Sigma programme.

11. Engineering Graduates

Companies hold recent engineering school graduates in high regard. Graduates of co-op programmes are especially valued in these industries. Many companies expressed a clear preference for graduates from co-op programmes.

Companies often indicated a preference for recent graduates when looking for individuals with significant programming skills. There is a widespread perception that engineering schools and computer science departments are current with programming languages. By contrast, companies have less confidence in the programming skill currency of engineers who graduated ten years ago.

Companies commonly find that the non-technical skills of recent graduates are under-developed. However, in suggesting solutions, the exclusive focus of companies was on undergraduate instruction. Few companies were aware of supervised internships, mentoring programmes or "engineer-in-training" programmes administered by professional associations. **Engineering schools were criticized for not providing skills that could more properly be seen as the focus of "internship" programmes preceding formal P.Eng. qualification.** Companies with fewer than 500 employees attached considerable value to a combined engineering/MBA qualification. Larger companies also valued this combined qualification, but were more likely to rely on internal management training to meet their needs for broader business skills.

12. Professional Associations

Companies in the biotechnology, software development and IT industries strongly identify with technology oriented professional associations, such as IEEE. The affinity for other types of professional associations is much less pronounced.

A moderate proportion of companies interviewed – approximately 30-40% - appreciate the role of professional associations in promoting ethics and standards of professionalism. However, only 25-30% of companies interviewed are supportive of membership in professional associations that are not technology oriented. Virtually none of the companies interviewed would make membership in a professional association mandatory. Few would regard it as a factor in recruitment or promotion.

Approximately 2/3's of companies interviewed are negative towards professional regulation, if it impinges on their managerial prerogative.

It should be noted, however, that in each of the three industries studied there is a sub-set of companies that were established by professional engineers. These companies often have a markedly stronger identification with the profession and with professional registration and licensing.

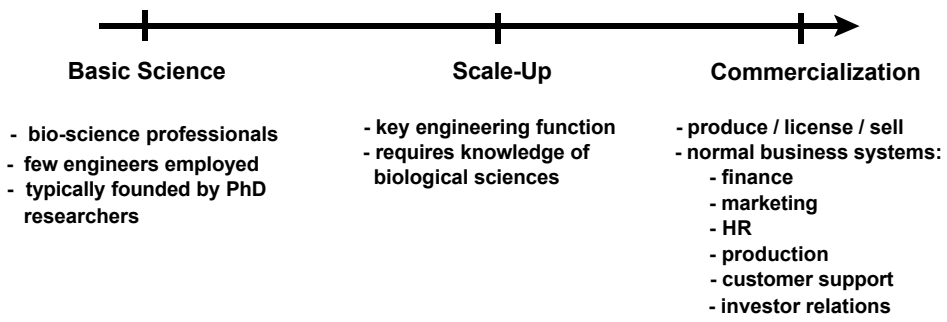
Biotechnology

The biotechnology industry comprises companies that have developed or are developing products or processes with a basis in biological processes. Among the technologies which are central to the biotechnology industry are: cell fusion, recombinant DNA and the creation of new organic compounds. The Biotechnology Human Resources Council estimates that in 1998, approximately 24,100 persons were employed in biotechnology. Of these, roughly 40% were in R&D.

- Life Cycle of Biotechnology Companies

The industry can be described in terms of three stages of development. illustrated in Figure No. 6:

Figure No. 6
Biotechnology: Stages of Development



In the first phase, the basic science is developed. In this stage, professional employment is dominated by persons with advanced degrees in the bio-sciences. Few engineers are employed by companies in this stage of development. In Canada, the majority of biotechnology companies are in the basic science stage.

In the second phase, a bio-technology company scales-up the process developed in the laboratory to an industrial prototype scale. **In this phase, a bio-technology company requires engineering support – either directly employed or contracted.** For engineers, there are three critical skills:

- understanding biological processes,
- ability to design a biology-based process,
- ability to manage a design project.

In this industry, engineers must also be able to write analytical reports that meet the standards of the US Food and Drug Administration (FDA) standards and the Health Protection Branch in Canada.

In the commercialization stage, companies must also put in place their various non-technical business systems. These include: financial management, investor relations, marketing, product support, inventory management and human resources planning and management. To advance into the ranks of general management, engineers must be trained in developing and implementing these essential, business systems. Among
the companies interviewed, there were virtually no engineering jobs that did not involve significant managerial functions.

- **Nature of Engineering Work in Bio-technology**

There are six characteristics that distinguish engineering work in bio-technology from industries which have traditionally provided the preponderance of engineering positions:

1. Knowledge of the bio-sciences is essential.
2. The scaling up of laboratory processes to industrial scale is seen by the biotechnology industry to be significantly more complex than in other manufacturing industries. As well, in most biotechnology industries, manufacturing systems must comply with the US FDA's Good Manufacturing Procedures (GMP) standards.
3. Mechanical and chemical engineering are the most relevant specializations. However, companies find that most engineers with training in these fields are insufficiently prepared to deal with biology-based processes, e.g., fermentation, separation, purification and preservation.
4. The level of regulation, the stringency with which regulations are applied and the commercial consequences of non-compliance set the biotechnology industry apart from other sectors. Companies can also face potentially crippling liabilities from civil litigation.
5. Biotechnology companies are developing leading edge technologies. Companies are primarily concerned about the ability of their science-based employees to learn technologies that they were not taught in school. Consequently, these companies stress continuing competence.
6. Project management is an essential skill. Engineers without project management skills are of relatively little value to the biotechnology industry.

- **Technical Skills**

Key technical skills cited by companies included:

- experimental design and interpretation of results;
- statistical process control;
- separation and purification technologies;
- protein chemistry;
- fermentation technologies;
- irradiation technology
- the application of traditional mechanical engineering skills in an environment requiring high degrees of end product purity and

extreme process control — temperature control systems, chillers, air quality control, high pressure boilers, high speed packaging equipment, heat transfer, fluid control, etc.

- **Advanced Degrees**

It is common for science professionals in the biotechnology industry to hold graduate degrees. In most industries, undergraduate training in engineering is sufficient. In the biotechnology industry, the strong preference for post-graduate training applies to engineers as well.

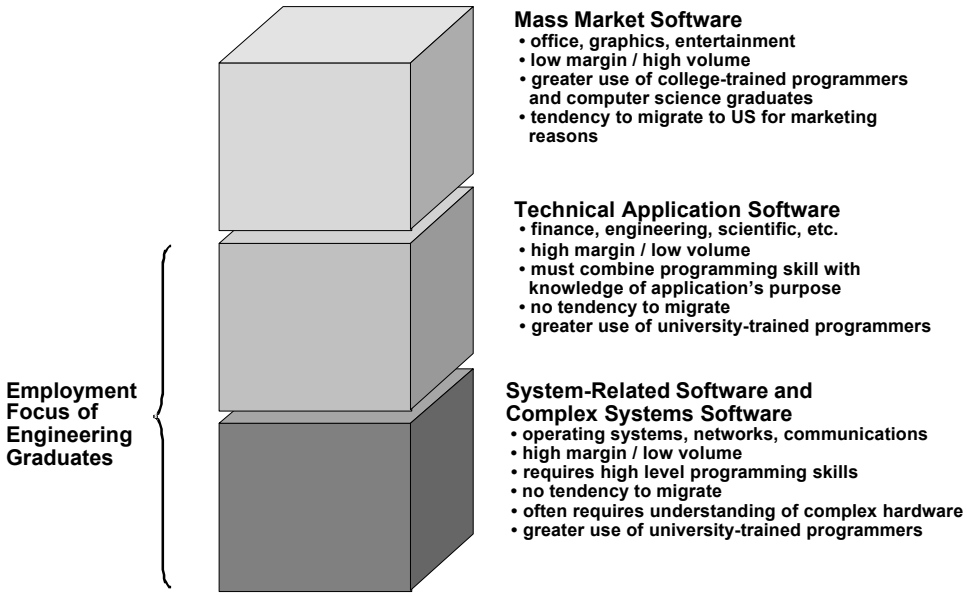
- **Future of Engineering in Bio-technology**

Opportunities for engineers in the biotechnology industry will expand dramatically over the next ten years as the large bloc of companies that are in the basic science stage move into scale-up and commercialization. The profession has a significant opportunity to influence the biotechnology industry's level understanding of the profession and the role of engineers in the industry.

Software Development

Figure No. 7 illustrates the structure of the software industry, by type of product.

Figure No. 7:
Structure of The Software Development Industry



Engineers are employed chiefly by developers of technical application software, system-related software and software that controls complex systems.

- Nature of Work done by Engineers

There is no consistent occupational nomenclature in the software industry. Nor is there any consistent pattern in qualifications. In general, companies regard training in engineering as commensurate with training in computer science, except where system integration is involved.

There is an important, though imprecise, distinction between high level software development and second level programming or code writing.

- **High level software development** involves the basic architecture of a programme, its relationship to hardware (where applicable) and the determination of programming languages. High level software development requires advanced training in mathematics.
- **Second level programming (or code writing)** involves developing code for components whose basic design was established by a high level programmer. Second level programmers are also involved in testing and de-bugging programmes.

Figure No. 8 illustrates the employment of engineers in terms of functions in the software industry.

Figure No. 8:
Employment of Engineers by Type of Work in the Software Industry

Type of Work	Qualifications	Significance to Employment of University Engineering Graduates
Product Support	Usually persons trained to the technologist level by colleges or private training institutes.	Negligible (The exception is complex technical application software).
Second Level Programming	Usually persons trained to the technologist level by colleges or private training institutes.	Not significant.
High Level Programming	Usually engineering or computer science graduates.	*Very significant.*
System Integration	Usually, though not exclusively, engineering graduates.	*Very significant.*

- Technical Skills

The technical skills stressed by companies were programming languages. The languages identified as current priorities are:

- Java;
- C++;
- Oracle database programming;
- Visual Basic; and
- Object programming.

Strong math skills are seen by companies as the foundation of competence in programming languages and the basis for learning new languages. This makes engineering school graduates especially attractive in the software industry.

- **Non-technical Skills**

  Companies stressed:

  - creativity;
  - ability to work in a team;
  - project management skills; and,
  - competitive analysis skills.

- **Balance Between Technical and Non-Technical Skills**

  The software industry attached a higher weight to technical skills than either the biotechnology sector or the IT industries. **From this industry's perspective, the defining characteristic of the labour market is the shortage of programmers with both technical qualifications and a track record of successful projects.**

- **Trends in Technology and Skills Requirements**

  Companies pointed to four trends that are affecting skill requirements:

  1. Software based solutions are replacing hardware based solutions. In manufactured products, research and development is often focused on the design of embedded software.

  2. Programming languages change rapidly within five-years or less. This implies an increasing importance for the high level math skills which constitute the underlying logic for programming languages.

  3. The Internet is affecting virtually every type of software product. This affects the programming languages required and increases both the complexity of design and the amount of high level programming.

  4. Object oriented programming is reducing the time required to write component code, increasing the number of features (or modules in programmes) and shortening development cycles.

- Future of Engineering in Software Development

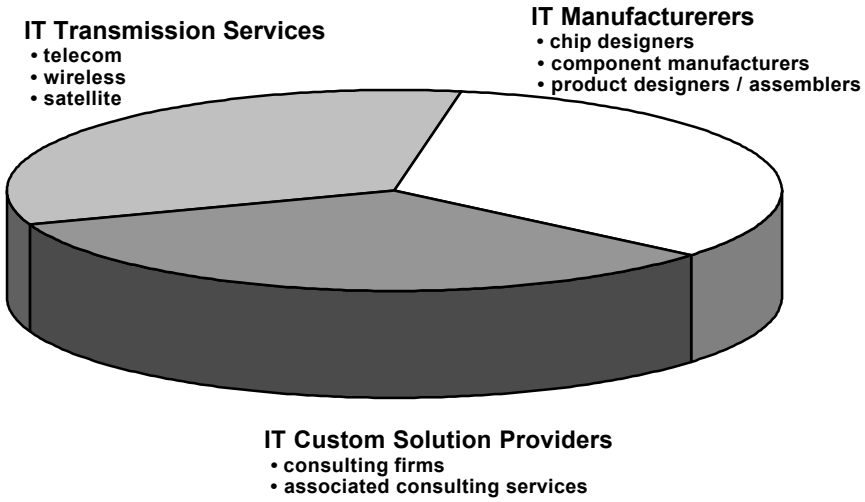
Employment opportunities for engineers will be concentrated in high level programming related to the development of technical application software, system related software and software that controls complex systems. However, except in system integration, the software industry, shows no preference for engineers over computer science graduates.

The management of R&D projects is a critical function in the software industry. Engineers who link this skill to their technical abilities have significant scope for advancement in the industry.

Information Technology (IT)

Figure No. 8 illustrates the structure of the IT industry:

Figure No. 8:
Structure of The IT Industry



Of the three industries, IT is by far the largest employer of engineers. There are also significantly more large companies in the IT sector than in biotechnology or software development. As a result, proactive human resource development is more common in IT. This includes skill development plans at the individual employee level.

- Nature of Work done by Engineers

A significant proportion of R&D is focused on developing software. Indeed, **programming skills are now a core skill for R&D work in the IT industry.** The emphasis on programming is so pronounced that a professional engineer entering the IT industry without programming skills will have limited career opportunities.

The widespread use of engineering software has eliminated much of the computationally intensive work that was previously done by engineers. This has had three effects:

- the utilization of junior engineers may be somewhat lower than it would have been in the absence of engineering software;
- the elimination of computationally intensive work has enabled engineers to explore design options and to achieve degrees of precision that were previously too time-consuming to pursue;
- the elimination of computationally intensive work has freed engineers to be more involved in direct dealings with customers.

Overall, in the IT industry, **the impact of engineering software is to increase the importance to higher level design skills.**

Companies also indicated that **the lines separating design work from R&D and manufacturing, have blurred.** Consequently, while design is the core of engineering work in the IT sector, engineers must also have the skills required to work in the manufacturing and commercialization stages of a product's development. This requires, in particular, that engineers acquire basic business management skills.

- Technical Skills

The technical skills stressed by IT companies varied, depending on the nature of the products or services being marketed. **Virtually all companies, however, emphasize the need for engineers to be familiar with internet protocol (IP) and programming languages, chiefly Java, Unix and C++.** Companies in all three segments of the industry underscore the importance of familiarity with engineering software.

IT manufacturers emphasize the need for circuit board and chip design skills. Companies developing wireless and fibre optic transmission systems stress the need for knowledge of RF (radio frequency) technology and photo optics theory.

- **Technical and Non-Technical Skills** — **Most companies regard technical skills as a necessary qualification, but not as a sufficient qualification.** On average, non-technical skills are assigned a weight that averaged around 40%.

- **Trends in Technology** — Companies pointed to three trends in technology that are affecting skill requirements:

  - in the IT industry, software-based solutions are replacing solutions that rely solely on hardware;

  - the internet has affected every aspect of the IT industry. Knowledge of Internet Protocol (IP), html and its variants and cross-platform programme languages, such as Java, are skills that are in short supply. **The change in skill-sets required by the Internet has had its most serious effect on professional engineers who graduated approxi-mately 10 years ago or earlier and who did not acquire these programming skills in their undergraduate training. Engineers in the IT industry who did not learn IP, html, C++ and Java as undergraduates must acquire these skills as part of their continuing competence;**

  - RF, *i.e.*, radio frequency/wireless communication, is emerging as the principal means of data transmission. Companies in this field report a significant shortage of qualified technical staff.

- **Future of Engineering in IT** — Growth will continue to dominate the demand for engineers. However, in the IT industry, more than in software, non-technical skills are essential to career advancement. Advancement prospects are greatest for those engineers that combine their technical training with managerial training.

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