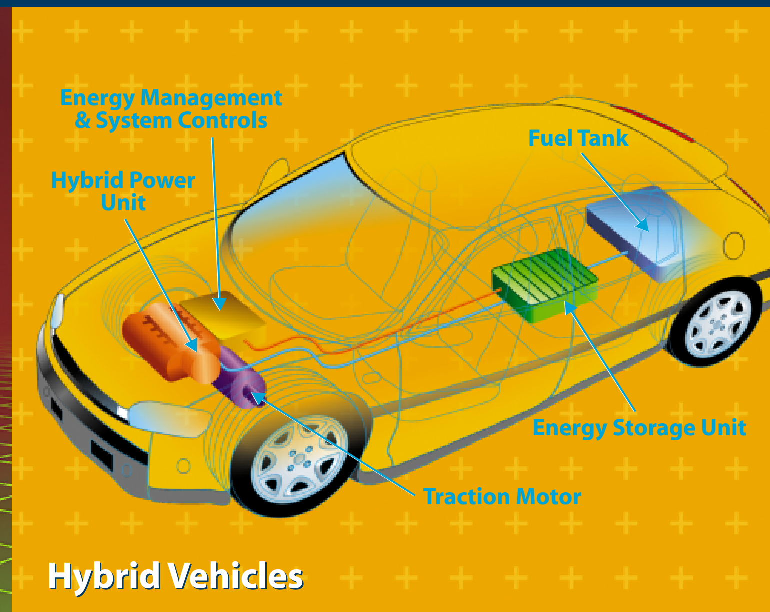
Emerging Technology Programs
ADM, Hybrids, Computer Forensics, & MEMS

Implications for Community & Technical Colleges in the State of Texas



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Texas State Technical College

Emerging Technology Programs for Texas Colleges

Advanced Digital Manufacturing
Hybrid Vehicles
Micro-Electromechanical Systems
Computer Forensics

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This technology forecast was funded by the Carl D. Perkins Vocational and Technical Act of 1998 as administered by the Texas Higher Education Coordinating Board.

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Acknowledgments

Analyses of the type described in this report that involve many technologies addressed from a number of perspectives, of necessity, must include input from many different sources. The authors of this report were very privileged to have been able to call upon a number of renowned experts for information, insight, and advice. We are very grateful to the following experts for their cooperation in this project and for their contributions to its successful completion.

Advanced Digital Manufacturing

Jerry Franklin
Elaine Hunt
Larry Liles
Timothy Stokes

Hybrid Vehicles

Joseph Casaletta
John Frala
Toby Gustavus
Tom Hudson
Richard Humanic

Computer Forensics

Mike Denn
Gary Kessler
Greg White
Ira Wilsker

MEMS

Robert Hall
Brad Nelson
Gerhard Salinger
John Simcik
Kevin Speller
John Wexler

During the conduct of this project, the authors had the opportunity to visit several laboratories at Texas State Technical College Waco. This visit was very useful to us in envisioning how the recommendations that we offer could, in actuality, be realized. We send our thanks to the following people for making that visit possible.

Joe Bergstrom	Laboratory Assistant, Laser Electro-Optics Technology & Semiconductor Manufacturing Technology
Daniel Deiterman	Instructor, Automotive Technology
Bradley Hennig	Student Worker, Recruiting Services - Guide
Fred Khozein	Department Chair, Biomedical Equipment Technology
Robert Lovelace	Instructor, Electrical Computerized Control Systems & Robotics
John Pedrotti	Instructor, Laser Electro-Optics Technology & Semiconductor Manufacturing Technology

No project of this type is possible without funding support. In this case the authors would like to particularly thank **Robert Franks**, Director of Perkins Grants Administration, Texas Higher Education Coordinating Board, for authorizing a Carl D. Perkins grant to support this project. Mr. Franks has shown a keen understanding of the purpose and value of analyses of this type.

The authors would like to send special thanks to **Dr. Larry Grulick** (Associate Vice Chancellor of Instructional Support and Research). Larry not only assisted directly in the selection of emerging technologies to be analyzed, but also offered valuable advice on how to improve the analysis processes. In addition to his assistance on this project, he has been a major participant in the development of the Program for Emerging Technology (PET) process and in the conduct of many of the technology forecast/analysis projects conducted in previous years.

Finally, the authors would like to thank **Mark Burdine**, Coordinator of Photography, Texas State Technical College Waco, for his excellent cover art and many of the images, charts and diagrams found throughout this report; **Debbie Moore**, Prepress Technician I, Printing Production, Texas State Technical College Waco, for her outstanding layout skills, final editing and the recreation of many tables and other report elements; **Eliska Flores**, Associate Vice Chancellor for Marketing and Communications, Texas State Technical College System and **Jan Osburn**, Director of Marketing and Communication, Texas State Technical College Waco, for their continued support of this research and expert advice; and **Bill Evridge**, Director of Printing Production, Texas State Technical College Waco and **TSTC Waco Printing Production** for printing, duplicating and binding this report. This report would not have been possible without the efforts of these individuals, and their skills and dedication are greatly appreciated.

The primary foundation of this report is the input that we have received from the listed experts, primary research and third party sources consulted during the conduct of this research. The report reflects the authors' interpretations of these inputs. Any misinterpretations of these inputs are the fault of the authors, and we apologize for these to the people who have so obligingly contributed to our efforts.

Finally, the authors would like to send special thanks to Dr. Larry Grulick (Associate Vice Chancellor of Instructional Support and Research). Larry not only assisted directly in the selection of emerging technologies to be analyzed, but also offered valuable advice on how to improve the analysis processes. In addition to his assistance on this project, he has been a major participant in the development of the Programs for Emerging Technology (PET) process and in the conduct of many of the technology forecast/analysis projects conducted in previous years.

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September 2004

Emerging Technologies: Executive Summary

To start this project, Technology Futures, Inc. (TFI) and Texas State Technical College (TSTC) identified over 40 emerging technologies that showed a potential to provide attractive employment opportunities for the graduates of the state's colleges and to provide a skilled workforce for the state's high-tech companies. The identification process was based on TFI and TSTC experience in technology forecasting and analysis, extensive reviews of appropriate literature sources, and consultation with experts in technology and education.

This list of 40 technology topics was reduced to 14 in an initial elimination process conducted by TSTC and TFI. TFI and TSTC then conducted an evaluation of the remaining 14 technologies in terms of the following factors:

- Employment opportunities for college graduates
- Impact on the state's economy
- The ease with which current curricula could be modified and expanded to meet the requirements of the selected technology, including requirements for special equipment or materials and specially qualified faculty
- Career attractiveness and the opportunity for long-term upward mobility
- Number of colleges in the state that currently offer programs in the technology.

Using these evaluation criteria, TFI and TSTC selected four of the original 14 technologies for a more detailed analysis. The selected technologies were advanced digital manufacturing, hybrid vehicles, micro-electromechanical systems (MEMS), and computer forensics. Each of these technologies was then analyzed in terms of:

- Technical characteristics
- Industry trends
- Compatibility with existing college programs
- Special factors
- Employment opportunity.

Based on these analyses, the following conclusions were drawn:

- ***Advanced digital manufacturing*** is a process for forming a product using a layered manufacturing process. Although this form of manufacturing has existed since 1987, a number of technical breakthroughs have increased the functionality and application of the underlying techniques. Employment opportunities for graduates with knowledge and training in these advances will become significant as the industry continues to change and grow.
- ***Hybrid vehicles*** are vehicles using integrated internal combustion engines and electric motors for power. The vehicles contain a number of unique systems not found in conventional gasoline vehicles. Although the demand for new technicians to service the small number of these vehicles currently available is quite low, colleges with existing relationships with hybrid manufacturers will probably introduce hybrid training into some of their existing automotive technology curricula.
- ***Micro-electromechanical systems*** (MEMS) are miniaturized, self-contained systems that integrate electrical and mechanical functionality to sense, process, and act upon information in their environment. MEMS will have a significant effect on the development of "intelligent" products in a wide range of industries including

aerospace, healthcare, and automotive. Therefore, employment opportunities for graduates in the field of MEMS will become significant as the industry grows.

- ***Computer forensics*** is the science of using specialized hardware and software to gather, correlate, and analyze information related to computer crime and fraud in a manner consistent with established legal procedures. As computer crime has grown, the demand for appropriately trained and qualified forensics technicians has become strong at all levels in law enforcement, government, and the private sector.

Emerging Technologies: Introduction & Background

A highly skilled workforce is essential to the success of Texas companies and the overall economic competitiveness of the state. By anticipating and proactively responding to future Texas workforce demands, community and technical college curricula can be a constructive force in attracting high-tech companies to the state and ensuring that existing high-tech companies have an appropriately skilled source of employees.

In pursuit of this goal, Texas State Technical College and Technology Futures, Inc., in partnership, have conducted the following research on emerging technologies that are likely to provide attractive employment opportunities for the graduates of the state's colleges. This report presents the results of this research and their implications for Texas colleges. The report is designed to provide the Texas State Leadership Consortium for Curriculum Development (CCD) and Texas Higher Education Coordinating Board (THECB) with timely analyses and actionable insights into emerging technologies and their potential impacts on existing and new technical education curricula. Through this research, TSTC hopes to facilitate the informed and well-considered development of new, or enhancement of existing, emerging high-tech education and training curricula at Texas colleges.

The Program for Emerging Technologies (PET) Process

The importance of emerging technologies to the economic well being of Texas and to the quality of life of its citizens was clearly recognized in 1999 when the Texas State Senate charged TSTC to "develop and administer a program to forecast the types of technical education programs that are needed to maintain and improve the State's economic and technical competitiveness." To meet this charge, TSTC, together with TFI of Austin, Texas, developed the Program for Emerging Technologies (PET) process for identifying and evaluating emerging technologies that promised to offer attractive employment opportunities for the graduates of the State's Colleges.

Since the development of the PET process, analyses have been conducted by TSTC and TFI on nanotechnology, fuel cell technology, and homeland security technologies. TSTC and the IC^2 Institute (IC^2) analyzed gaming and M2M wireless technologies. Reports for each of these analyses were distributed to the education decision makers of the Colleges and other interested people and organizations. Surveys of recipients attest to the high quality and utility of the reports.

All of these projects were supported by Carl D. Perkins grants that were administered by the Texas Higher Education Coordinating Board and were coordinated with the Texas State Leadership Consortium for Curriculum Development.

Current Analyses

Based on the success of the previous analyses, the PET process was extended into the 2003-2004 fiscal year. As previously stated, the process involved selection of technologies to be analyzed and conduct of the analyses. The selection process involved two separate steps.

Identification of Technologies to be Considered for Analysis

The purpose of this step was to identify a large number of diverse emerging technologies that might justify detailed analysis. Three approaches were used to accomplish this task:

- Surveys of three groups with particular insight into emerging technology areas.
- Searches of relevant literature.
- Interviews with subject matter experts.

Using these approaches, a total of 40 candidates for analysis were identified. A description of the conduct of the surveys is presented in Appendix A. A listing of publications reviewed, together with other references utilized in this report, is presented in Appendix B, and a list of the experts interviewed is presented in Appendix C. A chart showing the 40 technologies identified is presented in Appendix D, and a brief description of these technologies is presented in Appendix E.

Selection of Technologies for Analysis

Once the 40 emerging technologies were identified, the next task was to select a small number (four) that were judged to offer the most promising opportunities for the state's Colleges. This selection process was conducted in two stages:

First, the 40 technologies were reduced to a more manageable list of 14 by eliminating those technologies:

- For which forecast analyses had already been conducted.
- That duplicated programs currently being conducted by a number of State Colleges.
- That did not promise meaningful employment opportunities for College graduates.
- That did not appear appropriate for College programs.

The following technologies were selected for further consideration:

- Hybrid (electric-gas) automobiles
- Advanced logistics technologies (RFID, GPS/GIS, etc.)
- Advanced digital manufacturing
- New process technologies
- Alternative energy technologies (gas, solar, wind, etc.)
- New environmental protection/remediation technologies
- Sleep inducement technologies (polysomnography)
- New cardiology-related technologies
- Deepwater drilling technologies
- New hospital equipment technologies (e-Health, etc.)
- Computer forensics
- Micro-electromechanical systems
- Bioinformatics
- Gerontology technologies

From this group, representatives of TSTC and TFI selected four technologies for more detailed analyses. This selection was based on a formal rating process supplemented by discussions with subject matter experts. A detailed discussion of this selection process is presented in Appendix F.

Emerging Technologies Selected

For each of the technologies selected, a listing of related vendors, manufacturers, and associations is presented in Appendix G, and a description of programs currently being conducted is presented in Appendix H.

Advanced Digital Manufacturing

Born of the rapid prototyping (RPT) industry, advanced digital manufacturing is the process of manufacturing a product using a layered manufacturing methodology. RPT programs commonly exist around the country for non-destructive testing and prototype construction, but now actual finished products can be made with similar additive and subtractive processes. Hearing aids, car parts, and a tremendous variety of customized end products are becoming more affordable to produce on an "as needed" basis.

This process is also called three-dimensional printing (3DP), layered manufacturing, or solid freeform manufacturing. These are additive processes where parts are built from the bottom up using a variety of powdered materials (various metals and plastic resins), solid materials (plastics and metals), and liquids (primarily plastics). According to Wohlers Associates, Inc., the worldwide market for prototyping devices is over $500 million (Wohlers, 2003). Dr. Stokes of TSTC Marshall has indicated that there will be a demand for about 300 to 500 highly-paid technicians ($40,000 to $50,000 per year) in this field by 2008. These technicians will load materials into the machine, program designs (CAD instructions), and perform centering and infiltrating. The TSTC Marshall campus has a $480,000 digital manufacturing device onsite (Stokes, 2004) and two additional plastic-based systems. According to Dr. Stokes, Texas employers who have expressed an interest in hiring these graduates include General Motors, Toyota, Nokia, and Goodrich.

Hybrid Automobiles

The Department of Energy defines hybrid electric vehicles as "vehicles that combine the internal combustion engine of a conventional vehicle with the battery and electric motor of an electric vehicle, resulting in twice the fuel economy of conventional vehicles" (Department of Energy, 2004). The demand for hybrid vehicles has risen dramatically with recent increases in the cost of gasoline because they offer "the extended range and rapid refueling that consumers expect from a conventional vehicle, with a significant portion of the energy and environmental benefits of an electric vehicle." In fact, in a June 10, 2004 *Wall Street Journal* article entitled "Forget Rebates: The Hybrid-Car Markup," Sholnn Freeman points out that there is a nationwide backlog of 22,000 orders for Toyota's Prius hybrids. Likewise, an Austin dealership has indicated that it has to turn away three potential customers for every Prius it sells. New hybrid models that will soon be released include several sports utility vehicles (SUVs), such as the Toyota Highlander, Ford Escape, and Lexus RXV. Thus, the demand for technicians capable of servicing both internal combustion engine and battery/electric motor packages will, undoubtedly, increase in the future. However, it appears that, for the near future, most hybrid automobile mechanics will be trained by the manufacturers.

Micro-Electromechanical Devices (MEMS)

MEMS is a product design and manufacturing technology that enables the development of electromechanical systems using batch fabrication techniques similar to those used in integrated circuit design.

MEMS integrate mechanical elements, sensors, actuators, and electronics on a silicon substrate using a process technology called microfabrication. This combination of silicon-based microelectronics and micromachining technology allows the system to gather and process information, decide on a course of action, and control the surrounding environment. This, in turn, increases the affordability, functionality, and performance of products using the system. Due to this increase in value, MEMS are expected to drive the development of "smart products" within the automobile, scientific, consumer goods, defense, and medical industries (Wave Report, 2001).

In-Stat/MDR forecasts that the MEMS industry will grow to about $7 billion by 2005 (In-Stat/MDR, 2004). According to John Simcik, Texas employers that have expressed an interest in employing MEMS technicians include Texas Instruments, Lockheed, Hughes Aerospace, and Raytheon (Simcik, 2004).

Computer Forensics

Computer forensics is the scientific examination and analysis of data held on, or retrieved from, computer storage media in such a way that the information can be used as evidence in a court of law. The subject matter includes the secure collection of computer data, the examination of suspect data to determine details such as origin and content, the presentation of computer-based information to courts of law, and the application of a country's laws to computer practice (DIBS USA, 2004).

Market research firm International Data Corporation (IDC) predicted the market for incident response services, which include computer forensics, will jump from $133 million in 2001 to $284 million by 2004 (LeClaire, 2003). Additionally, Mel Mireles, Director of Enterprise Operations at the Texas Department of Information Resources, indicated that there is a current and growing need for entry-level employees trained in computer forensics in both the public and private sectors (Mireles, 2004). Although network security programs and courses are quite common throughout the State and nation, these tend to focus on more preventative and edge technologies.

Future Activities

Given the success of the PET process to date, TSTC, in coordination with the CCD and THECB, will continue these research activities in the 2004-2005 fiscal year. TSTC will utilize direct feedback from report recipients and survey evaluation data to continually refine and improve the structure and timing of analysis reports in order to make them more useful for College deans and other education decision makers.

Overview of ADM

Advanced Digital Manufacturing (ADM), a service mark of 3D Systems, also called rapid manufacturing, encompasses a number of manufacturing technologies that have been developed to reduce the design and production cycle of manufactured goods. In contrast to traditional machining processes that cut, bend, and machine a part from stock material, ADM utilizes layered manufacturing technologies that build parts from the addition of successive layers of material. Although layered techniques typically do not produce parts as rapidly as traditional mass manufacturing processes, they eliminate the need for expensive machine tooling and setup procedures. As a result, complex, custom parts with arbitrary dimensions and features can be produced for prototyping and small production runs very quickly and at a much lower cost.

Although the first of the layered systems was introduced in 1987, a number of technical breakthroughs have increased both the machines' production rate and the functionality of manufactured parts. Technicians who design and build parts with ADM systems must have an up-to-date understanding of the nature of these breakthroughs and their effects on industrial prototyping and manufacturing capabilities. In particular, ADM technicians must be familiar with developments that have (1) increased the utility of three dimensional computer aided drafting and simulation software and (2) increased the diversity of fabrication materials available to designers with the latest generation systems.

Employment opportunities for College graduates in the field of ADM with knowledge and training in these advances will become significant as the industry continues to change and grow. Colleges that want to capitalize on these opportunities must work closely with manufacturers in the state that use ADM to assess workforce demand and training requirements. These assessments will allow Colleges to make informed decisions regarding the future impact of ADM and the resulting technical training needs their programs must address.

ADM Technology Review

ADM involves the use of layered manufacturing techniques to produce parts in a single process by the addition of successive layers of material. Using ADM, parts of an arbitrary shape can be created without the use of traditional machining procedures, which are often labor intensive and involve a number of different steps and cutting tools. Since ADM designers are not constrained by the limitations of traditional machining and forming techniques (milling, drilling, lathe work, etc.), a much more varied range of shapes, including intricate geometries and cavities, can be created quickly and efficiently. ADM techniques, used by a number of companies in a wide range of industries, have reduced the amount of time and money it takes to introduce products to the market. As a result, they have become increasingly important in product development and manufacturing environments (Krar & Gill, 2002).

Figure 1 Rapid Manufacturing Machine

Source: 3D Systems

Advanced Digital Manufacturing Principles

Essentially, every ADM system consists of two parts: (1) a computer-aided design (CAD) system and (2) a layered manufacturing machine that is capable of producing a part in successive layers according to instructions from the CAD system. The ADM process works in the following way:

First, a designer (draftsman) creates a three dimensional representation of a part using CAD software such as AutoCad, ProEngineer, Inventor, or SolidWorks. The 3D CAD representation of the part is then divided into 2D layers of some thickness, usually .1 to .25 mm (Yang, 2002). These 2D profiles are saved in a triangulated (tessellated) format, or .STL file. The ADM software converts the .STL files into machine files (.CL) that the operation machine can use to fabricate each layer of the part until it is complete. The final step of the process involves post-fabrication finishing and cleaning. This includes the removal of fabrication support materials and polishing and painting to improve the final appearance of the part.

Over the years, a number of ADM techniques that are capable of using an increasing variety of materials have been developed. As these material advances increased the size and durability of produced parts, ADM vendors increased the quality and repeatability of their machines. As a result, ADM is frequently used not only to fabricate functional prototypes but for small production runs of custom designed parts (Yang, 2002).

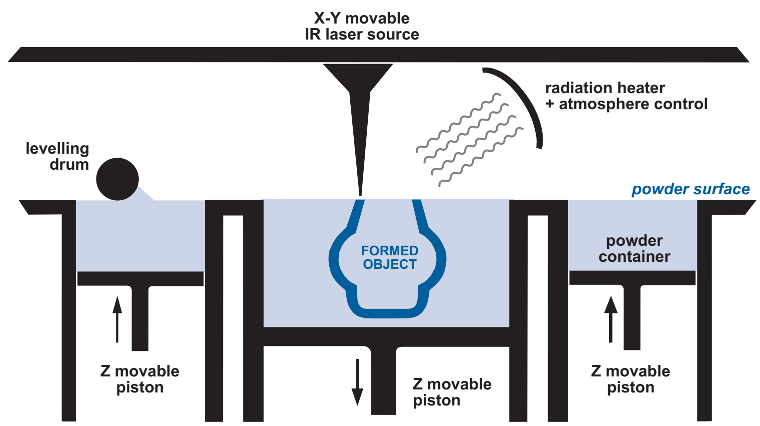
ADM Fabrication Techniques

There are a number of ADM fabrication techniques. Each uses some form of layered manufacturing methodology:

- ***Stereolithography.*** The first commercial layer manufacturing system was a stereolithography (SL) machine introduced by 3D Systems in 1987 for rapid prototyping applications (Yang, 2002). These systems create parts using ultraviolet (UV) lasers and a photo-sensitive, UV curable polymer resin. The UV lasers traverse the bath in the pattern dictated by the computer-generated files, causing the polymer resin to cure in the shape of a layer of the part. The bottom most layer is situated on a platform that is lowered by the slice thickness after each new layer is formed on the preceding surface. The successive addition of the layers results in the 3D representation of the part. SL can be used to generate polymer prototypes, plastic molds for injection molding, and blocks for metal sheet forming (Yang, 2002).

- ***Laser sintering.*** Laser sintering (LS) enables the use of a broader range of materials than SL. SLS can be used to fabricate parts from metal, metal oxide, ceramic, plastic, and sand powders. These powders are deposited on a platform and a carbon dioxide (CO_2) laser is used to selectively sinter (melt) the powder into the CAD generated shape for each layer. After each layer is complete, it is lowered onto a platform. Unconstrained powders around the developing 3D structure act as support for the top layer of powder. The yield strength and packing density of the final sintered part can be controlled by adjusting the scanning speed and power of the CO_2 laser (Materialise, 2004). A schematic representation is shown in Figure 2.

Figure 2 Laser Sintering

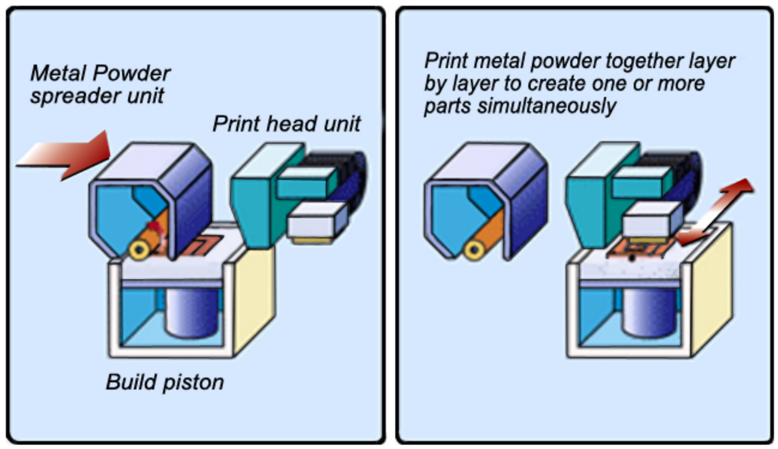


Source: Materialise

- ***Shape deposition manufacturing.*** SDM combines layered manufacturing and traditional computer numerically controlled (CNC) machining. In SDM processes, each layer is machined (milled) after it is created, and support material is added and machined to support subsequent layers. The use of the machining steps creates smoother surfaces in the final part and allows for layers with overhanging, undercut, and separated features to be supported during the layered fabrication process. SDM is typically used for custom tooling and precision assemblies and allows a high quality surface finish, complex undercut features, and multi-material parts with inserts (Wang, 2002).
- ***3D printing.*** 3D printing uses inkjet printing technology to build 3D models in successive layers using ceramic, metal, and thermoplastic powders. In this process, powder is distributed on a build platform. An inkjet print head moves across the powder selectively depositing liquid binder in the pattern dictated by the CAD files. The liquid binder creates a layer of bound powders in the shape of the desired layer. The unbound powder functions as a support for overhangs and undercuts. After the print heads have followed their dictated pattern for a particular layer, the part is lowered, more powder is added, and the process is repeated. When the part is complete, it can be fully sintered ("fired") to reduce its porosity. Alternatively, the

part can be “seeded” with a lower melting point metal powder such as bronze, and then sintered to improve its mechanical strength (ExtrudeHone, 2004). TSTC Marshall uses a 3D machine, the R2 manufactured by ExtrudeHone, in its ADM program (Liles, 2004). According to ExtrudeHone, the machine is capable of producing metal parts with dimensions on the order of 8 × 8 × 6 inches.

Figure 3   3-D Printing Process



Source: ExtrudeHone

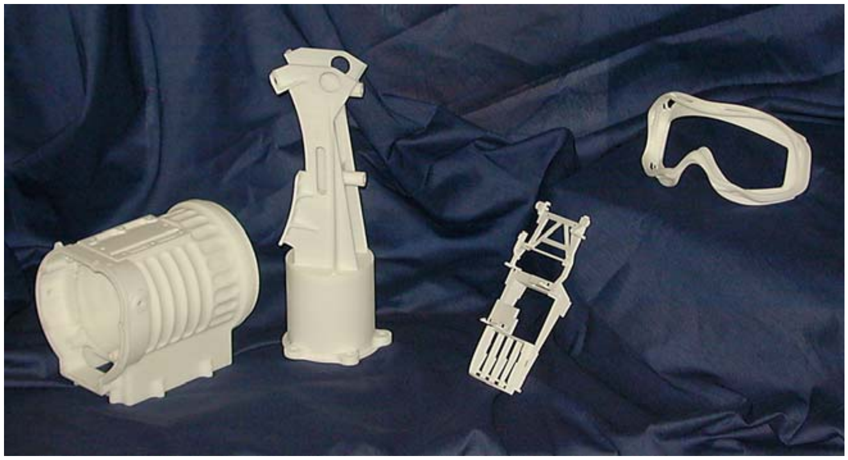
- ***Bioplotting.*** Bioplotting is very similar to 3D printing except that it uses biomaterials for applications related to tissue engineering and drug delivery systems. 3D dispensers, controlled by CAD software, deposit layers of biochemicals and even living cells to create structures of interest. The bioplotter technology, invented at the Freiberg Materials Research Center in 1999, is being commercialized by Envisiontech GmbH, a German company (Envisiontec, 2004).
- ***Layer object modeling.*** Layered object modeling (LOM), developed by Helisys (Torrance, California), bonds sheet material together in layers to form a laminated structure. Materials available to designers using this process include paper, plastic, water-repellent paper, ceramic, and metal powder tapes. Casting dies for automotive parts have been produced using LOM (Yang, 2002).

ADM Applications

A wide range of industries use ADM equipment:

- ***Automotive.*** All of the major automakers use ADM to generate functional and non-functional (ornamental) prototypes in their research and development departments. Additionally, NASCAR and Formula One teams use ADM to quickly build prototypes for aerodynamic performance testing and in some cases, custom made parts for the actual competition cars (Hargreaves, 2002).

Figure 4 Variety of Parts Producible by Advanced Digital Manufacturing



Source: Phoenix Analysis and Design Technologies

- ***Aerospace.*** Major aerospace manufacturers such as Boeing and NASA use ADM to manufacture low-volume, flight ready components. The use of ADM avoids the cost and delay of developing expensive custom tooling for small production runs.
- ***Military.*** The Army is utilizing ADM to expedite the replacement of parts in battlefield operations (tank parts, etc). Additionally, the Navy is using ADM in fleet service.
- ***Consumer goods.*** The R&D departments of consumer goods manufacturers often use ADM to produce relatively small production runs of new products. These produced goods can be used to conduct market surveys that allow manufacturers to assess the "marketability" of a product before committing to a full-blown production and marketing campaign.
- ***Biomedical.*** This is a rapidly growing area of ADM application. Using ADM, labs are able to convert MRI and CT images into models of a patient's joints and bones. Surgeons can use these models to test surgical procedures before an actual operation. Additionally, hearing aid manufacturers, such as Siemens, use SLS and SL to produce custom-fitted, in-the-ear devices (Krar & Gill, 2002).

According to Wohlers Associates, Inc., the leading analyst of the ADM industry, the worldwide market for these machines is over $500 million (Wohlers, 2003). There were almost 9,500 ADM units in operation worldwide at the end of 2002.

ADM Industry Trends

A variety of breakthroughs, events, or decisions could materially change the nature, rate, and implications of technical advances and market developments. The discussion below explores some of the factors that might accelerate or constrain the growth of the ADM market.

Drivers

- ***Legal issues in the ADM industry.*** In the recent past, a series of eight patent infringement lawsuits between two major ADM manufacturers, 3D Systems (Valencia, California) and EOS (Germany), slowed industry growth. Major corporations were unwilling to purchase these companies' products until the lawsuits were resolved, and any possible legal culpability on their part was eliminated. The two companies recently settled the lawsuit, which should spur pent-up demand (Wohlers Associates, 2004; Liles, 2004).
- ***ADM for low volume production.*** Improvements in the yield rates of ADM machines have allowed manufacturers to fabricate series production parts in quantities of one to several thousand. This has expanded the market for ADM machines among custom manufacturers (Wohlers Associates, 2003).
- ***Time-to-market considerations.*** Product manufacturers are always under pressure to reduce product design and manufacturing cycles (time to market). ADM tools reduce the number of steps in the engineering and manufacturing process, enabling users to improve their performance in this area.
- ***Advances in 3D CAD modeling and simulation software.*** Solid design and simulation software packages such as ProEngineer Wildfire that allow engineers to design and test the performance of parts before a prototype is built are becoming more powerful and less expensive. The designs generated by these packages can be easily converted into formats usable by ADM machines. As more manufacturers adopt these packages and learn about the capabilities of ADM, the demand for ADM machines will rise.
- ***Increasing variety of materials.*** Technical advances have allowed for the use of a wider range of materials in ADM machines. This variety, which includes more durable materials, allows users to create an increasing number of parts that are actually functional and not just concept models. This expanded ability to create functional parts will allow manufacturers to test designs more quickly and less expensively, which is a major driver for their ADM purchases. ExtrudeHone projects that, by the end of 2004, they will introduce a 3D printing machine capable of producing parts composed completely of titanium (Liles, 2004).

Constraints

Despite the capabilities of layered manufacturing methodologies, ADM manufacturers have had sluggish, even declining, sales in the last couple of years (Wohlers, 2003). Some factors that have constrained the development of the ADM industry are described below:

- ***Cost of entry.*** A $300,000 ADM machine can require up to $30,000 of annual maintenance. Mid-sized manufacturers, which represent a major untapped customer source for ADM tools, are unwilling to invest in ADM without a favorable return on investment (ROI) (Wohlers, 2004).
- ***Unfulfilled expectations/bad publicity.*** In the past, many ADM vendors have exaggerated the capabilities of their products. Convincing dissatisfied customers to return to the market and explore the capabilities of new machines has been a challenge.
- ***Investment in R&D.*** Stagnant sales reduced ADM vendors' willingness to invest substantial amounts of resources in research and development that would improve the reliability and performance of their products. This reluctance inhibited industry growth because these vendors' customers were demanding such improvements before they purchased additional new machines (Liles, 2004).

ADM and the Role of Colleges

Program Compatibility

Computer-aided drafting and modeling and layered manufacturing methodologies are the foundation of ADM fabrication techniques. Therefore, Colleges with existing manufacturing technology and/or mechanical engineering technology programs are the most likely to initiate ADM curriculum or introductory training modules. TSTC Marshall has instituted such a program. Their curriculum includes several courses in digital manufacturing, as well as courses in computer-aided drafting and computer numerically controlled machining. Because of the breadth of subjects covered in the curriculum, graduates are well qualified for employment as ADM and non-ADM technicians in manufacturing and machining environments.

Equipment

ADM equipment with a light production volume capability can be quite expensive. Typical purchase costs are in the low-to-mid six-figure range, with maintenance costs running about $30,000 per year. However, a number of 3D printing machines are available anywhere from $40,000 to $70,000 (Wohlers, 2004). Therefore, equipment costs should not discourage Colleges from exploring ADM training modules.

Technician Profiles

ADM technicians fall into two broad categories: designers and machine operators. The two will work together closely to ensure that the final products of the ADM process are produced as accurately and cheaply as possible.

Design Technicians

Design technicians must possess a thorough understanding of advanced 3D modeling and simulation software including AutoCad, Inventor, ProEngineer Wildfire, and SolidWorks. They must also understand the conversion of design files from these programs into triangulated (tessellated) format as .STL files and then into the machine format of .CL. They must also be able to troubleshoot these converted .STL and .CL files and remove excess clutter (dense point clouds) that result in unnecessary machine steps (Liles, 2004). Design technicians must also have an understanding of the materials used in ADM processes and their suitability for different applications.

Combining these two skill sets and knowledge of the capabilities of ADM processes, design technicians will compare and evaluate all the data before them concerning tolerances, function, manufacturability, cost, and expected quality to make appropriate decisions about the creation of a 3D model for ADM fabrication.

ADM Operators

ADM operators will be familiar with the maintenance and management of ADM equipment. They must also have a basic familiarity with common shop equipment and machinery. In addition, model-making (finishing) skills such as polishing and sanding are a requisite. Furthermore, operators will be responsible for orienting (centering) parts on ADM build platforms. They will be responsible for supplying appropriate build materials (base and infiltrating materials) to the ADM machine and monitoring the process for irregularities during the build process.

Existing ADM College Programs

TSTC Marshall

Texas State Technical College Marshall offers an Associate of Applied Science in Advanced Digital Manufacturing. Students who graduate from the program are competent in ADM technologies such as 3D printing, selective laser sintering, and stereolithography. Students in this program also complete coursework in solid modeling, computer-aided drafting, engineering materials, CNC programming, and troubleshooting conversion programs into .STL and .CL files. Students in the program have access to a 3D printing machine, the R2, manufactured by ExtrudeHone. The machine is capable of producing metal parts with dimensions on the order of 8 × 8 × 6 inches.

Danville Community College

Danville Community College's Regional Center for Applied Technology & Training (RCATT) owns and operates an Advanced Digital Manufacturing Laboratory, that is widely recognized "among the finest and most state-of-the-art in the nation" (Danville Community College, 2004). The goal of the lab is to give students hands-on experience in the use of ADM equipment. Currently, the lab features a Vanguard Selective Laser Sintering machine built by 3D Systems. One of RCATT's goals, under its charter, is to help existing businesses improve and expand their product lines which will result in more employment opportunities for citizens in the Danville region. ADM Lab Manager Jerry Franklin can be reached at (434) 822-6805 or franklinj1@adelphia.net.

Pueblo Community College

Pueblo Community College (Pueblo, Colorado) offers a Rapid Production Development Option within its Engineering Technology AAS degree program. The option provides students with courses and labs that utilize 3D solid modeling software, such as Pro Engineer, and state-of-the-art rapid prototyping machines. The option prepares students to work as mechanical design and prototyping technicians at service bureaus and manufacturing facilities.

ADM Employment Opportunities

Number of Technicians and Salaries

Dr. Timothy Stokes, Vice President and Dean of Student Learning, TSTC Marshall projects that there will be a demand for 300 to 500 highly-paid technicians ($40,000 to $50,000 per year) in the ADM field in Texas by 2008. According to Dr. Stokes, Texas employers that have expressed an interest in hiring these graduates include General Motors, Toyota, Nokia, and Goodrich.

Special Texas Factors

A number of Texas-based companies use ADM equipment including General Motors, Toyota, Nokia, Goodrich, NASA, Bell Helicopter, Siemens (LasR hearing aid), and Allegiance Healthcare (Stokes, 2004).

Conclusions and Recommendations to Colleges

Colleges that want to initiate ADM training modules have a couple of options. Those with existing machining, manufacturing technology, or mechanical engineering technology programs could initiate a survey course or courses in ADM technologies and processes. These courses would cover the various digital manufacturing methods including 3D printing, stereolithography, and selective laser sintering. (These colleges could purchase or obtain through donations relatively inexpensive ADM equipment that students could use to obtain foundation level experience in the production of parts.) Students would continue to obtain an AAS degree in their chosen discipline but would have experience in ADM that would make them more attractive to potential employers.

On the other hand, colleges with existing programs and more ambitious curriculum goals dictated by the needs of manufacturers in their regions could choose to develop full-blown, autonomous ADM programs. These programs would instruct students on ADM equipment very similar to that used by employers with strong workforce needs in their regions. In addition to several courses in ADM technologies, other portions of the curriculum would include standard courses in CAD design, CNC machining, and engineering materials. Students in these programs would earn an AAS or Advanced Certificate of Completion in advanced digital manufacturing. However, because of their training in traditional manufacturing disciplines, they would also be very well qualified for non-ADM manufacturing employment. Colleges that choose this option should use TSTC Marshall's Advanced Digital Manufacturing Curriculum as a guide.

In either case, because of the emerging nature of the ADM industry, College deans and other instructional officers should work closely with Texas ADM manufacturers and trade groups in order to make informed decisions about the design, initiation, and conduct of ADM programs. Such interaction should mitigate the risk of initiating programs inappropriately at their institutions.

An index of related ADM manufactures and industry groups is presented in Appendix G.

Overview of Hybrid Vehicles

Hybrid vehicles are vehicles that are powered by both an internal combustion engine and an electric motor. By optimizing how power is drawn from each of these sources under various operating conditions, automotive engineers have been able to achieve fuel economy and emission results superior to those produced by traditional gas powered automobiles. Just as important, these results have been achieved without degrading vehicle performance, a key factor in customer acceptance. Toyota and Honda are already selling hybrid production models. In addition, a number of automakers, including Ford and General Motors, have announced their intention to release hybrid versions of popular models in the near future.

As the cost of these vehicles continues to decline and approach that of already available models with similar performance characteristics, the number of hybrids on the road will increase. This growth will present a challenge to the State's automotive technician/mechanic workforce because these vehicles use a number of new systems that require unique service and repair procedures. However, hybrid manufacturers have chosen to restrict most of this proprietary information to their dealer technician networks. The fact that there are still relatively few hybrids on the road dictates that the role of non-manufacturer (dealer) affiliated technicians in servicing the vehicles will be minimal for the near future. On the other hand, Colleges with existing training programs sponsored by hybrid carmakers will probably see the introduction of some hybrid training into them.

Hybrid Vehicles Technology Review

Hybrid vehicles use both an internal combustion engine (ICE) and an electric motor. The vehicles are designed to combine the best features of a traditional gasoline powered vehicle, including acceleration capability and range between refueling, with the fuel economy and emission characteristics of electric vehicles (Department of Energy, 2004). Additionally, in contrast to pure electric vehicles, hybrids do not need to "plug in" for recharging because their batteries are recharged as the car is driven. They can be used in a wide variety of vehicles, including personal automobiles, commercial trucks, and buses. In general, hybrid vehicles contain these basic systems:

- ***Internal combustion engine.*** Hybrid cars utilize gasoline powered ICEs very similar to ones found in traditional vehicles. However, the ICEs in hybrids are designed to be much smaller and efficient (three or four cylinders), which results in increased fuel economy and decreased emissions. Gasoline for the ICE is stored in a traditional fuel tank.
- ***Electric motor.*** The electric motors in hybrid cars perform two functions. One, they can draw power from the car's batteries and drive the car's transmission in the same manner an ICE does. Alternatively, the motor can act as a generator and recapture energy from the deceleration of the car during braking. This process is known as *regenerative braking*. The electric motors in hybrid vehicles employ very sophisticated feedback and control systems.
- ***Generator.*** Generators are very similar to motors in design, except they do not actually drive the car's power train. Instead, they supply energy to the batteries, or in the case of series hybrid cars (see below), to the electric motor. The generator is driven by the ICE.

- ***Batteries.*** The high energy density nickel-metal hydride (NiMH) batteries in a hybrid vehicle supply power to the electric motor, or in the case of regenerative braking, capture power delivered from the motor. The batteries are recharged primarily by the ICE.
- ***High voltage circuitry.*** Typically, a hybrid contains a number of circuits that are capable of producing voltages in excess of 300 volts. These voltages are well above what are required to electrocute a person, which has generated concern in the accident response (first responder) and service repair communities (Larson, 2002).
- ***Energy management systems.*** Energy management systems (EMS), run by various feedback and control elements, function to efficiently distribute power from the power producing devices to the energy storage devices. For example, the EMS ensures that adequate power reserve levels in the batteries are available for difficult driving conditions. Additionally, the EMS works to distribute power in such a way that the ICE works at optimal conditions (e.g., constant speed above 15 mph, no hard acceleration) and that the motor acts as a generator during regenerative braking. This complex system, which does not exist in a traditional vehicle, allows hybrids to achieve design objectives, such as high fuel economy and low emissions.
- ***Transmission.*** Just as in a traditional vehicle, the transmission in a hybrid transmits power to the drive train. This power can be produced by the ICE, electric motor, or some combination of both. Some hybrids have traditional manual transmissions; others employ a variation of the automatic transmission called the continuously variable transmission (CVT). To the driver, the CVT, although a unique mechanical design, functions just as a traditional automatic transmission does.

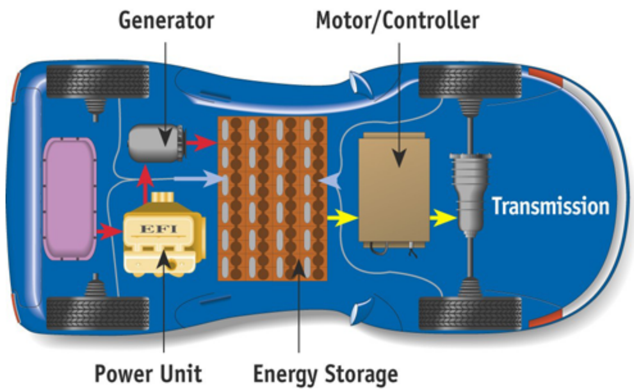
Hybrid Vehicle Configurations

The fuel economy and emissions performance of hybrid vehicles is a function of how the subsystems described above are configured and integrated. Three different configurations–parallel, series, and series/parallel hybrid–are discussed below:

Parallel Hybrid

In a parallel hybrid, the ICE and electric motor are connected to the transmission independently, although they can both drive the transmission simultaneously. Since the ICE and electric motor operate together, they are smaller than their corollaries in traditional ICE, electric, or other hybrid configurations. The use of a smaller ICE results in reduced emissions and better fuel economy. For the parallel hybrid configuration shown in Figure 5, the energy storage device is the battery pack that drives the electric motor and the power unit is the ICE. The Honda Insight, which starts at $21,280, is a parallel hybrid (Nice, 2004).

Figure 5 Parallel Hybrid Configuration

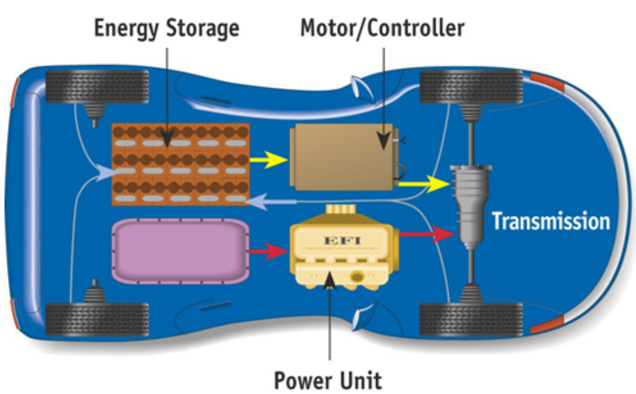


Source: Department of Energy

Series Hybrid

In a series hybrid, the ICE does not directly transfer power to the transmission. Instead, the ICE drives a generator that charges the batteries or, if needed, supplies power to the electric motor. Since the electric motor is the only device that drives the transmission, it is usually as large as an electric motor in a purely electric vehicle. A series hybrid configuration is shown in Figure 6. Once again, the energy storage device is the battery pack that drives the electric motor, and the power unit is the ICE.

Figure 6 Series Hybrid Configuration



Source: Department of Energy

One advantage of a series hybrid is reduced emissions. For example, the incomplete combustion of gasoline generates emissions that increase air pollution. Incomplete combustion is at its most severe when an ICE is run at a low power setting (e.g., idling). Since the ICE in a series hybrid does not directly power the car and is set to supply power to the generator at above-idle speeds, the problem of incomplete combustion is severely reduced. A disadvantage of series hybrids is that, since only the battery powered electric motor propels the vehicle, the battery pack is much larger than one in a hybrid. This can generate serious space constraints for smaller vehicles.

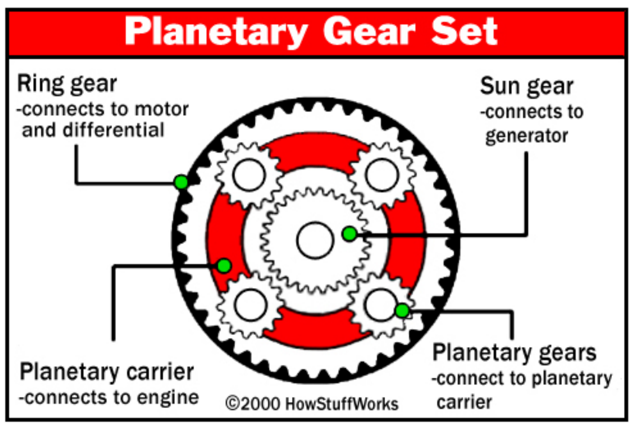
Series/Parallel Hybrid

The series/parallel hybrid design combines the best features of series and parallel hybrids. These vehicles, the most prominent of which is the Toyota Prius, employ ingenious mechanical devices (gearboxes) that connect the ICE, electric motor, and generator together. These vehicles can operate as a series design where the ICE supplies power to the generator, as a parallel where the ICE and motor operate together to propel the vehicle, or as a combination of both where the ICE drives the vehicle and supplies power to the generator at the same time.

Toyota Prius Operation

In the Toyota Prius, the gearbox, also called power split device, is a planetary gear set. The mechanism, shown in Figure 7, consists of a set of meshed gears: the sun gear, the planetary gears, and the ring gear.

Figure 7 Toyota Prius Planetary Gear Set



Source: HowStuffWorks

The Toyota Prius uses the planetary gear set to transmit power from the ICE and electric motor to the generator and differential at various controllable speeds and torques. The planetary gear set also functions as a continuously variable transmission (CVT), which eliminates the need for a manual or automatic transmission (Nice, 2004).

The ICE in the Toyota Prius does not start until the driver accelerates the car above 15 miles per hour. Up to this speed, the car runs on the battery powered electric motor, which is optimal because electric motors are better than ICEs at accelerating at low speeds (Valdes-Dalpena, 2004). This allows the ICE to run in a narrow speed band where its fuel economy and emission performance is optimized. Like most hybrids, the Prius has a small ICE (1.5 liters, max rpm = 4500) that burns less fuels and produces reduced emissions than average ICEs. A 2004 Toyota Prius, which has a sticker price of $20,295, is shown in Figure 8.

Figure 8 2004 Toyota Prius

Source: IGN.com

Hybrid Vehicle Production

Because of demand, hybrid production and sales have increased. To a large degree, this demand has been generated by the recent surge in gas prices.

- ***Toyota.*** According to Cindy Knight, spokesperson for Toyota Motor Sales USA, Toyota has raised its 2004 Prius allocation for the U.S. market from 36,000 to 47,000 vehicles (AIADA, 2004). An Austin Toyota dealership reports that hybrid cars have become so popular that they have three interested customers for every Prius that is available (KXAN, 2004).
- ***Honda.*** Honda sold over 20,000 hybrid vehicles in 2003. Honda's hybrid models are the Civic and Insight.
- ***Ford.*** Ford expects to sell 20,000 of its new Escape hybrid SUVs in the next year. The vehicle will be available for sale in late summer 2004 (O'Dell, 2004).

A number of automakers have announced plans to release hybrid models in the next few years. What is telling about these announcements is that they include not only small, compact cars such as the Prius, Civic, and Insight, but also full-sized models such as the Ford Escape SUV. The decision by automakers to include full-sized vehicles in their hybrid offerings could result in a surge of demand. A listing of pending hybrid releases is provided in Table 1.

Table 1 Future Hybrid Releases in North America

Make and Model	Release Date
Ford Escape SUV	August 2004
Chevy Silverado Pickup	August 2004
Lexus RX400 SUV	Winter 2004
Toyota Highlander SUV	August 2005
Nissan Altima Sedan	Late Summer 2005
Saturn VUE SUV	Late Summer 2005
Chevy Malibu	Late Summer 2006

Source: Department of Energy

Figure 9 Ford Escape Hybrid Vehicle

Source: Ford Motor Company

Hybrid Vehicle Industry Trends

The discussion below explores some of the factors that might accelerate or constrain the growth of the hybrid vehicle market.

Cost

The demand for hybrid vehicles increased dramatically as gasoline prices surged in spring 2004. Hybrid vehicles, whose fuel economy performance is typically 30% to 50% higher than their twin conventional models, appealed to many consumers trying to lower their increasing gasoline bills. However, despite their excellent fuel economy, it should be noted that hybrid vehicles typically cost $1,500 to $4,000 more than equivalent gasoline-only vehicles (Lazarony, 2003). For example, a conventional Honda Civic LX costs about $3,200 less than a hybrid Civic (Valdes-Dapena, 2004). The following example considers the cost tradeoff:

A Civic hybrid equipped with a manual transmission gets an EPA calculated 46 miles per gallon (mpg) in the city and 51 mpg on the highway. A conventional Civic, using the same EPA-generated figures, achieves 33 mpg in the city and 39 mpg on the highway (Lazarony, 2003). Table 2 considers the savings for a typical year of driving approximately 18,000 miles.

Table 2 Fuel Cost Comparison: Honda Civic

Model Gallons	Consumed to Travel 18,000 Miles	Cost of Gas ($2.15/gallon)
Honda Civic LX (city)	545 gallons	$1172
Honda Civic Hybrid (city)	391 gallons	$841
Savings (city)	**154 gallons**	**$331.00**
Honda Civic Hybrid (hwy)	391 gallons	$841
Honda Civic Hybrid (hwy)	353 gallons	$759
Savings (hwy)	**38 gallons**	**$82.00**

Even using the city mpg figures, which generate the largest gasoline savings, it would take 180,000 miles, or approximately 10 years, to generate the savings needed to justify the extra expense of the hybrid. Furthermore, even if the price of gasoline increased to $3 per gallon, the annual savings for a buyer would only equal $462 per year. Manufacturers respond to these figures by stating that they expect the price of the vehicles to decline as the demand increases. However, this presents a classic chicken/egg quandary because the demand for the vehicles will probably not increase dramatically until the cost comes down. Government incentives, which are discussed next, could be the solution to this problem.

Government Incentives/Regulation

There a number of ways that the government could increase the demand for hybrid vehicles through the use of incentives. For example, the Internal Revenue Service allows purchasers of hybrid vehicles to claim a one-time $1,500 deduction against their adjusted gross income in the year of purchase (Department of Energy, 2004). Unlike those who purchase an electric vehicle, the hybrid deduction is not a tax credit and varies with a taxpayer's tax income. For those in the lowest bracket (10%), the cash savings is $150 dollars. For those in the highest bracket (35%), the savings total about $525. Obviously, this deduction does not significantly reduce the cost differential discussed in the preceding section, but it is a start. Furthermore, to address concerns about air quality and pollution, Congress could decide to increase the amount of the deduction or convert it into a credit. They could also vote to provide a credit to manufacturers who manufacture and sell a certain number of hybrid vehicles per year.

Additionally, increased government regulation concerning emissions and fuel economy standards could increase hybrid sales. For example, the government's Corporate Average Fuel Economy (CAFE) standards require automakers to achieve an average fuel economy of 27.5 mpg on their production models. Thus, if an automaker manufactures three conventional models with a fuel economy of 20 mpg and one hybrid with a fuel economy of 50 mpg, they are in compliance. A strengthening of CAFE standards and penalties could provide an incentive to automakers to produce and sell more of the vehicles. Those who were at a risk of violating CAFE and suffering a significant fine would have a motive to introduce additional hybrid models. Automakers could increase the sale of the new models through the use of incentives such as low interest financing and rebates. These incentives would increase the number of hybrids sold.

Poor Publicity (Misinformation)

First responders and automotive technicians have raised concerns about working around the cars' high-voltage circuitry. To some degree, their concerns are unwarranted. The cars are designed to discharge their voltage in the event of an air-bag deployed accident, and there are manufacturer-published "best services" practices that should protect technicians during service and repair work. Despite these measures, overcoming these fears will be a challenge, especially if there are a series of unfortunate mishaps.

Additionally, the general public is not familiar with the operation and performance of hybrid cars. For example, many consumers are unaware of the ICE's role in charging the battery pack and believe that hybrids require drivers to periodically "plug in" for a recharge. Additionally, until recently, most production model hybrids have been marketed to consumers in the economy market, where vehicle performance (power and acceleration capability) were not as important as fuel economy. In order for the sale of hybrids to continue to increase dramatically, automakers must produce SUV and sedan hybrids that can provide a level of performance acceptable to consumers in these segments of the market.

Resale Value

To overcome consumer fear about the reliability of hybrid technology, manufacturers offer warranties on unique hybrid components that last much longer than the warranty on other parts of the car. For example, the Prius has an eight-year/100,000 mile warranty on the battery and power train and a three-year/36,000 mile warranty on the rest of the car, which is composed of parts that are found on other Toyota vehicles (Nice, 2004). These extended warranties prop up the resale value of the cars. On the other hand, however, Toyota estimates that a replacement battery pack for the Prius costs about $3,000 to $3,500 (Consumer Reports, 2004). The long-term performance of the batteries and other unique hybrid components is still undetermined because most of the vehicles have been placed in service only within the last one to three years. Obviously, if the cost of these batteries and other unique hybrid components does not decrease and they begin to need replacement soon after the manufacturer's warranty expires, the resale value of the cars will drop dramatically. As more of this kind of service information becomes available, consumers will have a better sense of the resale value of the cars which will have a huge effect on demand.

Hybrid Vehicles and the Role of Colleges

Automaker Partnerships with Colleges

A number of Colleges in the State have specializations within their automotive technology programs that are sponsored by specific carmakers, including Toyota. Students enrolled in these programs are trained using standardized curricula that covers vehicle systems specific to the sponsoring manufacturer. The goal of these programs is to supply technically proficient apprentice technicians to specific manufacturer dealerships. Member institutions of the Toyota Technical Education program, called T-TEN, include Texas State Technical College Waco, Dallas Community College, and San Jacinto College (Gustavus, 2004).

Program Compatibility

Hybrid manufacturers have been very reluctant to share vehicle service and repair information with technicians outside of their dealer networks for proprietary and liability reasons (Gustavus, 2004; Humanic, 2004). They want to ensure that mechanics who work on their hybrids have been properly trained and certified for hybrid work. Part of their reluctance is driven by the fact that hybrid vehicles have high voltage circuitry that could easily electrocute service personnel if improper procedures were followed during maintenance and repair operations. Additionally, they want to ensure that the vehicles are repaired properly to prevent consumers from having unfavorable experiences with the car, which would drive unfavorable publicity. By restricting service and repair information, manufacturers can avoid these issues by effectively forcing consumers to return to their dealers for service and repair work.

There are other factors that are working to restrict service and repair of hybrid vehicles to dealer technicians. First, the equipment and software needed to diagnose the cars is quite expensive and proprietary. Diagnostic procedures require dealer-specific training since the specifications of each manufacturer's hybrids are quite unique (Associated Press, 2004). Second, many manufacturers are treating some unique hybrid systems, like the continuously variable transmission, as non-serviceable items. In other words, if one of those systems malfunctions, their approach is not to repair the component but to replace it at one of their dealerships. Currently, manufacturers are comfortable with this approach because they offer extended warranties on the cars unique hybrid specific components (Humanic, 2004). This precludes the failure to service and repair certain items from being a customer relations issue. Finally, of the 16,000,000 cars sold annually, only about 40,000 are hybrids. Dealers are more than capable of repairing and servicing the small number of hybrids in operation.

As a result of these factors, the current demand for non-dealer technicians with hybrid training is quite low and does not justify the expense of non-manufacturer sponsored training programs. The only Colleges that will offer some basic hybrid training are those with existing training partnerships with hybrid manufacturers. This training will be part of the standardized curricula that automakers have developed for their technician training programs (e.g., T-TEN). In the future, if the demand for technicians should increase as the vehicles operate beyond their warranty periods, manufacturers will lead the way in the development of more advanced curricula because they control all of the service information.

Introductory Hybrid Training

In addition to the training that carmakers provide directly to technicians at their affiliated dealerships, currently-available hybrid training is introductory in nature (Humanic, 2004). The goal of this training is to provide students with a general overview of hybrid operations and a list of specific safety procedures that should be followed when performing routine service on the vehicles (Humanic, 2004). Students who complete these introductory courses are not certified to repair the hybrids, just to work safely around the cars and diagnose basic car functions (Gustavus, 2004).

According to Toby Gustavus, an automotive technology instructor at Texas State Technical College Waco, Toyota will begin offering introductory hybrid training in their T-TEN program. The program currently offers training on nine Toyota vehicles, and with the addition of a hybrid Prius, that number will rise to 10. Los Angeles, which operates 240 hybrid Honda Civics, relies on Rio Hondo Community College (Whittier, California) to provide introductory hybrid training for its fleet technicians. Rio Hondo participates in Honda's Professional Automotive Career Training (PACT) program, which is the equivalent of Toyota's T-TEN program.

Additionally, a number of colleges across the country, including Tarrant County College in Fort Worth, are members of the National Alternative Fuels Training Consortium (NAFTC), based at West Virginia University, which is developing two new hybrid vehicles courses that should be ready for public release in late October 2004 (Hudson, 2004). The first course is "Electric and Hybrid Vehicles: Technicians Guide," which teaches the fundamentals and technical aspects of electric and hybrid vehicle operation including the difference between series, parallel, and series/parallel hybrid vehicles. The course is the front end to vehicle-specific training (e.g., Toyota Prius, etc.). The second course is "Electric and Hybrid Vehicles: Fleet Manager's Guide," which deals with issues that would be of interest to a fleet manager, such as charging and maintenance costs and hybrid performance capabilities. Members of NAFTC are granted access to course materials.

Hybrid Curriculum Development Efforts

Institutions in California are at the forefront of adopting hybrid technology. In fact, 62% of the hybrids sold in the United States are sold in California. Community colleges in California, including Rio Hondo and Cypress College (Orange County), are leading the way in developing two-year hybrid curricula. For example, John Frala of Rio Hondo has been charged by Honda to develop a national hybrid training curriculum (Frala, 2004). According to Frala, because of the "newness" of the technology, the process is very time intensive. He has been working on a service training manual for one-and-a-half years and he expects it to take equally long to complete it. Frala is also leading a joint hybrid vehicle curriculum/ training project with Dick Bettendorf at Cypress College.

Los Angeles, which also uses hybrid Priuses in its fleet, is working with Toyota to develop a more advanced training curriculum that covers actual hybrid diagnostics (Humanic, 2004).

Colleges should continue to monitor the activities of these institutions. Although there is not a significant demand for hybrid technicians at this time, a sudden increase in the number of hybrids on the road could change this dynamic. The programs being developed by these institutions will serve as a useful model if such a demand should develop.

Employment Opportunities

Number of Technicians

Opportunities exist for auto mechanics with introductory hybrid training at the dealerships of hybrid manufacturers.

Salaries

The salary for entry-level automotive technicians/mechanics is about $12 per hour or $25,000 per year.

Conclusions and Recommendations to Colleges

Colleges that have existing programs in automotive technology, with specializations sponsored by hybrid automakers will probably begin some introductory hybrid training through these programs. Toyota's T-TEN and Honda's PACT programs have begun to offer such training. Other carmakers that are set to release hybrid vehicles will probably follow suit. As more hybrid vehicles are sold and reach advanced ages beyond their warranty periods, there will be an increase in the demand for non-dealer technicians able to repair them. There are some efforts, mostly by institutions in California, to develop more advanced hybrid curricula, but most of these efforts are in the early stages. Colleges should closely monitor the activities of these groups and work closely with automakers to determine when and if it is appropriate to develop hybrid curricula.

Overview of MEMS

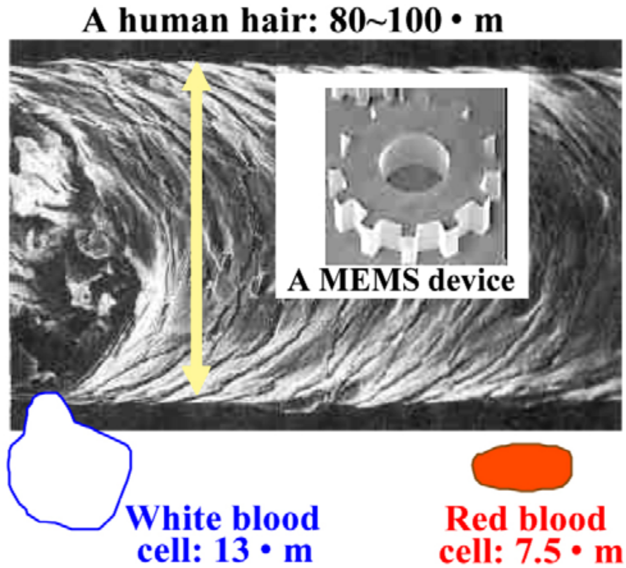
Micro-electromechanical systems (MEMS) are miniaturized, self-contained systems that integrate electrical and mechanical functionality to sense, process, and act upon information in their environments. The autonomous, miniaturized nature of MEMS decreases the cost and increases the functionality of the products into which they are integrated. Therefore, it is widely believed that MEMS could have a significant effect on the development of "smart" products in a number of industrial sectors.

Although many of the processes used to fabricate MEMS come from the semiconductor industry, technicians who design and build MEMS devices must have a much more advanced understanding of system-level design than traditional semiconductor technicians. In particular, MEMS technicians must be familiar with principles from other scientific domains such as fluid and heat transfer, solid mechanics, biochemistry, and control systems. Therefore, it appears that employment opportunities for College graduates in the field of MEMS will become significant as the industry grows. Colleges that want to capitalize on these opportunities must work closely with MEMS manufacturers in the State to assess workforce demand and training requirements. These assessments will allow Colleges to make informed decisions regarding the future impact of MEMS and the resulting technical training needs their programs must address.

MEMS Technology Review

Micro-electromechanical systems are devices that have dimensions on the order of the width of a human hair (microns [μm] or 10^{-6}m to 10^{-4}m). MEMS are fabricated using methods that are very similar to the semiconductor manufacturing techniques employed to mass produce low-cost integrated circuits (ICs). In general, however, MEMS are designed to incorporate a much broader range of technologies and components (gears, motors, sensors, actuators, and electronics) on a silicon substrate than is typically found on a conventional semiconductor chip for electronics (Wave Report, 2001). As a result, MEMS, as their name implies, are often self-contained systems that integrate both electrical and mechanical devices to gather information from their environment (sensor), process it (processor), and quickly design and execute a response (actuator). The autonomous, miniaturized nature of MEMS decreases the cost and increases the functionality of the products into which they are integrated. Therefore, it is widely believed that, as the technology develops and matures, MEMS will have a significant effect on the development of "intelligent" products in wide variety of industrial applications (Albany Nanotech, 2002).

Figure 10 MEMS Device Dimensions



Source: Professor J. B. Lee, University of Texas at Dallas

MEMS Production Principles

Traditional semiconductor manufacturing techniques lie at the core of MEMS fabrication.

Production Core—Semiconductor Processing

In semiconductor processing, the reduction of feature (transistor) sizes has resulted in increased electrical switching speed and information density. The result of these improvements has been faster and more powerful microchips. The famous Moore's Law, which predicts that the number of transistors on a chip will double every 18 months, is recognition of this fact. To achieve these breakthroughs, three key semiconductor processing techniques have been developed and refined over the years.

- ***Chemical and physical vapor deposition.*** Chemical and physical vapor deposition employs various evaporative and chemical reaction processes to deposit thin metal and metal oxide films on a substrate, typically silicon. The produced films are then reduced to their final form by a lithographic or etching step.
- ***Photolithography.*** Photolithography utilizes a light-sensitive material (photoresist) to create a pattern (e.g., circuit interconnects) on a surface. The process is very similar to conventional print lithography in that a mask is used to create specific patterns. Circuit feature dimensions can be reduced by decreasing the wavelength of the light sources and the use of very expensive lenses capable of focusing them.
- ***Etching.*** Etching involves the use of specific chemicals (e.g., hydrogen fluoride) to selectively remove material and create desired circuit features.

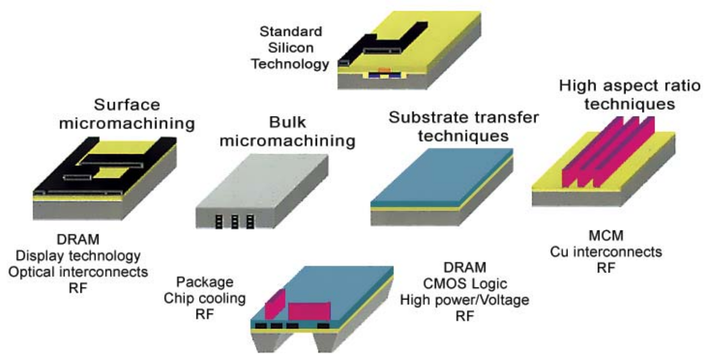
MEMS Fabrication Techniques

There are three classes of MEMS fabrication techniques (Speller, 2004). Each uses some combination of the traditional semiconductor processes of deposition, lithography, and etching:

- ***Bulk micromachining.*** Bulk micromachining is a subtractive process that utilizes a bulk silicon substrate. The bulk silicon is removed until the shape of the desired structure is realized. A thin layer of oxide or gold is then deposited on the surface of the structure. Bulk micromachining can be used to create holes, grooves, membranes, and other structural features.

- ***Surface micromachining.*** Surface micromachining is an additive process that employs polysilicon. In surface micromachining, a device is constructed from the bottom up by depositing several layers of silicon on top of each other. Gears, comb fingers, membranes, and structural features can be created using this technique.
- ***High aspect ratio micromachining.*** High aspect ratio micromachining (HARM) employs deep ultraviolet or X-ray lithography techniques to construct MEMS features. HARM allows for the fabrication of devices on stacks of multiple silicon wafers (silicon bonding). Using micro-sized molds, HARM can create MEMS features from polymers, metals, and ceramic oxide. In Figure 11, the major pieces of a standard silicon chip are shown, along with the technique used to fabricate them.

Figure 11 MEMS Fabrication Techniques and Applications



Source: J. N. Burghartz

Fabrication Equipment

The main semiconductor fabs, most notably Intel, have begun to use 300mm (wafer diameter) semiconductor equipment for IC production, which has rendered their old six-inch equipment obsolete. The old six-inch equipment, however, is ideal for MEMS application in terms of the wafer thicknesses they are capable of handling (Speller, 2004; Hall, 2004). A number of MEMS companies, including Intel and Houston-based Applied MEMS, employ six-inch equipment in their fabs. The Albuquerque Technical Vocational Institute uses spin-off six-inch equipment from Intel in their MEMS training laboratory.

MEMS Applications

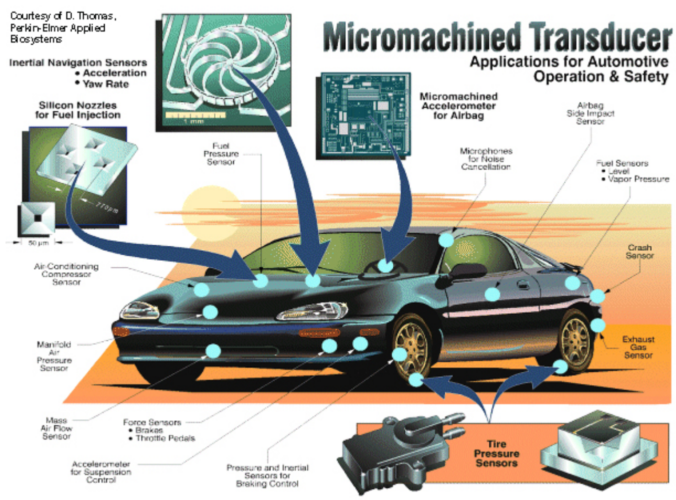
MEMS have found commercial success in a wide range of products:

- MEMS accelerometers are used to deploy automobile airbags. Applied MEMS (Houston) manufactures MEMS accelerometers for use in seismic oil and gas field exploration devices.
- MEMS actuators control the deposition of ink in inkjet print heads.
- Digital light processors (DLPs) are MEMS devices that use micro-mirrors (actuators) to direct the projection of light in portable video projectors and optical network switches. Texas Instruments (Dallas) is a long-time pioneer in this area.

- MEMS RF switches are used for complex signal switching in portable communication devices such as cell phones. TeraVicta (Austin) and Raytheon (Dallas) are manufacturers of MEMS RF switch and relay solutions.
- MEMS devices have found many applications in the medical world. Among others, so-called bioMEMS devices are used to monitor a patient's blood pressure, vital signs, and blood oxygen levels. BioMEMS are also used to monitor and control vital functions in kidney dialysis machines and insulin/drug delivery pumps (Joseph, et al., 1997).

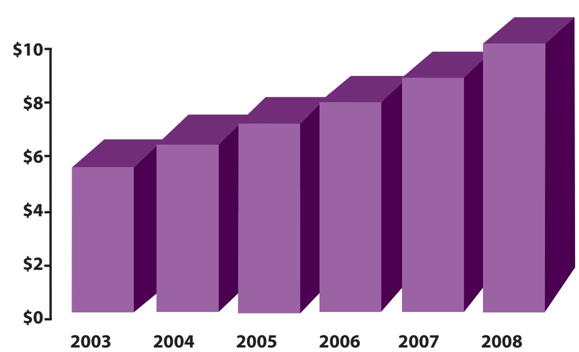
The MEMS Industry Group's 2003 survey found that 90% of commercially manufactured MEMS devices can be divided into six categories: inertial sensors (accelerometers, gyros, motion sensors, etc.), optical mirrors, microfluidic devices/microarrays (channels, reservoirs, actuators), RF communication components, physical sensors (pressure, temperature, flow), and inkjet nozzles (MEMS Industry Group, 2003). Figure 12 provides an illustration of how some of these technologies could be used in an automotive application. In-Stat/MDR has projected that MEMS sales will reach $7 billion by 2005 (In-Stat/MDR, 2004) (see Exhibit 4.4).

Figure 12 MEMS in Automotive Applications



Source: In-Stat/MDR (June 2004)

Figure 13 Forecast Sales of MEMS Worldwide, 2003-2008



Source: In-Stat/MDR (June 2004)

Special Texas Factors

A number of Texas-based companies are MEMS manufacturers. Table 3 lists some of those companies and their area of MEMS specialization. Contact info, including websites, for these companies is listed in Appendix G.

Table 3 Texas MEMS Companies

Technology Area	Typical Devices/Applications	Companies
Inertial Measurement	Accelerometers, Rate Sensors, Vibration Sensors	Texas Instruments, Boeing Motorola, Applied MEMS
Microfluidics and Chemical Testing/	Gene Chip, Lab on Chip, Chemical Sensors, Flow Controllers, Micronozzles, Microvalves	Texas Instruments, Motorola
Optical MEMS (MOEMS)	Displays, Optical Switches, Adaptive Optics	Northrop- Grumman, Texas Instruments
Pressure Measurement	Pressure Sensors for Automotive, Medical, and Industrial Applications	Texas Instruments
RF Technology Inductors, Antennae, Phase	RF Switches, Filters, Capacitors, TeraVicta, Hughes Aerospace Shifters, Scanned Apertures	Texas Instruments, Raytheon,
Other	Actuators, Microrelays, Humidity Sensors, Data Storage, Strain Sensors, Microsatellite Components	Zyvex, Northrop-Grumman

Source: DARPA

MEMS Industry Trends

In an emerging technology as dynamic as MEMS, various unexpected breakthroughs, events, or decisions could materially change the nature, rate, and implications of technical advances and market developments. The discussion below explores some of the factors that might accelerate or constrain the growth of the MEMS market.

Drivers

- ***Rich set of MEMS components for many applications.*** MEMS can be employed in a diverse set of applications. It is expected that MEMS will have a significant effect on products in a wide range of industrial sectors including transportation, electronics, homeland security, and defense. As a result, MEMS have the potential to become even more pervasive than integrated semiconductor chips (Albany Nanotech, 2002).
- ***Disruptive technology to today's macro-sensor/actuator technology.*** MEMS erase the divide between mechanical devices and processors (ICs). In the past, mechanical sensors and actuators were the most expensive and unreliable components of a macro-scale device that combined these devices and a "thinking" capability (processor). MEMS allow complex electromechanical devices to be fabricated economically and reliably in much the same way that ICs are created. Therefore, not only will the performance of MEMS devices be superior to that of their macro-scale equivalents, their price will be much lower.

As a recent example of the advantages of MEMS technology, consider the MEMS accelerometers, which are quickly replacing conventional accelerometers for crash airbag deployment systems in automobiles. The conventional approach uses several bulky accelerometers made of discrete components mounted in the front of the car with separate electronics near the airbag and costs over $50. MEMS have made it possible to integrate onto a single silicon chip the accelerometer and electronics at a cost between $5 and $10. These MEMS accelerometers are much smaller, more functional, lighter, more reliable, and are sold for a fraction of the cost of the conventional macro-scale accelerometer elements (Albany Nanotech, 2002).

- ***Premium on size reduction in several key uses.*** The size of a device is important to end users because it makes the use of the device more convenient. At a given level of convenience that varies by importance to the user and psychological factors, a small size enables the device to be used or attached to or within their bodies. Examples of this need are cell phones, MP3 players, and pacemakers. One of the major market segments that will drive MEMS technology from the size standpoint is the toy market. This market puts a premium on "magical function" (such as a wand that directs miniature helicopters) and the ability to create fads where everyone has to have a particular new toy.
- ***Military applications.*** The U.S. military's focus on information superiority and precision tactical operations has spawned the need for many new sensor and communications capabilities. These needs have led to reducing the size and weight and increasing operational life of high-tech devices in order to speed up logistics and avoid weighing down weapons/surveillance platforms and the combatant. The diversity of threats and new sensor-based techniques for identifying them in real time has increased the requirements for variety, sensitivity, and bandwidth in sensors. The Defense Advanced Research Projects Agency (DARPA) believes that MEMS devices can provide this functionality. As a result, DARPA has contributed billions of dollars for academic, government, and private MEMS research. DARPA's continued support of research programs is key to the continued development of the nation's MEMS industry.
- ***Special space technology needs.*** MEMS devices can improve the per unit mass and volume performance of systems used in space and aerospace-related applications (Suski, 2003).

Constraints

Despite their potential use in the applications listed above, MEMS manufacturers have had difficulty commercializing the technology in key applications. Some factors that have constrained the development of the MEMS industry are described below.

- ***MEMS fabrication resources.*** Current MEMS devices are manufactured in semiconductor clean rooms that employ the same costly technologies used to manufacture semiconductor chips. However, unlike semiconductor processes, which are very standardized across companies and market segments, MEMS production techniques tend to be very diverse because of the wide range of applications. For example, semiconductor manufacturing technology was not designed to handle the 3D mechanical structures that many MEMS devices employ. Any significant change in the functionality of a MEMS device requires significant changes to manufacturing processes. These changes can require several years of design work and millions of dollars of development funding (Microfabrica, 2003).

- ***Packaging issues.*** For a variety of reasons (application environment, mechanical functionality), the packaging of MEMS devices is much more demanding than semiconductor packaging. The unique functionality of MEMS devices almost always requires that a unique package design must be developed for each separate MEMS device, which is a very expensive process. Thus, most MEMS manufacturers find that "60% to 85% of the cost of a MEMS device is packaging" (MEMS Exchange, 2004).
- ***Lack of venture funding.*** It takes anywhere from seven to ten years to bring a MEMS product from the laboratory to the marketplace. A number of prominent MEMS companies, including Corning Intellisense and Standard MEMS, closed their doors in 2003. These companies were able to raise significant venture capital funding in the pre-2001 "boom" period without a clear commercialization strategy. Convincing venture capitalists to return to the MEMS market will be a major challenge for this industry. An encouraging sign is that venture funding for MEMS companies in the first half of 2004 surpassed the entire 2003 funding level by 33% (Bourne, 2004).
- ***Lack of industry standardization.*** Because of the wide variety of applications and production processes, there are no agreed-upon manufacturing or product standards.

MEMS and the Role of Colleges

Program Compatibility

Semiconductor processing technologies are the foundation of MEMS fabrication techniques. Therefore, Colleges with existing semiconductor manufacturing technology (SMT) and/or electronics technology (ET) programs are the most likely to initiate MEMS curriculum or introductory training modules. The Albuquerque Technical Vocational Institute (TVI) and Austin Community College (ACC) are two such institutions. By attaching MEMS programs to existing SMT programs, Colleges can leverage their existing assets in terms of both faculty and equipment to quickly initiate programs.

Technician Profiles

Initially, MEMS technicians will fall into two broad categories: design or fabrication technicians. As is the case in a traditional manufacturing environment, the interactive routine of technicians and engineers, somewhat unique in the manufacturing workforce, will apply in the MEMS manufacturing environment—from prototype design to final product. Additionally, technicians who design and build MEMS devices must have a much more advanced understanding of system-level design than traditional semiconductor technicians (Hall, 2004). In particular, MEMS technicians must be familiar with principles from other scientific domains such as fluid and heat transfer, solid mechanics, biochemistry, and control systems.

Fabrication Technicians

Fabrication technicians will be responsible for operating clean room production equipment. Therefore, fabrication technicians will have to understand the semiconductor processes (chemistry, materials science, etc.) used in MEMS production (see MEMS Fabrication section). However, with regard to MEMS production specifically, fabrication technicians must be knowledgeable about the construction of 3D electromechanical devices where deposition methods and cleaning methods are more critical than lithography, which is not necessarily always true in the semiconductor environment (Nelson, 2004).

Design Technicians

Design technicians, on the other hand, will have to be familiar with MEMS design rules, the most prominent of which is Sandia National Laboratories' SUMMiT design program, which teaches Sandia's Surface Micromachining Process and Design Technology. Colleges that participate in the Sandia University Alliance Program have access through AutoCAD to the Sandia-developed MEMS design package, design rules, and checkers. Students who graduate from the program have training in a widely-recognized MEMS design package and are employable as MEMS design technicians.

Displaced semiconductor workers with experience and expertise in semiconductor processing and electronics are ideal MEMS technician candidates. Currently, more than 50% of the students enrolled in TVI's MEMS program are displaced semiconductor employees (Hall, 2004).

Existing MEMS College Programs and Courses

Albuquerque Technical Vocational Institute (TVI)

The Albuquerque Technical Vocational Institute (TVI) and the University of New Mexico initiated their MEMS program after NASA and Sandia expressed an interest in developing MEMS technicians and engineers. NASA provided TVI with a $300,000 grant to develop six MEMS courses. Four of these courses are already being taught. The other two will be ready in spring 2005.

Sandia, run by Lockheed Martin, has invested $500 million in the Microsystems Engineering Sciences Application (MESA) complex for construction and new lab space that will facilitate MEMS research and development. This fiscal commitment indicates that the federal government believes MEMS will be an important technology (industry) in the future. There is a significant industrial MEMS cluster in Albuquerque of about 40 to 45 start-up companies (some venture funded, others Sandia funded) that are commercializing various MEMS technologies applications. TVI's goal is to provide technicians for this cluster.

TVI's MEMS program is a concentration within their preexisting SMT program. Since TVI has an existing SMT program, they decided their program would address both MEMS design and fabrication. Students in the program, unless they have prior semiconductor industry experience, complete existing SMT courses that provide them with a foundation in electronics, semiconductor manufacturing concepts, and quality assurance. The MEMS-specific courses, one of which includes a laboratory requirement, provide students with a foundation in MEMS design and manufacturing theory. Eventually, TVI will conduct a formal DACUM in MEMS and develop an independent standalone program that leads to the award of an Associate of Applied Science (AAS) degree or Advanced Technical Certificate in MEMS. TVI is licensed to teach Sandia's SUMMiT process and design technology.

Austin Community College

Austin Community College (ACC) offers a course in MEMS design. ACC has an alliance agreement with Sandia that gives them access to Sandia's SUMMiT design program.

Special Factors—Texas Colleges

Due to the huge diversity in applications and production processes in the MEMS industry, MEMS curriculum will require the skillful integration of traditionally disparate topics, hence, courses across several technology and industry boundaries. Fortunately, this diversity in production processes speaks to large niche markets that Colleges can exploit to establish MEMS programs that are closely aligned with the interests of institutions in the regions they serve. Therefore, Texas Colleges should work closely with MEMS manufacturers and trade organizations in the State to develop MEMS curricula that address the specific needs of employers most likely to hire their graduates. Such partnerships have worked well for TVI in New Mexico. John Simcik, Instructor, Laser Electro-optics Technology Department, Texas State Technical College Waco, indicated that a number of such organizations, including Lockheed (Sandia), Hughes Aerospace, Raytheon, and Texas Instruments, have expressed an interest in College graduates for MEMS technician positions.

MEMS Employment Opportunities

Number of Technicians

The semiconductor industry productivity rate is about $400,000 per person (Hall, 2004). In-Stat/MDR forecasts that worldwide sales of MEMS will reach $7 billion in 2004 (In-Stat/MDR, 2004). Therefore, the worldwide demand for MEMS employees is estimated at about 17,500 employees. When calculated using an industry standard 2:1 ratio of direct labor to indirect labor and a 5:1 ratio of technicians to engineers, the worldwide forecast for technician is about 9,700 employees (Hall, 2004). Obviously, most of these technicians are already employed by companies that are producing commercially available MEMS products for applications such as airbags and inkjet printers. Therefore, Texas Colleges must coordinate closely with MEMS manufacturers to determine their specific workforce demands in the State.

Salaries

According to several people with whom the authors spoke, the salary structure for MEMS technicians will closely resemble the existing salary structure for technicians in the semiconductor industry. There will be a dual range in salaries:

- Students who graduate from an MEMS program after receiving a high school diploma but with no previous semiconductor experience will start at about $30,000 to $35,000 per year.
- Students who graduate from an MEMS program with previous semiconductor experience, or college degrees, will earn $35,000 to $45,000. The high end of the salary range ($45,000) is typically reserved for a person with a master's degree or five to ten years of prior semiconductor experience.

MEMS Conclusions and Recommendations to Colleges

Colleges that want to initiate MEMS programs have several options. For example, Colleges that lack existing SMT programs may not find it feasible to offer training in MEMS fabrication because of the expensive startup costs associated with faculty recruitment and clean room equipment. However, these Colleges may find that initiating a course or courses in MEMS design is feasible because it only requires access to licensed software (AutoCAD), computer labs, and one or two faculty members with expertise in MEMS design rules like SUMMiT.

On the other hand, Colleges with existing SMT programs and the necessary production and clean room equipment can choose to offer some combination of training in MEMS design and fabrication. They might choose to develop full-blown, autonomous MEMS programs, or they can offer MEMS concentrations within their existing SMT programs.

Finally, because of the emerging nature of the MEMS industry, College deans and other instructional officers should work closely with Texas MEMS manufacturers and trade groups in order to make informed decisions about the design, initiation, and conduct of MEMS programs at their institutions. Such interaction should mitigate the risk of initiating programs too soon or too early.

An index of related MEMS Texas manufacture's and industry groups is presented in Appendix G.

Overview of Computer Forensics

Computer forensics is the science of conducting investigations related to computer crimes and abuse in a manner that is legally sound and reproducible. Using specialized hardware and software tools, computer forensics technicians gather evidence about all kinds of activity including fraud, embezzlement, child pornography, and intellectual property misappropriation. Whether they are employed in the public or private sector, the evidence these technicians produce must be collected in a way that adheres to widely accepted evidentiary procedures and processes. Thus, two-year programs in computer forensics will include courses in both the technical (computer systems and networks) and legal (criminal justice and evidence) aspects of investigations.

The demand for appropriately trained and qualified forensics technicians is quite good at all levels in law enforcement, government, and the private sector. This demand extends across the entire state, in fact, the entire nation. In the near future, salaries for graduates of two-year computer forensic programs will be quite good.

Computer Forensics Technology Review

Computer forensics is the "science of acquiring, preserving, retrieving, and presenting data that has been processed electronically and stored on computer media" (FBI, 2000). In criminal and civil law applications, computer forensics is concerned with the search, seizure, analysis, and preservation of evidence from a digital crime scene in a way that is consistent with specific legal standards that govern its admissibility in a court of law. In non-legal applications, computer forensics can be used to recover data that has become irretrievable due to physical (e.g., fire) and/or electronic (e.g., accidental deletion of files) events.

The demand for technicians skilled in computer forensic techniques is ever growing. The 2004 FBI Computer Crime and Security Survey indicates that computer crimes against businesses are widespread, accounting for millions of dollars in identifiable losses (CSI/FBI, 2004). Moreover, FBI surveys indicate that only about 15% of felony level computer crimes are reported to law enforcement authorities, 5% are investigated, and 2% are prosecuted (Wilsker, 2004). The main reason for the low enforcement and prosecution rates is the shortage of law enforcement personnel qualified to deal with computer crime.

In fact, a number of small local law enforcement agencies in the state that typically use the Secret Service for forensics investigations have begun to train their detectives in basic computer forensics techniques to deal with their growing case loads (Wilsker, 2004). Additionally, there is a growing demand for computer forensics technicians in the corporate arena to investigate intellectual property misappropriation and human resource issues related to the abuse of corporate assets and wrongful termination (e.g., discrimination, harassment).

Computer Forensics Principles

Role of the Computer

There are three different ways that a computer or other digital device can be used in a crime or abuse situation. (*Note*: In this report, we will use the term computer to refer to any digital or electronic device that stores or transmits information such as servers, personal digital assistants, etc.) The computer can be the target of a crime, the instrument of a crime, or the repository of evidentiary information about a crime (Oseles, 2001). An example of each of these situations is provided below:

- ***Target of a crime.*** A hacker could gain unlawful access to a computer and steal or destroy information. Other examples include harmful viruses and Trojan horses that are transferred to a machine in order to diminish its performance.
- ***Instrument of a crime.*** A computer could be used to gain unlawful access to another computer for the purpose of stealing or destroying files.
- ***Repository of evidence.*** A computer may contain a record of crimes that were committed. In some cases, the crime will be computer-related (Internet fraud, viruses, Trojan horses, etc.); in other cases, it will not. For example, in a narcotics investigation, computer forensic technicians might be called upon to search for spreadsheet files that contain the names of suppliers and transaction amounts.

Most often, the role of a computer will be some combination of situation 3 and either situation 1 or 2.

Technical Issues—Evidence Examination

Once it is determined that a computer may have been involved in a crime, forensics technicians must examine the computer for evidence. In addition to a number of critical legal procedures that must be observed before, during, and after the seizure (see Legal Issues section), forensics technicians must abide by a number of technical procedures to protect and preserve critical information:

- ***Computers should not be simply turned off and on.*** The act of shutting down and restarting a computer changes the time and date stamps of certain files on hard drives (or other kinds of storage media) that may be critical to an investigation (May, 2002). Therefore, one of the first things that must be done is to "freeze" evidence. This can be accomplished by write protecting the original storage media using one of several different methods (Oseles, 2001). The most widely used method is to remove the hard drive and reconnect it to a trusted machine that is hard wired to write protect the media.
- ***Evidence reproduction.*** Analysis is never performed on the original storage media, which must be preserved in its original state for legal reasons. Therefore, it is absolutely critical that an identical copy of the hard drive, including files that have been deleted and storage areas that a normal backup would not copy, be produced. Not only must the forensic software be capable of producing this copy, but the method used to create the copy must "be recorded in detail to later prove the original image was not altered and the copies are true copies" (Oseles, 2001). Forensic recovery of evidence devices (FREDs), which employ forensic software, allow forensic investigators to produce exact copies of a hard drive, bit-by-bit, without altering the original. These devices are described in more detail in the Forensics Recovery of Evidence Equipment section.

  EnCase, produced by Guidance Software, is the most widely used and accepted forensics software tool. Evidence gathered by the tool is admitted by the courts as non-destructive for analyzing hard drives. The FBI and most other law enforcement agencies (the police departments of Austin, Beaumont, Houston, Dallas, and Waco, among others) use EnCase almost exclusively in their investigations (Denn, 2004). In addition, federal courts accept evidence gathered with EnCase. Other forensics tools of interest are listed in Table 4.

- ***Analysis of files.*** The actual analysis of storage media is the next step in the investigation. Investigators use background information gathered during the course of an investigation to develop "evidence search" strategies. Obviously, the first places they look for information are in easy-to-access, visible files such as e-mails, Microsoft Word/Excel documents, and graphics and video files. However, these are not the only files they search for evidence. Using the exact copy of the hard drive, so-called "hidden files" in free space, file slack, and swap files are also analyzed by forensics software (Kruse, 2003). Figure 15 illustrates some principles around these concepts.

Figure 14 Forensic Recovery of Evidence Device

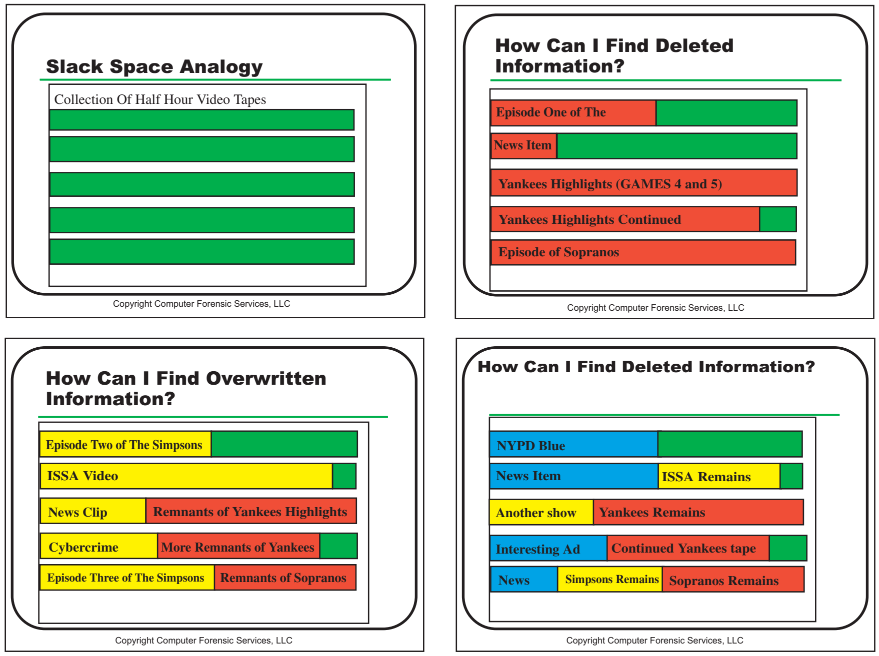
Source: Digital Intelligence, Inc.

Table 4 Forensics Software Tools

Name	Description	Website
Symantec Ghost	Produces bit-by-bit copy of a hard drive that can be used for forensics investigations.	http://sea.symantec.com/content/product.cfm?productid=9
Accessdata Forensic Toolkit	Toolkit provides filtering and search functionality through e-mail, program, registry, and operating system files.	www.accessdata.com
Coroners Tool Kit	A data collection and analysis tool that can be used on UNIX and LINUX systems after they have been broken into.	http://www.porcupine.org/forensics/tct.html

Source: Technology Futures, Inc.

Figure 15 Slack Space Analogy



Source: Computer Forensics, LLC

Free or unallocated space is part of the hard drive's available storage and may include spaces where files existed before but have been deleted. File slack is the storage space available from the end of a file to the end of a cluster. "For example, if a cluster is 512 bytes and a file only uses 312 bytes, the free or unallocated space is 200 bytes" (Oseles, 2001). This space may contain evidence of value to an investigation. Swap files are files on the hard drive that are used to temporarily store or "cache" information that is exchanged between a hard drive and random access memory (RAM). Valuable files could also be stored here. Employing relevant keywords, forensic software can be used to automate the search for evidence through the files described above and other places such as temporary files, hex files, log files, directories, and hardware such as read-only memory and flash BIOS (Radcliff, 2002).

Forensics software can also be used to "crack" encrypted and password protected files that suspects may try to conceal. The EnCase software module includes this capability:

> The EnCase EFS Module provides forensics examiners with the ability to automatically decrypt Microsoft Encrypting File System (EFS) encrypted files and folders, for locally authenticated users. Since EFS is key-based, only the user who encrypted the file(s) is able to decrypt and view the file contents, unless the user's password is known. EFS encryption has traditionally posed obstacles for examiners, as the EFS encryption process creates illegible and indecipherable text within files. The automation and decryption capability of the EnCase® EFS Module allows examiners to concentrate their efforts on investigative analysis, rather than spending excessive time attempting to break EFS encryption (Guidance Software, 2004).

Network Forensics

Network forensics, a branch of computer forensics, employs intrusion detection and TCP/IP (transmission control protocol/Internet protocol) tracking software to trace network activity across "multiple jurisdictions by analyzing Internet protocol addresses, system logs, and packet header information" (Radcliff, 2002). This branch of computer forensics also employs tools such as network sniffers (listening and logging software), observation traps, and domain name lookups to establish a comprehensive view of how the security and availability of an organization's system resources are being affected by network communications. Although organizations are increasingly employing network forensics to assess compliance with internal HR and security policies, "network forensics is currently a niche area, but it is nonetheless an increasingly valuable one" (Lawson, 2004).

Legal Issues

There are a number of procedures that forensics technicians must follow to ensure the admissibility of the evidence they gather in court. A number of those procedures are discussed below:

- ***Legal procedures.*** Search warrants that include specific information related to the reasons for the seizure of computers or computer-related evidence must be executed (Oseles, 2001). Data that is unrelated to a crime (e.g., confidential patient records of a doctor implicated in a Medicare scam) should be left untouched. Other important legal processes that must be followed include depositions, hearings, trials, and discovery that preserve the rights of the accused.
- ***Integrity of evidence.*** As discussed above, the original data is always left untouched. Exact, bit-by-bit copies of the original media must be available to both sides for analysis in a legal proceeding. Additionally, a chain of custody that establishes and documents the "who, what, where, when, and how of the computer forensics process must be documented during every step of the investigation" (Oseles, 2001). The most important pieces of this documentation are a comprehensive list of the items seized and a list of all the people who have had access to that evidence since it was collected.
- ***Rules of evidence.*** There are various tests, including the Daubert and Frye test, that courts apply to the "methodology and testimony of an expert to determine admissibility, reliability, and relevancy" (Hailey, 2003). These rules of evidence vary across local and state jurisdictions and apply to digital and non-digital evidence alike.
- ***Interpretation.*** Although there are a number of powerful software tools that can be used to gather forensics evidence, there is still a need for expert analysis to build strong cases that demonstrate intent, motive, opportunity, and means. One example of how information can be misinterpreted is provided below:

  > The experts for the prosecution in a case used a popular graphical user interface (GUI) tool that came with a script for finding Internet search engine activity. When they ran the script, they found literally hundreds and hundreds of "searches" that supposedly had been conducted by the defendant. Therefore, the defendant had intentionally accessed certain types of information related to these searches—the searches showed intent. When the experts for the defense examined the same evidence, they realized that each and every one of these "searches" was actually a hyperlink and not a search at all. The hyperlinks were formed in such a way that when a link was clicked, a database was searched to pull up the most current information related to the link. The way that the links within the page

were formed was what the GUI tool honed in on, as they were formed similarly to fragments and Web pages that could be found to indicate search engine activity.

The experts for the prosecution took for granted that their automated tool was accounting for any variables, and would only show them searches that had actually been conducted–a big mistake. These experts lacked the technical skills to authenticate their results, so they depended entirely on a single automated tool. This leads to a very important lesson. Results from any tool should always be thoroughly checked by someone versed in the underlying technology to see if what appears to be a duck is actually a duck (Hailey, 2003).

Forensics Recovery Equipment Devices

As indicated in the Evidence Reproduction discussion above, forensic recovery of evidence hardware devices (FREDs) are used to gather evidence from digital crime "scenes." A hard drive, or other digital storage medium of interest, is removed from its original case and plugged into the FRED. The function of the FRED is to facilitate the use of forensics software that can create a reproducible, analyzable copy of the medium that does not alter the original. The FRED accomplishes this task through the use of various write blocking (write protection) hardware tools that can capture data from various kinds of media (CDs, floppies, memory sticks, compact flash, etc.). Otherwise, the equipment consists of widely available hardware equipment (Intel processors, Dual Channel DDR400 memory, etc). Digital Intelligence (Waukesha, Wisconsin) is a major vendor of these devices. Their website is http://www.digitalintel.com/products.htm.

Computer Forensics Applications

Computer forensics has found application in a number of areas:

- ***Law enforcement.*** Law enforcement agencies such as the Secret Service, the FBI, the Department of Public Safety (DPS), and local police agencies use computer forensics to investigate crimes ranging from network break-ins to child pornography, fraud, and drug investigations.
- ***Corporate sector.*** In the private sector, computer forensics is used to investigate the unauthorized use of sensitive or proprietary data, employee fraud and embezzlement, and misuse of corporate information technology (IT) assets (Hailey, 2003).
- ***Data recovery.*** Computer forensics tools can be used to recover seemingly inaccessible data from storage media. This media could be rendered inaccessible for any number of reasons, ranging from user error (accidental deletion of files) to physical events (fire, water damage, etc.).
- ***Consulting/private investigations.*** An increasing number of private individuals are turning to consultants to investigate the online activities of their children and spouses. Digital evidence of interest includes deleted emails and access to inappropriate Websites.

Market research firm International Data Corporation (IDC) predicted the private sector market for incident response services, which include computer forensics, will jump from $133 million in 2001 to $284 million by 2004 (LeClaire, 2003). A sample of potential computer forensics employers is provided in Appendix G.

Industry Trends

The discussion below explores some of the factors that might accelerate or constrain the growth of the computer forensics market.

Drivers

- ***Increasing rates of computer crime.*** Law enforcement agencies are overwhelmed by their computer crime caseloads. There is a strong demand for forensics technicians at all levels of law enforcement (Wilsker, 2004).
- ***Prevention.*** Forensics technicians are moving from purely investigative roles to actually developing blocking, prevention, and tracking strategies that prevent harmful activities from occurring in the future.
- ***Increasing recognition that incident response is not forensics analysis.*** The focus of most IT administrators during an attack is not the preservation of prosecutable forensics evidence, but the restoration of function. After an attack, it is often discovered that the recovery actions of the administrator rendered much of the evidence useless. The management of many organizations is increasingly recognizing that incident response and computer forensics involve competing interests (rapid return to full functionality versus the preservation of evidence). These companies are beginning to draft security policies that balance these concerns and increasingly involve the expertise of forensics technicians in system administration teams, which has not been true in the past (Fischer, 2002).
- ***Authorship attribution.*** In non-digital applications, many forensic techniques are employed to irrefutably identify a victim or establish the incontestable identity of a victim. Currently, this is very difficult to accomplish in computer forensics. For example, a question that often arises is "Who actually wrote incriminating files on a computer that many people have access to or is pre-owned?" Applications from Forensic Linguistics and Stylometry are being developed to address these challenges (Palmer, 2002).
- ***Theft of corporate intellectual property.*** The misappropriation of corporate trade secrets and intellectual property is forever a problem. Corporations are aware of this threat and are increasingly turning to the courts to seek redress. Computer forensics play an important role in these investigations and in the development of strategies that prevent future transgressions (May, 2002).

Constraints

Some factors that might constrain the growth of the computer forensics industry are described below.

- ***Budgetary constraints.*** Many law enforcement agencies have a demand for increased forensics services, but do not have the necessary budgetary resources to pay for them (White, 2004).
- ***Increasing use of strong forms of encryption and steganography.*** Criminals are turning to strong forms of encryption that lock their sensitive information in undecipherable files and make it inaccessible to investigators. Although these encrypted files can often be cracked by highly-skilled, dedicated forensics experts, they increase the amount of time and money required for investigations. Especially troublesome is steganography, a method of encrypting text messages inside of graphics files that is almost impossible to decipher (informIT, 2004).

- *Privacy legislation.* Concerns about so-called “Big Brother” law enforcement tactics might result in legislation that severely restricts the ability of law enforcement agencies and employers to investigate the computer-related activities of individuals. Such legislation could severely restrict computer forensics activities.

Computer Forensics and the Role of Colleges

Program Compatibility

Computer information systems, network security, network administration, and criminal justice form the foundation of computer forensics. A number of Colleges across the nation have computer forensics programs that teach skills in these areas. Some typical core courses include computer forensics with a laboratory component employing industry standard software such as EnCase, fundamentals of network security and administration, criminal law and procedure, evidence search and seizure, computer hardware, and operating systems. A partial, but representative, list of Colleges with AAS programs in computer forensics is presented in Appendix H. Salaries for experienced forensics experts qualified to teach the forensic portions of these curricula can be quite high. Therefore, a significant challenge for these programs is finding and affording qualified instructors with field experience.

Technician Profiles

Forensics technicians should have a fundamental understanding of computer hardware and operating systems, network security and administration, and hands-on training in a well accepted forensics software tool (e.g., EnCase). However, as many experts have pointed out, the major weakness in many computer forensics investigations is not a lack of technical expertise, but the failure of technicians to produce repeatable results and follow established evidentiary processes and procedures, which can invalidate their investigations in a court of law (White, 2004). Therefore, there is a critical need for technicians trained not only in the technical aspects of forensic investigation, but also in the legal rules and procedures that govern the search, seizure, and custody of evidence. In fact, almost all of the forensics programs we reviewed have a very significant criminal justice component (at least 12 hours, in some cases.). A curriculum that addresses both the legal and technical aspects of computer forensics will produce graduates more prepared for entry-level positions in law enforcement agencies, corporate IT departments, and consulting firms. These students will be employed as entry-level forensic and data recovery technicians.

Currently, there are no widely recognized certifications in the area of computer forensics that are the equivalent of certifications such as the Certified Information Systems Security Professional (CISSP) certification in general network security (Kessler, 2004). As Ed Tittel points out in *Certification* magazine,

> With any certification that isn’t extremely well known, IT professionals must be prepared to explain to HR and hiring managers where the value in such credentials resides. That is, they must be prepared to explain what they know, what they can do, and what kinds of problems they can solve and why their certifications bring merit to the job they seek to fill (or stay in) (Tittel, 2004).

A list of computer forensics certifications that Tittel compiled is provided in Table 5. A complete description of the requirements for the certifications is provided at the listed URL address.

Table 5 Computer Forensics Certifications

Name	Acronym	URL
EnCase Certified Examiner	EnCE	www.encase.com/certification/ence.shtm
CERI Advanced Computer Forensic Examination	CERI, ACFE	www.cyberenforcement.com/certification/
CERI Certified Forensics Examiner	CERI - CFE	www.cyberenforcement.com/certification/
Certified Computer Crime Investigator (Basic & Advanced)	CCE	www.htcn.org/changes.htm
Certified Computer Examiner	CCE	www.certified-computer-examiner.com/
Certified Computer Forensic Technician (Basic & Advanced)	CCFT	www.htcn.org/changes.htm
Certified Electronic Evidence Collection Specialist	CEECS	www.cops.org/certification.htm#CEECS
Certified Ethical Hacker	CEH	www.eccouncil.org/CEH.htm
Certified Forensic Computer Examiner	CFCE	www.cops.org/certification.htm
Certified Information Forensics Investigator	CIFI	http://www.infoforensics.org/certification/certification.asp
Computer Hacking Forensic Examiner	CHFE	www.eccouncil.org/chfi.htm
Professional Certified Investigator	PCI	http://www.asisonline.org/certification/pci/pciabout.xml

Source: Certification (April 2004)

Special Factors—Two-Year College Programs in Texas

The Cyber Security/Computer Forensics Project at Del Mar College, in partnership with Collin County Community College, Richland College, and Southwest Texas Community College, received $887,775 from the National Science Foundation to launch a three-year "Cyber Security/Computer Forensics Project" that will train technicians in the areas of cyber security, computer forensics, data recovery, and create curricula modules for dissemination to other Colleges throughout the State and nation (TEES, 2003). The Texas Engineering Experiment Station (TEES) is administering the project. According to Ira Wilsker, the Director of the Management Development Program at Lamar Institute of Technology and one of the project's co-principal investigators, part of the group's charge under the grant is to seek approval from the Texas Higher Education Board for a uniform curriculum in computer forensics.

The project will identify the KSAs, competencies, course outlines, and textbook recommendations for a "turnkey" curriculum any College can use to establish a computer forensics program (Wilsker, 2004). In April 2006, at the end of the grant period, the program syllabus, curriculum, DACUMs, competencies, and advisory committees created by the project should be validated, recognized, and complete. The leaders of the project hope to receive approval from THECB for both an AAS degree and a concentration in computer forensics by this date.

Del Mar has already purchased five copies of the EnCase forensics software (educational version) and is in the process of establishing a lab with off-the-shelf networking equipment and PC hardware. Students who enter the program will have to undergo background checks and screening. According to Wilsker, who is also a Beaumont police officer, there are a number of well paying jobs for entry-level computer forensics technicians, who are appropriately trained, at both public and private institutions.

Larry Lee, Chair of Del Mar's Department of Computer Science is the project's principal investigator. He can be contacted at llee@delmar.edu.

Computer Forensics Employment Opportunities

Number of Technicians

Opportunities exist for computer forensic specialists in both the public and private sectors. The majority of currently available jobs are with law enforcement agencies, but many corporations are recruiting these services for their in-house IT teams to combat employee misbehavior and the misappropriation of intellectual property. Additionally, a number of private consulting agencies are hiring computer forensics analysts to assist in "digital detective" and data recovery tasks.

Salaries

The salary for entry-level computer forensics specialists and data recovery technicians can range anywhere from $45,000 to $60,000, depending upon previous experience and qualifications. The compensation of public sector employees is generally much lower than that of the private sector.

Conclusions and Recommendations to Colleges

Colleges that have existing programs in computer hardware, network administration, network security, and criminal justice are well suited for training individuals in the area of computer forensics. In some cases, there will be a demand for graduates with associate degrees in computer forensics; in other cases, there will be a need for continuing education of law enforcement personnel in specific technical computer forensic techniques.

The turnkey curricula being developed by the Cyber Security/Computer Forensics Project at Del Mar College will provide training modules that can be used for both of these groups. Although Colleges in specific regions of the State may have different training requirements, any College planning to offer computer forensics courses would be well advised to become familiar with the Del Mar project.

An index of related Computer Forensics employers and industry groups is presented in Appendix G.

Emerging Technologies: Conclusions

Selected Technologies

The identification and selection processes used in this project succeeded in identifying four emerging technologies worthy of detailed analysis. Three of these offer promising opportunities for College graduates, each for different reasons.

Advanced digital manufacturing represents a technology that is emerging from an existing technology–digital prototyping–that presents an effective new technique for the manufacture of items with special characteristics.

Interest in and employment of *MEMS* devices are growing daily. The fact that MEMS production utilizes many of the skills and much of0 the equipment of semiconductor manufacture means that a lot of the expertise and many of the facilities developed for semiconductor curricula can be modified to provide superior training in the MEMS area.

Increasing commitment to homeland security, the growing prevalence of computer viruses and identity theft, and the enhanced sophistication of law enforcement have all multiplied interest in *computer forensics* in both the public and private sectors. There is every indication that graduates in this field will have very attractive employment opportunities.

Recently, there has been a great deal of interest in *hybrid vehicles* throughout the United States. However, our analysis indicates that, for various reasons, the establishment of College programs in hybrid vehicle repair does not appear to be desirable. Addition of individual courses in hybrid vehicle principles to existing auto mechanic programs does appear desirable. This example indicates the value of analyzing emerging technologies, even if they are not well suited for current College programs, because the analyses do provide information and insights that can assist in effective curricula development.

Identification and Selection Processes

Although the emerging technology identification and selection process used in this project resulted in four useful analyses, the processes can, undoubtedly, be improved. For example, there are techniques that could be used to expand the initial list of technologies for analysis, perhaps by increasing the scope of people offering suggestions to include groups such as investors, entrepreneurs, new business owners, and lawyers. A more formal procedure for technology selection would also be of value.

Scope of Analyses

The four analyses described in this report were of considerably smaller scope than those conducted previously, e.g., the nanotechnology, fuel cell, homeland security, gaming, and M2M wireless analyses. Although these analyses did not cover the various factors involved in the depth of the earlier reports, there appears to be a consensus that the shorter reports provide sufficient information and insight to meet the needs of College deans and other education officials. The reduced scope decreases the time and effort required to conduct the analyses, permits earlier distribution of results, and results in more careful focus on the most important considerations. These factors argue for the continuation of analyses of this type.

Changing Selection Criteria

A key criterion for technology selection for PET projects has been that they be "emerging technologies." Perhaps, it would be useful to expand the criterion to include analysis of other types of technologies, e.g., existing technologies that are experiencing significant changes, technologies that have appeared to be obsolete or obsolescent but that may be reemerging, or technologies that are attracting new markets.

Analyses Updating

Previously, a total of nine analyses have been completed using the PET process. By definition, the technologies that have been considered are volatile and subject to rapid change. Important advances in nanotechnology are occurring daily. However, the nanotechnology and fuel cell forecasts conducted by TSTC and TFI are already more than two years old. Because of the rapid changes taking place in areas previously analyzed, a process for routinely updating reports would be highly desirable.

Technology Grouping

To date, all of the conducted analyses have focused on a single technology. In today's complex world, advances in a single technology almost always impact and are impacted by other technologies. Because of this, it would appear desirable that at least one analysis in the future focus on a nest of related technologies to better understand the relationships between different technologies. An understanding of these symbiotic relationships would assist the Colleges in planning more comprehensive instructional programs.

Summary

Feedback from the Colleges, the CCD, and the THECB has indicated that the forecasts and analyses conducted under the PET process have been both valuable and of high quality. This feedback, together with the lessons learned by TSTC, TFI, and IC^2, has contributed to improvements in the process, and improvements will, undoubtedly, continue. From an overall standpoint, however, the program has been quite successful and deserves continuation.

A Appendix: Emerging Technologies Surveys

To assist in the identification of emerging technologies that might be considered for analysis, a series of surveys was conducted by TSTC. Three groups with particular insights in emerging technologies were included in these surveys:

- Texas Association of College Technical Educators (TACTE).
- Texas Administrators of Continuing Education (TACE).
- Members of the technical and business community, both within and outside of the State, that had registered with TSTC's Program for Emerging Technology (PET) Website for previously published forecasts.

TACE and TACTE survey respondents were asked to:

- Identify emerging technology areas that they believed would require and support a growing workforce of skilled technicians.
- Identify companies and/or government organizations that were most likely to employ technicians in the identified area.
- Identify the knowledge and skills required for technicians in the area.
- Identify programs or courses that their Colleges currently offer that are closely related to the emerging technology.

In addition to these items, PET respondents were asked to:

- Identify the markets or industries that would be impacted by the emerging technology area they identified.
- If possible, provide an estimate of the number of technicians that would be required to meet workforce demands in the area over the next three to five years.

B Appendix: References

Listed below are references used during the conduct of the analyses described in this report.

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C Appendix: Experts Interview

In the conduct of the analyses described in this report, interviews were conducted with the following experts.

Advanced Digital Manufacturing

- *Jerry Franklin* (ADM Lab Manager, Danville Regional Center for Applied Technology & Training) provided information about the center's efforts to support the development of the ADM industry in the Danville, Virginia area by creating strategic alignments between the community college and regional manufacturers. Mr. Franklin also provided information on employment opportunities in ADM for two-year college graduates.
- *Elaine Hunt* (Former Director, Now Defunct Clemson University Laboratory to Advance Industrial Prototyping) provided information about the laboratory's efforts in the past to support the development of the ADM industry. Ms. Hunt also provided information on the survey of ADM employment positions and salaries that she formerly maintained as part of her duties at the lab. The Lab has been disbanded.
- *Larry Liles* (Associate Dean, Enterprise Systems, Texas State Technical College Marshall) provided information about the advanced digital manufacturing program at TSTC Marshall. Mr. Liles also provided information about employers in the state that use ADM equipment.
- *Dr. Timothy Stokes* (Vice President and Dean of Student Learning, Texas State Technical College Marshall) provided insight into employment opportunities for graduates of ADM programs.

Hybrid Vehicles

- *Joseph Casaletta* (Training Department, Department of General Services, City of Los Angeles) provided information about the City of Los Angeles' experience with hybrid vehicles and hybrid vehicle training.
- *John Frala* (Curriculum Developer/Instructor, Rio Hondo Community College) provided information about job requirements and opportunities for hybrid technicians with two-year degrees. Mr. Frala also provided information about Rio Hondo's hybrid training programs with Los Angeles and his efforts to develop hybrid training curriculum for Honda.
- *Toby Gustavus* (Instructor, Automotive Technology Department, Texas State Technical College Waco) provided information about TSTC's plans to introduce introductory hybrid training into their Toyota Technical Education (T-TEN) Program.
- *Tom Hudson* (Curriculum Director, National Alternative Fuels Training Consortium) provided valuable information about NAFTC's efforts to develop training curriculum for hybrid vehicles.
- *Richard Humanic* (Alternative Fuel Vehicles, Department of General Services, City of Los Angeles) provided information about the City of Los Angeles' experience with hybrid vehicles and the city's efforts to develop advanced hybrid training programs for fleet mechanics.

MEMS

- *Robert Hall* (MEMS Technologies Director, Albuquerque Technical Vocational Institute) provided insight into TVI's MEMS curriculum efforts. Mr. Hall also provided information about possible job profiles for MEMS technicians and expected starting salaries.
- *Brad Nelson* (Vice President of Manufacturing, TeraVicta) provided information on the KSAs required of MEMS technicians with two-year college backgrounds.
- *Dr. Gerhard Salinger* (Program Director, National Science Foundation, Advanced Technological Education program) provided information about the creation of the MEMS ATE center at Albuquerque Technical Vocational Institute (TVI).
- *John Simcik* (Instructor, Laser Electro-optics Technology Department, Texas State Technical College Waco) provided information about developments in the area of MEMS.
- *Kevin Speller* (Senior Engineer, Market & Applications Development, Applied MEMS, Inc.) provided information about various MEMS fabrication techniques. Mr. Speller also provided valuable insight into the role of various technicians in the MEMS fabrication process.
- *John Wexler* (Program Manager, Office of Science and Technology, State of New Mexico) provided information about New Mexico's efforts to support the development of a MEMS industry by creating strategic alignments between Sandia National Laboratories, the University of New Mexico, TVI, and the 40+ MEMS companies based in Albuquerque.

Computer Forensics

- *Mike Denn* (Department Chairman, Network Security Technology, Texas State Technical College Waco) provided information about computer forensics software tools and the demand for computer forensics expertise at law enforcement agencies in the State.
- *Gary Kessler* (Program Director, Computer and Digital Forensics, Champlain College) provided information on the KSAs required of computer forensics technicians. Mr. Kessler also provided information about expected entry level salaries for these graduates and the lack of industry-wide certification standards. Champlain has been selected by the National Institute of Justice to develop a model curriculum for undergraduate electronic crime investigation.
- *Dr. Greg White* (Technical Director, Center for Information Assurance & Security, University of Texas at San Antonio) provided information about job requirements and opportunities for computer forensics technicians with two-year degrees in the public and private sectors.
- *Ira Wilsker* (Director, Management Development Program, Lamar Institute of Technology and Police Officer, City of Beaumont) provided valuable information about the Cyber Security/Computer Forensics Project headed by Del Mar. Mr. Wilsker also provided valuable information about the demand for computer forensics technicians at local law enforcement agencies and the skill sets required of such employees.

D Appendix: Emerging Technologies Considered

Ranking	Technology	Classification
✓	Fuel Cells	Complete
✓	Gaming	Complete
✓	Homeland Security	Complete
✓	Nanotechnology	Complete
✓	Advanced Digital Manufacturing	Complete
✓	Computer Forensics	Complete
✓	Hybrid Automobiles	Complete
✓	MEMS	Complete
✓	M2M Wireless	Full Report In Progress, Strong Potential
✰✰✰✰	Bioinformatics	Strong Potential
✰✰✰✰	Genomics	Strong Potential
✰✰✰✰✓	RFID	Strong Potential, Addressed in Wireless
✰✰✰	Advanced Logistics	Under Development, Related to Wireless
✰✰✰✓	Biometrics	Strong Potential, Addressed in Homeland
✰✰✰	Criminal Forensics	Possible Topic
✰✰	Alternative Fuels (see hybrid, fuel cell, solar, wind, etc.)	Established with Some Potential
✰✰	Biophotonics	Some Potential
✰✰	Deepwater Drilling/Process Engineering	Established with Some Potential
✰✰✓	Digital Datacasting	Some Potential, Addressed in Wireless
✰✰	Digital Television	Some Potential
✰✰	e-Health	Established with Some Potential
✰✰✓	Home Technology Integration	Some Potential, Relationships to Wireless
✰✰	Pharmacogenomics	Some Potential, Related to Genomics
✰✰	Polysomnography	Some Potential
✰✰✓	Portable Wireless Devices	Some Potential, Addressed in Wireless
✰✰	Video Lottery Systems	Some Potential
✰✰	Wind Energy	Some Potential
✰	Composites	Somewhat Established Topic
✰	Field Bus	Somewhat Established Topic
✰	Gerontology	Limited Potential
✰	Grid Computing	Limited Potential
✰	Histology	Limited Potential
✰	Metallurgy	Limited Potential
✰	Vehicle Collision Avoidance	Limited Potential
✗	Biomedical	Well Established
✗	Biotechnology	Well Established
✗	Cardiography	Well Established
✗	New Environmental/Remediation	Somewhat Established
✗	Public Use WLANS	Well Established, Addressed in Wireless
✗	Solar Energy	Well Established

Legend

✓	Indicates that forecast/analysis has already been conducted
✰	Number of stars (4 – 1) indicates relative attractiveness for colleges
✗	Indicates that sufficient curriculum is already established for this technology

E Appendix: Technology Index and Classification

Advanced Digital Manufacturing

Complete

Rapid prototyping has evolved into a new industry called advanced digital manufacturing. RPT programs commonly exist around the country for non-destructive testing and prototype construction, but now actual finished products can be made with similar additive and subtractive processes. Invisalign is a popular example. Hearing aids, car parts, and a tremendous variety of customized end products are becoming much more affordable to produce as equipment costs in this sector reach more sustainable levels.

Advanced Logistics

Under Development, Related to Wireless

The time-sensitive logistics industry will employ new technologies such as radio frequency ID tags and global positioning systems. These technologies will enable shipping and freight forwarders, delivery companies, cartage agents, and couriers to process and transmit shipping information electronically in real time. This information includes invoices, purchase orders, bills of lading, and other documentation that provides robust track-and-trace capabilities. This topic was not chosen for further study because THECB has already funded a project focused on upgrading existing curriculum and development of new courses for Logistics/GPS associate's degrees and workforce certificates. This group should be able to adequately address any new technical developments in this area.

Alternative Fuels

Established with Some New Potential

These technologies use alternative energy sources such as wind and sunlight to generate power. Technologies employed in this area include solar cells and windmills. Although the potential of these technologies to reduce the nation's dependence on traditional sources of energy is promising, the tangible results achieved thus far have been quite small. For example, the installed windmill base in the state had a power generating capacity of 1103 megawatts in 2002 (Vitus Energy Research Associate's degree, 2003). In contrast, the State Energy Conservation Office reports that about 87,000 mW of electricity is currently generated by the state's electric utilities (SECO, 2002). Unfortunately, power produced by windmills costs twice as much as power generated by electric utilities (Department of Energy, 2002). Solar-generated power is even more costly (five to ten times the cost of utility generated power) (Department of Energy, 2002). Wind and solar sources, by their very nature, are not as available as the combustion fuels used by utilities. Thus, it appears that the demand for technicians in this area will stay extremely low until some significant technological advances are achieved.

Bioinformatics

Strong Potential

According to the Wake Technical Community College Bioinformatics Program Outline, "bioinformatics is the field of biology concerned with computational methods and theories applicable to molecular biology including manipulation of models and datasets" (Wake Technical Community College, 2004). Advances in the life sciences are being fueled by advanced computational modeling and experimentation; therefore, students with training beyond the basics in biology will be in high demand. However, this topic was not chosen for further study because there does not currently appear to be a significant cluster of employers with a demand for two-year graduates with these skills within the state of Texas. If such a demand should develop and the need to develop such programs quickly arises, there are some programs outside of the state, including the one at Wake Technical Community College, that would serve as excellent models.

Biomedical

Well Established

Biometrics

Complete, Some Future Potential

Biometrics is the automated use of physiological or behavioral characteristics to determine or verify identity. Homeland security technologies are driving this industry's growth in applications such as iris, fingerprints, facial, voice, heat signature, and several other physical characteristics. This topic is addressed in detail in the Homeland Security Report, but may warrant future research as the market continues to mature.

Biophotonics

Some Potential

Biophotonics is broadly defined as the use of light to study and manipulate biological objects. In the 1930s, Russian scientist Alexander Gurwitsch discovered that plants weakly emit light, called biophotons. The phenomenon was passed over and forgotten for sometime until German biophycisist Fritz-Albert Popp rediscovered this property of living systems in the 1970s. Biophotonics might have applications in food quality analysis, water quality analysis (i.e., toxins), and disease analysis. This field is still maturing and may warrant future study.

Biotechnology

Well Established

Cardiography

Well Established

Cardiography is a diagnostic procedure that electronically records the activity of the heart using a cardiograph (and producing a cardiogram). However, there are new, rapidly-evolving technologies that directly record heart signals in digital format using solid-state processing and memory devices. The fact that the signals are directly recorded "reduces the amount of bias introduced into the recording process by the mechanical features of tape recording devices and the problems associated with recording data in an analog format, which requires analog-to-digital conversion before analysis" (American Heart Association, 1999). Although innovations in this field are interesting, it is somewhat questionable what their implications for two-year graduates will be. It appears that new training for these devices can be incorporated into existing biomedical equipment programs.

Composites

Established with Limited Potential

Composites are defined as a reinforcing fiber in a resin matrix whose cumulative properties are superior to the individual materials. This market is well established and continues to find new applications in aerospace, sporting equipment, automobiles, construction, and a wide variety of other applications. Composite programs and curriculum have been established at variety of colleges, and initial analysis shows this topic to be already established. However, Texas-specific research may yield useful.

Computer Forensics

Complete

Computer forensics is the science of conducting investigations related to computer crimes and abuse in a manner that is legally sound and reproducible. Using specialized hardware and software tools, computer forensics technicians gather evidence about all kinds of activity including fraud, embezzlement, child pornography, and intellectual property misappropriation. Whether they are employed in the public or private sector, the evidence these technicians produce must be collected in a way that adheres to widely accepted evidentiary procedures and processes. Thus, two-year programs in computer forensics will include courses in both the technical (computer systems and networks) and legal (criminal justice and evidence) aspects of investigations. The demand for appropriately trained and qualified forensics technicians is quite good at all levels in law enforcement, government, and the private sector. This demand extends across the entire state, in fact, the entire nation. In the near future, salaries for graduates of two-year computer forensic programs will be quite good.

Criminal Forensics

Good Potential

Criminal forensics is more generally related to law enforcement, crime laboratories, crime scene investigations, and forensic anthropology. Initial analysis reveals that some colleges in the nation do offer two-year awards on this specific topic, and additional Texas-specific analysis may be warranted.

Deepwater Drilling/Process Engineering

Established with Some Potential

Several petroleum companies have scheduled deepwater drilling projects off the Texas coast, and colleges with existing oil and gas partnerships are actively aware of this future employment opportunity. Process technicians install, repair, and maintain advanced supervisory control and automated data acquisition (SCADA) systems that monitor and operate production devices (valves, pumps, relays, switches, etc.) in process industries. The Center for the Advancement of Process Technologies (CAPT) at Mainland College has determined that "a shortage of process technicians currently exists within the chemical, oil and gas exploration and production, and power generation industries" (CAPT, 2004). This is especially true in the Gulf of Mexico where deepwater oil production "has increased over 50% since 1985 and gas production has increased over 20%" (CAPT, 2004). BP, a major sponsor of CAPT, has indicated that it needs over 200 technicians for its deepwater projects in the Gulf. CAPT has already developed DACUMs in these specialty areas and has excellent relationships with employers in these fields. Thus, further study of this topic is not necessary.

Digital Datacasting

Some Potential, Addressed in Wireless

Digital datacasting is a burgeoning technology that is in pilot phases in several major cities in the nation. Texas PBS stations in Austin, Dallas, Waco, and San Antonio are currently installing this equipment, but real-world applications are still in the early stages of development. Using newly acquired spectrum, these and other affiliate broadcast stations throughout the nation will be capable of broadcasting 19.2 Mb/s of downstream data. Recently, SMPTE approved enhanced compression algorithms that will essentially double this available bandwidth. Applications include municipal emergency services, digital signage, and consumer mobile devices (phones, PDAs, etc.), and it is forecast that this technology will play an integral role in future hybrid networking applications. An initial analysis of this new technology is included in the wireless and M2M report now in progress. See "Digital Television" below for establishing information.

Digital Television

Some Potential

Recent FCC regulations have mandated that broadcast television stations migrate to digital broadcast signals and away from their existing analog signals. Many Texas stations have already made this migration–especially tier 1 and 2 markets. Existing RF engineers and technicians are able to make these migrations, but stations will increasingly require IP and networking skilled technicians due to the packetized nature of these digital signals. This melding of RF and IP knowledge will become increasingly desirable, and existing broadcast engineering and related telecommunications programs should update curriculum accordingly.

e-Health

Established with Some Potential

The use of electronic medical records is becoming increasing popular among hospital administrators (and their insurers) because it can prevent errors, promote the use of standards, improve the efficiency of doctors and nurses, rationalize recordkeeping, and improve patient care. The drive to digitize medical records will increase the employment of technologies such as personal digital assistants, databases and data warehouses, wireless modems and routers, sensors, etc. This area was not chosen for further study, however, because the technologies covered are too broad and there are no specific identifiable technologies or training demands. All of the technologies employed in these e-health systems appear to be adequately addressed by existing programs.

Field Bus

Established with Limited Potential

Fuel Cells

Complete

Gaming

Complete

Genomics

Strong Potential

See "Bioinformatics."

Gerontology

Limited Potential

Gerontology is the study of human growth and development during adulthood. The field includes the physiological and psychological implications of the aging process and its implications for individuals and society. Gerontology technologies would involve the study and use of technology to increase the quality of people's lives as they age. Some examples of such technology include more portable oxygen machines, automatic drug dose regulators, and wireless sensors/communication devices that transmit patient vital signs to the doctor. This area was not chosen because it was considered to be too broad and because existing programs in biomedical equipment, electronics, and communications should be able to address new developments in this area.

New Environmental/Remediation

Somewhat Established

New environmental protection and remediation technologies will come to the forefront as new regulations in this area are developed and enforced. However, it was determined that new advancements could be handled quite well by existing programs in this area. Additionally, the Advanced Technology Environmental Education Center has conducted a series of DACUMs on environmental technology occupations. Therefore, this technology was considered to be a poor choice for further study.

Grid Computing

Limited Potential

Histology

Limited Potential

Histology is the study of biological structures at the microscopic level.

Home Technology Integration

Some Potential, Addressed in Wireless

Homeland Security

Complete

Hybrid Automobiles

Complete

The Department of Energy defines hybrid electric vehicles as "vehicles that combine the internal combustion engine of a conventional vehicle with the battery and electric motor of an electric vehicle, resulting in twice the fuel economy of conventional vehicles" (Department of Energy, 2004). The demand for hybrid vehicles has risen drastically with recent increases in the cost of gasoline because they offer "the extended range and rapid refueling that consumers expect from a conventional vehicle, with a significant portion of the energy and environmental benefits of an electric vehicle." In fact, in a June 10, 2004 *Wall Street Journal* article entitled "Forget Rebates: The Hybrid-Car Markup," Sholnn Freeman points out that there is a nationwide backlog of 22,000 orders for Toyota's Prius hybrid. Closer to home, an Austin dealership indicated that it has to turn away three potential customers for every Prius it sells. Automakers will be releasing new hybrid sport utility vehicles, including the Toyota Highlander, Ford Escape, and Lexus RXV. Thus, the demand for technicians capable of servicing both internal combustion engine and battery/electric motor packages will increase in the very near future.

MEMS

Complete

MEMS is a product design and manufacturing technology that enables the development of electromechanical systems using batch fabrication techniques similar to those used in integrated circuit design. "MEMS integrate mechanical elements, sensors, actuators, and electronics on a silicon substrate using a process technology called microfabrication. This combination of silicon-based microelectronics and micromachining technology allows the system to gather and process information, decide on a course of action, and control the surrounding environment. This, in turn, increases the affordability, functionality, and performance of products using the system. Due to this increase in value, MEMS are expected to drive the development of 'smart products' within the automobile, scientific, consumer goods, defense, and medical industries" (Wave Report, 2001).

Metallurgy

Limited Potential

Nanotechnology

Complete

Pharmacogenomics

Some Potential, Related to Genomics

Polysomnography

Some Potential

A polysomnograph is a medical device that converts electrical impulses (brain waves [EEG], eye movements [EOG], heartbeat [EKG], blood oxygen levels [SpO_2], and respiration) into a graphical representation that represents the "state" of a person's sleep (Kimbro, 2004). In recognition of the fact that sleep is essential to a person's overall wellbeing and health, the popularity of such studies has grown. However, because polysomnograph equipment is very similar to existing biomedical equipment, especially EKGs, it appears that the technicians needed to service the increasing number of installed machines can be adequately trained in existing biomedical equipment programs.

Portable Wireless Devices

Some Potential, Addressed in Wireless

Public Use WLANS

Well Established, Addressed in Wireless

RFID

Strong Potential, Addressed in Wireless

Solar Energy

Well Established

Vehicle Collision Avoidance

Limited Potential

Video Lottery Systems

Some Potential

Wind Energy

Some Potential

Wireless & M2M

Full Report In Progress, Strong Potential

Embedded micro computer networks are typically referred to as "machine-to-machine," "M2M," "pervasive computing," "hidden computing," "invisible computing," and "ubiquitous computing." Invisible, hidden, pervasive, and ubiquitous describe this 9th generation of computing—a world where the complexities of personal computers disappear and virtually all machines are networked into the physical environment. For this report, we chose machine-to-machine (M2M) to describe this technology.

F Appendix: Final Selection Process

In order to identify the final four technologies from the preliminary list of 14, TFI representatives conducted a meeting at Texas State Technical College System Operations in Waco on April 27, 2004 with Michael Bettersworth (Associate Vice Chancellor for Technology Advancement) and Dr. Larry Grulick (Associate Vice Chancellor of Instructional Support and Research). First, the group, relying on research and insight gathered during the preliminary selection process, discussed each technology's technical foundations and economic impact, as well as its career implications for College graduates. The group next rated each of the technologies with respect to four criteria, which are described below.

Rating Instructions

Employment Opportunities for College Graduates

Obviously, one of the most important factors to be considered in evaluating the attractiveness of the various technologies is the opportunity for employment. This evaluation includes the total number of technicians that will be required statewide and how long it will take the projected jobs to materialize. The rating scheme for this factor was based on a one to 10 scale. The following guide was developed to assist in common ratings by individual participants. Interim values, e.g., 5, 6, 8, or 9, were accepted.

10 Over 200 job opportunities will be created in the next two to five years
7 50 to 70 job opportunities will be created in the next two to five years
4 25 to 30 job opportunities will be created in the next two to five years

Economic Impact

Emerging technologies will play a very important role in creating future wealth and economic growth. Thus, another very important factor to be considered in evaluating the attractiveness of the various technologies is the anticipated economic impact of the technology on the State's economy. The rating scheme used for this factor was as follows:

10 The market for this technology will be over $200 million in five years
7 The market for this technology will be $50 to $100 million in five years
4 The market for this technology will be under $25 million in five years

Curriculum Compatibility

The ease with which currently available curricula can be modified and expanded to provide graduates with the knowledge, skills, and abilities (KSAs) required for successful employment within a technology area was also considered. This evaluation included consideration of specialized equipment and qualified faculty requirements. The rating scheme used for this factor was as follows:

10 Programs providing the required KSAs will be quite similar to current programs
7 Programs providing the required KSAs will be rather similar to current programs
4 Programs providing the required KSAs will be moderately similar to current programs

Career Attractiveness

The ability of a technology to provide challenging work and upward career mobility for graduates is important in evaluating its attractiveness to colleges. The rating scheme used for this factor was as follows:

10 Technology presents excellent opportunities for career advancement and lifetime upward mobility

7 Technology presents excellent opportunities for career advancement and upward mobility in the next ten years

4 Technology presents excellent opportunities for career advancement and upward mobility in the next five years

The Ranking Process

The rating of each participant was recorded. For each technology in each individual criteria area, an average rating was calculated by taking the mean of all participant ratings. This average criteria rating was then multiplied by the criteria's weighting factor in order to adjust its importance in calculating the final ranking. A weighting factor of five was applied to the employment opportunities and economic impact criteria. A weight of four was applied to current curriculum compatibility. Due to the uncertainty of predicting long-term career attractiveness, a factor of three was applied to that criterion. The four weighted criteria ratings were then totaled, and a mean was calculated to develop a total composite score. The final composite score for each technology is presented in the following table.

Although process technologies and offshore drilling technologies received high composite scores, it was discovered during the meeting that the College of the Mainland's NSF-funded Center for the Advancement of Process Technologies has already developed DACUMs in these specialty areas. In fact, two deepwater offshore production/process courses—Oil and Gas Production I and II—have been developed with employers (e.g., British Petroleum) that have guaranteed employment to students who complete the courses. It was also judged that new hospital equipment and new cardiology-related technologies are included in a number of programs now being offered by Colleges throughout the State.

Based on these considerations, the four technologies chosen for additional study were *digital manufacturing*, *hybrid vehicles*, *MEMS*, and *computer forensics*.

Composite Technology Scores

Technology	Final Composite Score
New process technologies, including supervisory control and automated data acquisition (SCADA)	39
Digital manufacturing (rapid prototyping)	37.38
New hospital equipment technologies (e-Health, etc.)	36.44
New cardiology-related technologies	35.44
Deepwater drilling technologies	34.5
Hybrid (electric-gas) automobiles	32.88
New environmental protection/remediation technologies	32.44
Advanced logistics technologies (RFID, GPS/GIS, etc.)	30.94
Micro-electromechanical systems	30.38
Computer forensics	30.38
Gerontology technologies	29.5
Alternative energy technologies (gas, solar, wind, etc.)	28.94
Bioinformatics	27.25
Sleep inducement technologies (polysomnography)	23.19

G Appendix: Vendors, Manufacturers & Associations

Advanced Digital Manufacturing

Company	Technology	Model Name	Build Volume (inches)	Material
3D Systems	SL	Viper SLA	10 x 10 x 10	Epoxy
	SLS	Vanguard	15 x 13 x 18	Polyamide, elastomer, polystyrene, stainless steel, other polymers
Envision Tec	Bioplotting	Bioplotter	8 x 8 x 5	Biomaterials
ExtrudeHone (ProMetal)	3D	R2	8 x 8 x 6	Stainless steel, other metals
		R10	40 x 20 x 10	Stainless steel, other metals
Solidica	Ultrasonic Welding	Formation	24 x 36 x 10	Aluminum alloy
Stratasys	SDM	Prodigy	8 x 8 x 12	ABS, WaterWorks

Source: Wohlers Report, 2004

Industry Groups

Organization Wohlers Associates
Website http://wohlersassociates.com
Description. Wohlers Associates is the leading analyst of the ADM industry. The company produces an annual report which describes international progress in advanced digital manufacturing, rapid prototyping and tooling. The latest report, Wohlers Report 2004, provides information on all aspects of the ADM industry, including business, product, market, technology, research, and application.

Organization Global Alliance of Rapid Prototyping Associations
Website http://www.garpa.org
Description. The Global Alliance of Rapid Prototyping Associations (GARPA) encourages the transfer of information about rapid prototyping and digital manufacturing across industry and national boundaries. A number of groups and associations from countries including Australia, Canada, China, Denmark, Finland, France, Germany, Hong Kong, Ireland, Italy, Japan, Korea, the Netherlands, South Africa, Sweden, the United Kingdom, and the United States are members.

Organization Society of Manufacturing Engineers (SME)
Website www.sme.org/rtam
Description. The Rapid Technologies and Additive Manufacturing Technical Community (RTAM) of the Society of Manufacturing Engineers addresses issues of interest to the rapid prototyping and manufacturing community. The group hosts an annual Rapid Prototyping & Manufacturing Conference. The latest conference was held in Dearborn, Michigan on May 11, 2004.

Hybrid Vehicles

See Hybrid Production Section of Chapter 3.

MEMS

Texas Manufacturers

Company Name Texas Instruments
Contact Dr. Larry J. Hornbeck, TI Fellow DLP™Products
Contact Info l-hornbeck@ti.com
Website http://www.dlp.com
Application Areas Micro-mirrors (digital light processors), accelerometers, optical switches, RF switches

Company Name Applied MEMS
Contact Kevin Speller, Senior Engineer, Market and Applications Development
Contact Info kspeller@appliedmems.com
Website http://www.appliedmems.com
Application Areas Micro-g accelerometers for seismic oil and gas field exploration

Company Name TeraVicta
Contact Brad Nelson, Vice President of Manufacturing
Contact Info bnelson@teravicta.com
Website http://www.teravicta.com
Application Areas RF switches for electronics products like cell phones

Company Name Zyvex
Contact George Skidmore, Director of Research
Contact Info gskidmore@zyvex.com
Website http://www.zyvex.com
Application Areas MEMS production equipment

Company Name Motorola (Freescale Semiconductor)
Contact Bishnu P. Gogo, Engineer, Sensor Products Division
Contact Info Bishnu.Gogoi@freescale.com
Website www.motorola.com/mediacenter/news/
Application Areas Inertial sensors

Company Name Lockheed (Sandia National Laboratories)
Contact Mahesh Kumar, Director of Research and Technology for Lockheed Martin Maritime Systems and Sensors
Website http://mems.sandia.gov/scripts/index.asp
Application Areas RF switches

Company Name Raytheon
Contact Brandon Pillans, Technical Lead, RF MEMS Group, Raytheon-Dallas
Contact Info pillans@ieee.org
Website http://www.raytheon.com/press/2000/jan/mems.html
Application Areas RF switches

Company Name Boeing
Contact Dietrich Riemer, RF MEMS Engineer
Contact Info dietrich.e.riemer@boeing.com
Website http://www.quid.com/ip/ipcs1.htm
Application Areas RF switches, accelerometers

Company Name Northrop-Grumman
Contact David Lewis, MEMS Engineer
Contact Info david.lewis@ngc.com
Website www.st.northropgrumman.com/capabilities/
Application Areas Optical MEMS, micropropulsion

Industry Groups

Organization Southwest Center for Microsystems Education
Website http://www.tvi.cc.nm.us/AdvancedManufacturingCareers/

Description. The goal of the Southwest Center for Microsystems Education (SCME) is to provide the MEMS industry with workforce development models, materials, and professional development opportunities for developing MEMS industrial centers (clusters). The SCME will assist the MEMS industry in establishing national skill standards for technicians and creating a skilled MEMS workforce. The Center is aligned with Sandia, the University of New Mexico, and the Albuquerque Technical Vocational Institute. TVI, through SCME, will make the results of its DACUM and curriculum development efforts available to colleges nationwide.

Organization MEMS Industry Group
Website www.memsindustrygroup.org

Description. This is a trade organization comprised of North American MEMS designers, manufacturers, and integrators. Member companies include Texas Instruments and Northrop Grumman. Membership in the organization has doubled since 2002 to include 36 companies.

Organization Micro and Nanotechnology Commercialization Education Foundation
Website http://www.mancef.org/

Description. This is a worldwide organization that "globally enables the creation, exchange, and dissemination of knowledge vital to people, organizations, and governments interested in the commercialization of miniaturization technologies." MANCEF publishes a number of papers that deal with the economic impact of MEMS and semiconductor technologies.

Organization Texas Area MEMS Workshop Series
Website http://arri.uta.edu/acs/jmireles/TEXMEMSV_03/

Description. TEXMEMS workshops are one-day meetings that encourage interaction between industrial, academic, and government engineers and scientists. The role of the workshops is to encourage interaction that drives MEMS-related activities at different levels: design, simulation, fabrication, and applications. Representatives from Texas Instruments, Applied MEMS, MANCEF, DARPA, TeraVicta, Raytheon, and others have presented at the conferences, which have been conducted since 1999.

Computer Forensics

Employers–Private

Company Swailes & Company, Inc.
Contact Ted Swailes
Contact Info ted.swailes@swailes.com
Website http://www.swailes.com

Description. Swailes & Company performs computer forensics and data recovery services mostly for law firms or corporate clients.

Company Southwest Data Recovery Services
Contact N/A
Contact Info hr@swstars.com
Website http://www.swstars.com

Description. Southwest Stars (San Antonio) specializes in data recovery from a wide variety of operating systems, platforms, and storage media.

Company Texas Data Recovery
Contact N/A
Contact Info (866) 448-1605
Website http://www.texas-datarecovery.com/info/
Description. San Antonio-based Texas Data Recovery specializes in data recovery and restoration.

Company Databank Services
Contact Wes Goodwin
Contact Info careers@databankservices.com
Website http://www.databankservices.com/
Description. Austin-based company that specializes in data recovery, media exchange, data conversion, and electronic media forensic evidence recovery services.

Company Flashback Data
Contact N/A
Contact Info info@flashbackdata.com
Website http://www.flashbackdata.com
Description. Austin-based company that specializes in computer forensics investigations and data recovery and restoration.

Company CyberEvidence, Inc.
Contact Paul Brown
Contact Info incident @ cyberevidence.com
Website http://www.cyberevidence.com
Description. Houston (The Woodlands) based company that specializes in computer forensics training, computer forensics investigation, and forensic data recovery.

Company Data Recovery Services
Contact N/A
Contact Info helpdesk@datarecovery.net
Website http://www.datarecovery.net/
Description. Data Recovery Services is an international company with a branch in Dallas that specializes in data recovery and computer forensics investigations.

Employers–Public

Organization Secret Service, Electronic Crimes Task Force
Contact Derrick Day
Contact Info ddday@usss.treas.gov
Website http://www.secretservice.gov/press/pub1903.pdf
Description. The Secret Service performs computer forensics activities for small law enforcement agencies in the State that lack the resources to conduct such investigations.

Organization Waco Police Department, Computer Crimes Unit
Contact Chris Kingrey
Contact Info chrisk@ci.waco.tx.us
Website http://www.waco-texas.com/city_depts/police/computercrimes.htm
Description. The Computer Crimes Division of the Waco Police Department has a computer forensics laboratory that is equipped to deal with computer crime in the Waco area.

Organization Austin Police Department, High Tech Unit
Phone 512-974-8600
Contact Info high.tech@ci.austin.tx.us
Website http://www.ci.austin.tx.us/police/htech.htm

Description. The Austin Police Department (APD) High Tech Crime Unit, which consists of five police officers, was created as a partnership between APD and Austin's high-tech industry on February 1, 1995. The group, which is modeled after a similar unit in San Jose, California, focuses on issues such as computer hacking and theft of intellectual property. Law enforcement agencies that work with the unit include the FBI, IRS Criminal Investigations Division, U.S. Customs, the Secret Service, U.S. Attorney's Office, Texas Attorney General's Office Internet Bureau, Texas Department of Public Safety, and the Travis County District Attorney's Office.

Industry Groups

Organization High Technology Crime Investigators Association
Website http://htcia.org

Description. The mission of the HTCIA is to "encourage, promote, aid, and effect the voluntary interchange of data, information, experience, ideas, and knowledge about methods, processes, and techniques relating to investigations and security in advanced technologies among its membership." A branch of the organization is located in Austin.

Organization North Texas Regional Cyber Forensics Laboratory
Website http://www.ntrcfl.org/

Description. "In January of 2000, to address the soaring backlog of computer evidence processing, the Dallas Division of the Federal Bureau of Investigation and the United States Attorney for the Northern District of Texas began seeding a concept to include federal, state, and local computer forensic examiners to address the needs of all law enforcement in the North Texas region. The premise was simple. To provide no-cost examination of computer and digital evidence to all law enforcement agencies throughout the 137 counties that comprise the North Texas region. Some of these agencies had no where else to turn and little resources to meet the growing demands."

Organization Digital Forensics and Emergency Preparedness Institute
Website http://www.utdallas.edu/research/dfepi/

Description. The Digital Forensics and Emergency Preparedness Institute conducts research in the areas of digital forensics, network security, and emergency preparedness. The Institute, which has been designated as a Center of Excellence in Information Assurance Education by the National Security Agency, is located in the Erik Jonsson School of Engineering and Computer Science on the campus of the University of Texas at Dallas.

H Appendix: Current Programs

Listed below are courses now being taught in various community and technical colleges, both in Texas and in other states.

Advanced Digital Manufacturing

College	Texas State Technical College Marshall
Contact	Larry Liles, Program Chair, Computer Integrated Manufacturing Technology
Email	larry.liles@marshall.tstc.edu
Phone	(903) 923-3316
Website	www.marshall.tstc.edu/students/pdf/marshall_catalog_03_05.pdf
Course Description	ADM Specific Courses

INMT 1371–Introduction to Digital Manufacturing. This is a basic study of various digital manufacturing methods including 3D printing technologies, stereolithography, and selective laser sintering. Also included is a survey in advanced metal deformation technologies as well as other additive processes.

INMT *2372–Advanced Digital Manufacturing.* This is a continuation of INMT 1371 with advanced studies in digital manufacturing methods including 3D printing, stereolithography, and selective laser sintering. Also included is a survey of advanced metal deformation technologies, as well as other additive manufacturing processes. Students in the class actually manufacture a part using an ADM process.

INMT 2373–Design/Prototyping/Manufacturing. Students will work in a team environment to explore a perceived need for a product or the improvement of an existing product in this capstone course. Students will design and produce a prototype of the product, and design a manufacturing process to mass produce the product. The group will present the product to a panel selected by the instructor. The presentation will be conducted as if the group is reporting to a manufacturing firm who has hired the group to develop the product.

College	St. Louis Community College
Contact	Prof. Ashok Agrawal, Chair, Engineering & Technology Department
Email	Aagrawal@stlcc.cc.mo.us
Phone	(314) 595-4535
Website	https://hank.stlcc.edu/docs/200430/catalog8.htm

Course Description

ME 231–Introduction to Rapid Prototyping. This course will examine the various rapid prototyping processes such as stereolithography, selective laser sintering, fused deposition modeling, and laminated object modeling. Laboratory activities will involve hands-on practice orienting, slicing, and editing solid model files in order to generate 3D SLA and FDM physical models.

College	Pueblo Community College
Contact	Jerry Christie, Department Chair
Email	jerry.christie@pueblocc.edu
Phone	(719) 549-3360
Website	http://www.pueblocc.edu/dept/ent.htm#Rapid%20Production %20Development

Course Description

ENT 256–Rapid Product Development. This course enables the student to develop 3D solid models for prototype products using CAD technology. It covers various types of prototyping including stereolithography, selective laser sintering, laminated object manufacturing, and CNC.

College	Delta College (University Center, Michigan)
Contact	Carolyn Sandford, Chair Science Division
Email	clsanfo@alpha.delta.edu
Phone	(517) 686-9249
Website	http://www.delta.edu/course/mda.html

Course Description

MDA 205–Rapid Prototyping and Tooling. This course surveys this emerging time-compression technology and identifies how it is changing the design/manufacturing interface. It covers specific rapid prototyping processes such as stereolithography, selective laser sintering, fused deposition modeling, and laminated object modeling and demonstrates the linkage between manufacturing and rapid tooling processes of core and cavity inserts for moldings and castings.

Hybrid Vehicles

College	Texas State Technical College Waco
Contact	Toby Gustavus, Senior Instructor, Automotive Technology Department
Email	toby.gustavus@tstc.edu
Phone	(254) 867-2260
Website	http://waco.tstc.edu/

Description. TSTC Waco will begin offering introductory training in hybrid vehicles through their existing Toyota Technical Education (T-TEN) Program. The goal of the program is to supply technically proficient apprentice technicians to Toyota and Lexus dealerships. Toyota offers a variety of support and benefits to students in the program including dealer sponsorship, paid dealership co-op opportunities, scholarships and tools, paid ASE certification, the latest educational and instructional course materials, and state-of-the-art equipment and facilities. The program currently offers training on nine Toyota vehicles, and with the addition of a hybrid Prius, that number will rise to 10.

Organization	National Alternative Fuels Training Consortium
Contact	Tom Hudson
Email	tom.Hudson@mail.wvu.edu
Phone	304-293-7882
Website	http://naftp.nrcce.wvu.edu/

Description. The National Alternative Fuels Training Consortium (NAFTC), based at West Virginia University, develops training curriculum for alternative fuel vehicles (electric, propane, natural gas). A number of colleges across the country, including Tarrant Community College in Fort Worth, are members of the consortium. The group at West Virginia develops the curriculum taught at all of the schools. NAFTC is developing two new hybrid vehicles courses that should be ready for public release in late October. The first course is "Electric and Hybrid Vehicles: Technicians Guide," which teaches the fundamentals and technical aspects of electric and hybrid vehicle operation including the difference between series, parallel, and series/parallel hybrid vehicles. The course is the front end to vehicle specific training (e.g., Toyota Prius, etc.). The second course is "Electric and Hybrid Vehicles: Fleet Manager's Guide," which deals with issues that would be of interest to a fleet manager, such as charging and maintenance costs and hybrid performance capabilities.

Organization Advanced Transportation Technologies Initiative
Contact Peter Davis, Director
Email outrchpd@adnc.com
Phone (619) 473-0090
Website http://www.attcolleges.org/index.html
Description. The Advanced Transportation Technologies Initiative is an economic and workforce development initiative of California community and technical colleges. The purpose of the initiative is to maintain California's leadership as an early adopter and user of advanced transportation technologies. The initiative has created 10 ATT centers in California, which provide training in the areas of hybrid and electric vehicles, alternative fuels, and other emerging automotive technologies. Working with employers in California, the ATT centers develop curricula and training programs related to these technologies. The community colleges with electric and hybrid programs are Rio Hondo Community College, Cypress College, Cerritos College, College of the Desert, and Sacramento City College.

College Tarrant Community College
Contact Jeff Parks, Coordinator Applied Automotive Technology
Email Jeffrey.parks@tccd.edu
Phone (817) 515-4785
Website http://www.tccd.edu/programs/dp.asp?dpid=131
Description. Tarrant Community College is a member of the National Alternative Fuels Training Consortium and has access to the organization's hybrid curriculum.

College Cypress College (Orange County, California)
Contact Dick Bettendorf, Automotive Technology Department
Email rbettendorf@cypresscollege.edu
Phone 714-484-7000, ext. 47258
Website http://votech.cypresscollege.edu/~autotech/autotech/
Description. Cypress College offers an Introduction to Hybrid/Electric Vehicles Course (AT 181C). This course is an introductory course in electric and electric/hybrid vehicles used in the transportation industry. Topics include the theory, design, operation, maintenance, and repair of batteries, motors, controllers, chargers, and regenerative braking systems. Technician safety is also covered.

College Rio Hondo Community College
Contact John Frala, Curriculum Developer, Automotive Technology
Email jfrala@riohondo.edu
Phone (562) 692-0921, ext. 3912
Website http://www.riohondo.edu/tech/auto
Description. Rio Hondo is a member of the National Alternative Fuel Training Consortium and also participates in Honda's Professional Automotive Career Training (PACT) program, which is very similar to Toyota's T-TEN program. Rio Hondo was the first U.S. campus to be certified for the program by Honda about 15 years ago. John Frala is responsible for developing Honda's national hybrid training curriculum. The school is also responsible for conducting Honda hybrid fleet technician training for Los Angeles.

Organization City of Los Angeles, Department of General Services
Contact Richard Humanic, Alternative Fuel Vehicles
Email rwhumani@gsd.lacity.org
Phone (213) 485-4962
Website http://www.ci.la.ca.us/
Description. Los Angeles operates 400 hybrid vehicles: 240 are Honda Civics and the other 160 are Toyota Priuses.

MEMS

College Albuquerque Technical Vocational Institute
Contact Robert Hall, Technologies Director, MEMS Program
Email rhall@tvi.edu
Phone 505-224-3340

Course Description. The following descriptions have been taken from the TVI Course Catalogue (http://planet.tvi.edu/catalog/).

MEMS 101–Introduction to MEMS. This course covers the theory, construction methods, terminology, and application of this emerging field. MEMS, micro-machines, and nanotechnology covers devices and systems ranging from DMDs (digital mirror devices) used in Internet and communications switching systems, nano-inductors used in RF systems, to biomedical "lab-on-a-chip" systems that draw samples, via nanopumps, to identify sample components via infrared spectroscopy (30 theory + 45 lab hours per term).

MEMS 220–MEMS Manufacturing Process. This course covers the various construction methods used to manufacture MEMS components and systems. Bulk micro-machining, surface micro-machining processes such as SUMMIT IV, and MUMPS will be covered in detail.

MEMS 221–MEMS Design I. This course introduces MEMS design techniques and standards via MEMS CAD software. Students will design simple MEMS components using industrial and research MEMS software (30 theory + 45 lab hours per term).

MEMS 223–MEMS Design II. This course introduces MEMS design techniques and standards via MEMS CAD software. Students will design MEMS components and systems using industrial MEMS CAD software. Students will also be introduced to MEMS analyst software (30 theory + 45 lab hours per term).

MEMS 225–MEMS Manufacturing Technology Theory. This course introduces micro-electromechanical systems manufacturing including the basics of MEMS materials and devices, MEMS systems, clean room technology, and topics in wafer processing.

MEMS 226L–MEMS Manufacturing Technology Lab. Provides lab course for MEMS 225. Laboratory exercises conducted in a clean room. Students meet twice per week (90 lab hours per term). Course fee: $60.

College Austin Community College
Contact Hector Aguilar, Professor – Electronics (SMT Program)
Email haguilar@austincc.edu
Phone 512- 223-6311

Course Description. The following course descriptions have been taken from the ACC Course Catalogue (http://www2.austincc.edu/edg/descrps.html)

DFTG 1495 Special Topics in Drafting–Micro-Electromechanical Systems. Micro-electromechanical systems (MEMS) are physical structures with dimensions in the micron range built using layers of poly silicon and sacrificial silicon dioxide. The designs are created using leading edge technology and design tools. The student will be introduced to MEMS through the use of AutoCAD as a base with extensions to support 2D and 3D modeling, layer cross-section views, and a design rule verification capability similar to the tools available in the integrated circuit design world.

Computer Forensics

College	College of San Mateo
Contact	Dr. Robert C. Kowerski, Dean of Computer Information and Sciences Department
Email	kowerski@smccd.net
Phone	(650) 574-6327
Course Website	http://smccd.net/csmcis/cf.pdf

College	Tompkins Cortland Community College
Contact	Marsha Powell, Computer Forensics Faculty
Email	powellm@sunytccc.edu
Phone	(607) 844-8211
Course Website	http://www.sunytccc.edu/academic/forensic/main.asp

College	Butler Community College
Contact	Lucy Wright-Scozzaro
Email	lucy.wrightscozzaro@bc3.edu
Phone	(724) 287-8711, ext. 247
Course Website	http://bc3.org/academics/technology/compforensics.htm

College	Champlain College
Contact	Gary Kessler
Email	gary.kessler@champlain.edu
Phone	(802) 865-6460
Course Website	http://digitalforensics.champlain.edu/details_degree_2004.html

Emerging Technology Programs ADM, Hybrids, Computer Forensics, & MEMS
Implications for Community & Technical Colleges in the State of Texas

A highly skilled workforce is essential to the success of Texas companies and the overall competitiveness of the State. By anticipating and proactively responding to future Texas workforce demands, community and technical college curricula can be a constructive force in attracting high-tech companies to the State and ensuring that existing high-tech companies have an appropriately skilled source of employees. This report is designed to provide Texas colleges with timely analyses and actionable insights into four emerging technologies:

- Advanced digital manufacturing,
- Hybrid vehicles,
- Micro-electromechanical systems, and
- Computer forensics.

Through this research, TSTC hopes to facilitate the informed and well-considered development of new, or enhancement of existing, emerging high-tech education and training curricula at Texas colleges. This research was conducted by Technology Futures Inc. and Texas State Technical College System in the third quarter of 2004.

Programs for Emerging Technologies
Programs for Emerging Technologies (PET) identities and forecasts new and emerging technologies and their respective future curriculum development opportunities for Texas community and technical colleges. This program fulfills a legislative mandate enacted by the 76th Regular Session, which charges Texas State Technical College with developing and administering a program to identify, evaluate, and forecast potential emerging technology programs which are likely to have a positive impact on the State's economy (SB1819). Visit **www.forecasting.tstc.edu** for more information and to access this and other PET publications.

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Funded by the Carl D. Perkins Vocational and Technical Education Act of 1998
as administered by the Texas Higher Education Coordinating Board.

www.forecasting.tstc.edu