Core Research Competencies in Oregon

This report was prepared by

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EXECUTIVE SUMMARY

Knowledge-based economic development is a key strategy for building economic growth in a region. It seeks to develop products, jobs, and companies from innovations emerging from research. Planning such development requires a clear understanding of the research strengths in a region, how those strengths cluster and interact (or could interact) between research institutions, and how those research strengths tie in to local industry strengths, whether existing or emerging.

The purpose of this study of Oregon's Core Research Competencies is to identify areas of research strengths. This is the first stage in developing an Oregon Technology Roadmap leading to enhanced economic vitality for Oregon. Development of the Technology Roadmap itself would require a second, thorough analysis of the linkages and gaps between the Oregon Core Research Competencies and Oregon's industries. This could prioritize actions to drive the state's economy toward a future including vibrant industries based on high-wage, innovation-driven jobs.

What are Oregon's Research Strengths?

In this study, the initial phase of an Oregon Technology Roadmap, we have gathered and analyzed data from Oregon's research universities and, to a more limited extent, Oregon's companies. Our goal was to identify Oregon's current research and technology clusters and to determine the potential for commercialized research. For the purposes of this study, research strength was not enough. The objective was to identify (1) a set of core research areas in Oregon with (2) high value commercial opportunities that (3) have potential to be commercialized in Oregon. The project was performed in three phases:

- Phase I: Analysis to identify core research areas
- Phase II: Determination of high value commercial opportunities
- Phase III: Selection of Core Research Competencies and recommendation for ongoing analysis

Strong research areas were identified by analysis of patents, publication and grant information from Oregon research institutions and companies, and interviews with key research and technology leaders in the state.

The following leading research areas were identified:

- **Multi-Scale Materials and Devices** (e.g., devices the size of a sugar cube that power electronic devices for a month)
- **Brain Function and Disease** (e.g., dealing with stroke and brain disorders)
- **Information to Knowledge** (e.g., making sense out of complex data)
- **Analog and Mixed Signal Circuits** (e.g., wireless products and services)
- **Education and Behavior** (e.g., improving learning and managing behavior)
- Agriculture (e.g. new varieties and products)
- Forestry and Sustainable Ecosystems (e.g., improving sustainability)
- Basic Biomedical Research (e.g., understanding the basis of health and disease)

The first five (in bold) were identified as Core Research Competencies that not only exhibit research strength, but also have high value market opportunities with significant potential to be developed by Oregon industry.

Where Could Oregon's Research Strengths Take Its Economy?

A major finding of the study was that (with some notable exceptions) there is a weak connection between the research being performed at Oregon universities and the research and product requirements of Oregon industry. This was very apparent during interviews with industry representatives. The essential driver of high-wage economic growth is innovation - the ability to acquire, adapt and advance knowledge and to move it to commercialization. In Oregon the new knowledge being developed at universities is not, for the most part, being accessed by Oregon industry.

For the universities in Oregon to be significant economic drivers, their future research growth must take into account relevance to Oregon industry. The universities themselves are major employers. They bring in both research funding and talented students from out of state, and train many employees for Oregon industry. But while there is academic excellence in many areas of Oregon universities, they have been modest in generation of new high wage jobs in Oregon. This is an additional significant opportunity for the universities to contribute to Oregon's economic future, and the state should invest strategically to achieve this result.

Of the top five Core Research Competencies in Oregon, two have received some type of recent investment by the state of Oregon. Multi-Scale Materials and

Devices has received an initial influx of funds from the Oregon Legislature, enabling establishment in 2003 of a signature MMD research center, the Oregon Nanoscience and Microtechnologies Institute (ONAMI). The new institute reaches across institutions, and has extended Oregon's research opportunities with $32M in new grant applications in the fourth quarter of 2003 alone. On the commercialization side, ONAMI includes active company involvement (including a $2M building lease donation from Hewlett Packard), has licensed its first new technology, and targets several multi-billion dollar commercial markets for Oregon's existing high tech and medical device industries, as well as for emerging and potential industries in bioremediation, biofuels, and many more. Continued investment in this new signature research institute, particularly through operating funds and researcher recruitment, makes sense as a high priority for knowledge based economic development for Oregon. Development of a Technology Roadmap for MMD would be particularly valuable.

Basic Biomedical Research benefits from the Oregon Legislature support in 2001 of the Oregon Opportunity. This has enhanced growth of the state's life science research base, health care delivery and training opportunities, and company spinouts. Brain Function and Disease and the life-science applications within Information to Knowledge benefit indirectly. The formal organization of Brain Function and Disease as a signature research center could enable specific opportunities to be developed in areas of unmet medical needs in areas such as stroke and obesity, and could focus development on clinical applications of basic research. It also could strengthen the developing intersection between Oregon's life science research strengths and its high tech industry.

In the Information to Knowledge area (concerned with large computing projects), a key opportunity exists to create statewide economic development and job opportunities and facilitate profitable collaborations with private industry. This opportunity involves development of a widely accessible super-computing resource. Existing hardware at multiple institutions could be linked, making excess capacity available to the larger region. Improved computing resources could enhance industry university interaction as well as attract world-class faculty to Oregon in areas of interest to Oregon industry. Of the top 25 fastest growing companies in Oregon 18 are software companies; this industry is crucial to the future economic development of the state.

Focused, relatively small-scale investments in Analog and Mixed Signal Circuits research could significantly enhance the development of related companies in Oregon. These companies particularly could target markets for wireless devices and services that are expected to expand over the next several years. Industry leaders were clear that attraction of a handful, or even one or two, national-stature researchers in key areas could provide valuable industry/research interactions, trained employees, and economic growth opportunities that would be greatly leveraged by local industry into job and new company development.

Education and Behavior is an area of great research productivity in Oregon. Economic development opportunities from this research will grow as the market opportunities continue to evolve. Thoughtful attention to the development of this area would help position it for economic development strength in the future.

Agriculture and Forestry and Sustainable Ecosystems likewise are areas of research strength in Oregon. Their focus has been on sustaining existing strong industries and jobs. Enhanced focus on the opportunities for new job development from commercializable research could be a way of continuing to link and strengthen these research areas and their mature industries in Oregon, adding innovation to that maturity.

Basic Biomedical Research has significant breadth, but no single cluster from a market perspective. Its intersections with market opportunities addressed by Oregon industry have been included in several of the top five Core Research Competencies – Multi-Scale Materials and Devices, Brain Function and Disease, and Information to Knowledge.

This study lays the groundwork for an Oregon Technology Roadmap that could identify and prioritize the path between Oregon's Core Research Competencies and its industry - both the industry of today and the increasingly vibrant industry Oregon could enjoy in the future.

INTRODUCTION

This project was designed to gather and analyze existing data from Oregon's research institutions to identify Oregon's current research and technology clusters and to determine the potential for commercialized research. The objective was to identify a set of core research areas in Oregon that could be commercialized in the state. In parallel, other efforts are moving forward in Oregon examining economic development from different perspectives, such as the Oregon Business Plan and the Innovation Network "hot team" approach to coalescing industry clusters in the state. It is interesting to note the clear areas of overlapping opportunity identified by these parallel efforts. The acknowledgement of other approaches also serves to point out the specific focus of this project, which is to assess the research base in Oregon, identify its strengths, project commercial opportunities, and lay the groundwork for developing a Technology Roadmap that can identify and prioritize the opportunities for economic development in based on the strengths of Oregon's research.

The project was performed in three phases:

- Phase I: Analysis to identify core research areas
- Phase II: Determination of high value commercial opportunities
- Phase III: Selection of core research areas and recommendation for ongoing analysis

Phase I involved data analysis to identify core research areas in two groups: technology clusters represented by intellectual property (patents) and industry collaborations, and research clusters as evidenced by high levels of grant funding and publications. Quantitative analysis of patents, publication and grant information from Oregon companies and institutions identified the following technology and research clusters:

Technology Clusters:

- ***Semiconductors and electronics*** – Oregon arguably is number one in manufacturing and advanced process R&D in the US.
- ***Computer peripherals for printing and imaging*** – Oregon leads the world in fundamental inkjet technology and nearby Clark County, Washington leads the world in desktop inkjet printer mechanisms.
- ***Measurement, control and semiconductor process equipment*** – Much of this group overlaps the first cluster; other portions of this group consist of technology that is becoming out-dated.
- ***Software for Electronic Design Automation, imaging and digital rights management*** – Oregon has strengths in these software niches and many rapidly growing software companies.

Research Clusters:

- ***Functional Neuroscience*** – This research studies cellular, developmental and functional aspects of the nervous system and is concentrated at OHSU, UO and at a few small companies.
- ***Materials Science*** – In addition to the expertise found in semiconductor companies there is a significant research effort in materials science at UO and OSU.
- ***Behavior and Decision-making*** – This research area addresses behavior associated with addiction and decision-making. Expertise is located at UO, ORI (Oregon Research Institute), OHSU, OSLC (Oregon Social Learning Center) and several small companies that received SBIR grants.
- ***Teaching, Assessment and Intervention*** – This research area is very strong at UO, which is rated number one in the nation in terms of productivity of research faculty and number four in total competitive funding.
- ***Oceanography*** – The field of computational modeling of oceans and waves is dominated by OSU and is well funded. The graduate research program in oceanography is rated fifth in the nation.
- ***Agriculture*** - Agriculture is important to Oregon's economy and agricultural research is continuing to grow.
- ***Forestry and Ecosystems*** –OSU has a national reputation. The Ecological Society of America determined OSU to be the best in the nation in the field of forest ecology.

The objective of **Phase II** of the project was to identify high value commercial opportunities linked to the core technology and research areas identified in Phase I. This involved further analysis of the Phase I data, market assessment, and interviews with key research and technology leaders in the state. In the Phase II study we re-organized some of the data and found different ways of connecting research and industry. This enabled us to define four research clusters with strong Oregon commercialization opportunities, along with three more modest opportunities. These were:

Commercial Opportunities:

- Multi-Scale Materials and Devices
- Brain Function and Disease
- Information to Knowledge
- Analog and Mixed Signal Circuits
- Education and Behavior
- Agriculture
- Forestry and Sustainable Ecosystems

In **Phase III** of the study the results from Phases I and II were combined to select the five top ***Core Research Competencies***, which are the first five listed above. Each of the five top Core Research Competencies is described, identifying the strengths and weaknesses relating to research capacity, intellectual property, market and growth potential and competitive differentiation or weaknesses. The line of site to Oregon industry is indicated. In addition, there is a limited analysis of Agriculture and Forestry to indicate relative strengths in these research competencies that relate to strong and mature industries in Oregon, and discussion of the many healthcare applications in basic biomedical research.

Also in Phase III, a mechanism is outlined to establish ongoing capacity to gather research information in a manner suitable for data analysis to enable the assessment of potential opportunities on a regular basis. In addition, specific opportunities are identified that could fit within the priorities of the Oregon Technology Roadmap.

Research at Oregon's universities is being driven almost entirely by grants from various federal agencies, NIH being the largest at $232 million in 2002. Industry sponsored research occurs at a very low level in Oregon. In 2000, according to a report by AAAS, only OHSU was ranked in the top 100 research institutions for industry-sponsored research funding. During that year, Oregon universities as a group received only $15 million research funding from industry.

The strongest link between university research and industry was found in the Multi-Scale Materials and Devices area where reasonably strong and growing collaborations among institutions and with Oregon industry and entrepreneurs are found. The establishment of the MMD institute will expand these collaborations. At a somewhat lower level we found significant Oregon and national industry support of university research in the Analog and Mixed Signal Circuits area.

The body of this report analyzes each of the five top Core Research Competencies in detail and highlights three additional areas. The detailed data upon which the analyses are based can be found in the appendices.

MULTI-SCALE MATERIALS and DEVICES

The National Science Foundation has recently estimated that the market for nanotechnology will reach $1Trillion sometime between 2012 and 2015. Of this total, semiconductors/nanoelectronics will represent 35-45%. NSF's projection, and the recent decision for the U.S. to embark on the largest federal R&D program (nanotechnology) since Apollo, is a dramatic illustration of the widely held belief that molecular technology at the intersection of biology, materials, and nanometer-scale structures will bring major changes to virtually every economic sector. In their highly regarded 2003 book, It's Alive (Crown Business), Cambridge, MA authors Christopher Meyer and Stan Davis persuasively argue that this next step (after microelectronics/internet) in technology will bring in a new "economic life cycle" comparable in impact and duration to the agricultural, industrial, and information ages. As before, the impacts will not be limited to science and commerce, but will alter the structure and behavior of organizations and society itself. Every region, including Oregon, needs to carefully consider its economic development opportunities in this coming revolution.

Nanotechnology has been defined as:

"Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1 - 100 nanometer range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size. The novel and differentiating properties and functions are developed at a critical length scale of matter typically under 100 nm. Nanotechnology research and development includes manipulation under control of the nanoscale structures and their integration into larger material components, systems and architectures. Within these larger scale assemblies, the control and construction of their structures and components remains at the nanometer scale. In some particular cases, the critical length scale for novel properties and phenomena may be under 1 nm (e.g., manipulation of atoms at ~0.1 nm) or be larger than 100 nm (e.g., nanoparticle reinforced polymers have the unique feature at ~ 200-300 nm as a function of the local bridges or bonds between the nano particles and the polymer)."

> National Science and Technology Council subcommittee for Nanoscale Science, Engineering and Technology (2000)

Nanotechnology thus is too vast to be thought of as a single opportunity, and successful regions will be ones that identify the niches in which they can lead. In the case of Oregon, the "Silicon Forest" concentration of world-leading semiconductor and MEMS industries coupled with some niche, world-class, but still relatively small university research efforts point to the field of *Multi-scale*

Materials and Devices (MMD) as Oregon's most promising and strategic research-based commercial opportunity in the next two decades.

"In considering investments in the areas outlined below [nanomaterials, interface of nanoscale technology with biology, integration of nanosystems, infrastructure and instrumentation], it is important that NSET base its decisions on the promise of the science involved, and not on rigid definitions of the nanoscale. For example, microscale technology will clearly be critical to the realization of nanoscale science, so NSET must think broadly when defining NNI mission and portfolio investments."

> National Research Council Review of the National Nanotechnology Initiative, Section 4 "Important Areas for Investment" (June 2002)

"interdisciplinary nanotechnology research centers which shall- …make use of ongoing research and development at the micrometer scale to support their work in nanotechnology;"

> Sect. 2b4D of The 21st Century Nanotechnology Research and Development Act (S.189, signed into law December 3, 2003)

MMD is the integration of nanotechnology and microtechnology over length scales ranging up to 8 orders of magnitude to produce materials, devices, and systems for high value markets in the fields of energy, sensors, electronics, medicine, chemicals, consumer goods, environmental remediation and others. The field may be subdivided into four types of activity:

> Nano enabling Micro: Integration of nanomaterials and nanostructures into microscale systems in order to greatly enhance performance. In addition to extending semiconductor technology, a high-value example of this is the coupling of bulk super-lattice thermoelectric materials with sub-watt microcombustors to provide small power sources for distributed sensors and portable electronic devices.
>
> Micro enabling Nano: High performance and high value nanomaterials will be of no commercial use unless means can be found for efficient large-scale manufacturing. "Beaker" methods suitable for research cannot do this, and it does not appear that existing bulk chemical production methods will have the necessary control. The best solution appears to be microreaction technology, and an example application is the use of laminated microchannel reactors with controlled temperature, flow rates, and reagent introduction "logic" to produce gold nanoparticles with a variety of functional ligand shells. Such particles will have application in catalysis, environmental remediation, medical diagnostics, and drug delivery.

Nano and Bio enabling Micro: For many reasons, an important emerging area of nano/bio research is the interaction between functional nanoparticles and living cells. One example of this is that cell-based biosensors for homeland security and drug discovery applications could be made more robust and manufacturable by using nanoparticles to extend the range of cells (e.g. to non-chromatophoric cells) that will exhibit a broadband visible and/or electrical response to biologically active agents.

Nano and Micro enabling Bio: Microchannel devices and nanomaterials will enable miniaturized organ function. A recent example is the announced license by Home Dialysis Plus (Portland) of MMD technology from OSU to develop a miniaturized filter that will enable portable dialysis systems suitable for use in patients' homes.

STRENGTHS

Although high technology markets (including most of the markets that will employ nanotechnology) are among the world's most competitive and expensive to enter, Oregon has made significant progress in identifying a research niche with enormous medium- and long-term market potential that stronger academic centers do not yet dominate, and which has at least strong adjacencies to the markets addressed by the exceptionally strong Portland/Willamette Valley semiconductor and electronics industrial base. In addition, the three doctoral research institutions in the Oregon University System have established an unprecedented collaboration that powerfully takes advantage of their complementary strengths, e.g. a strong engineering/applications program at Oregon State University is coupled with strong basic materials science research at University of Oregon and Portland State University. In just the last three months of 2003, this team submitted over $32M in federal proposals, at least half of which were collaborative. A trend of increasing aggressiveness and competitiveness is being established. Further, there is increasing generation and protection of OUS and OGI MMD-related intellectual property. Approximately 40 recent patent applications have been filed, which should build on a base of about 25 MMD/materials patents issued since 1995. Finally, the Oregon institutions are establishing successful partnerships with the regional national laboratory (PNNL) that are enjoying more success and generating more collaborative enthusiasm than PNNL's other academic partnerships.

Areas of Focus in Oregon

The Oregon State University **Center for Microtechnology-Based Energy, Chemical, and Biological Systems** (MECS) is the nation's leading university research program in microreaction technology and the fabrication of microchannel devices from a variety of engineering materials (e.g. US Patent 6,672,502 for intermetallic microstructures). This interdisciplinary (ME, IME, BioE, ChE, BioCh/Phys) center includes 20 PIs and 35-40 graduate students and

spends between $2M and $4M per year, depending on the stage of contracts from DARPA and other federal agencies. The central idea is that mass and heat transfer can be greatly accelerated by the use of parallel microchannels, enabling the miniaturization and distribution of energy, chemical, and biomedical systems.

Evidence of national leadership includes having the largest number of papers at the International Microreaction Technology Conference (American Institute of Chemical Engineers), the most successful ($4.6M, one of two to reach the final stage of competition) of 35 DARPA-funded cell-based biosensor projects, and a recent invitation to submit several pre-proposals based on the excellent progress being made on the high-priority DOD/Ft. Belvoir Man-Portable Heat Pump project ($6M). The leader of the center, Dr. Kevin Drost, is the inventor of the IR100 award winning and patented MicroHeater device, which miniaturizes a 1KW combustion system to the size of a deck of cards. This is among the MMD inventions currently being investigated by Oregon entrepreneurs.

Together with **Pacific Northwest National Laboratory's** Micro Chemical and Thermal Systems (MicroCATS) program (with $5 to$6M per year of competitively funded research), OSU has formed the Microproducts Breakthrough Institute in Corvallis, which is expected within a few years to employ 40-50 researchers, do $20M/year of research with near-term commercial potential, and assist Oregon companies in the commercialization of MMD technologies. This institute will be the world leader in the bulk processing of fluids in microstructures, with applications in energy, transportation, chemicals, heating and cooling, and environmental remediation. MBI research will be the focus of a session at the February 2004 AAAS conference in Seattle, and this session was chosen to be the focus of a press conference due to very high technological interest. This university-national lab partnership is believed to be unique in the U.S., and is an outstanding opportunity for Oregon.

Finally, OSU (leader for the 9-state western region) will be one of five national Sun Grant centers receiving up to $15M/year for 5 years if legislation recently passed by Congress is signed into law and the authorized funds are appropriated. MMD microreactor technology meshes well with the Sun Grant mission to develop high value bioproducts from crops, including fuels intended to reduce U.S. dependence on imported energy sources.

The University of Oregon **Materials Science Institute (MSI)**, **Center for Advanced Materials Characterization in Oregon (CAMCOR**), and **Oregon Center for Optics**, together account for 33 PIs (13 out of 15 eligible of the new faculty at MSI have won prestigious NSF Career/Young Investigator Awards) and more than 80 graduate students who win over $7M/year in competitively funded research. MSI faculty productivity ($$ research/FTE) is among the highest in the nation. CAMCOR has hired world-class microscopy, microprobe, and surface analysis experts, and provides expert analytical services to many Oregon companies. CAMCOR is also the pioneer for the shared facility model that will

make Oregon MMD researchers more competitive and productive than could otherwise be the case in a largely rural state.

UO researchers have developed the world's best (and scalable) gold nanoparticle process (at least 3 patents pending), the world's first fabrication process to produce a 1-cm scale bulk superlattice (used to produce 4-5x more efficient thermoelectric materials at reasonable costs, e.g. US Patent 5,994,639), and have one of the world's leading programs in green chemistry. These are all important strengths as Oregon seeks to win funding under the 21st Century Nanotechnology Research and Development Act.

The collaborative combination of these OSU, UO, and PNNL strengths was the genesis of the MMD opportunity. It is one thing to list multiple institutions' programs side by side, but another thing entirely for them to come together as a self-organized collaborative group, yet this is precisely what began to happen in 2000 when Kevin Drost, director of OSU's Center for MECS, sought to collaborate with Dave Johnson and Jim Hutchison at UO's Materials Science Institute. In the most recent demonstration of collaboration, the three universities have submitted (to the Chancellor and OSSHE board) a joint 2005 federal project request for two MMD projects (Miniature Tactical Energy Systems, Safer Nanomaterials and Nanomanufacturing) under the newly established multi-institutional MMD institute, the Oregon Nanoscience and Microtechnologies Institute (ONAMI).

Other "point sources" of excellence in Oregon MMD research include:

- Portland State University's microscopy laboratory includes the region's most advanced transmission electron microscope and other nanomeasurement equipment worth over $2.5M. Co-located with nanofabrication equipment (carbon nanotubes) this facility enables fast turnaround experimentation, and is attracting industrial use in the Portland area. Recent strategic hires are giving PSU a strong position in electron optics and selected areas of nano measurement and fabrication. PSU researcher Jun Jiao received a $307K, 3-year research grant from Intel to study carbon nanotubes for electronic applications.
- OSU's transparent electronics research (with 3 PI's and research approaching $1M per year) has developed the world's first transparent transistor, and is steadily improving its performance. There has been high local and international industry interest (both joint research and licensing) in this technology, which has the potential to improve the brightness/power ratios of electronic displays and enable all-new product categories.
- OSU precision mass spectrometry technology (e.g. US Patent 6,489,610) is the basis for the world's best-selling mass spectrometry equipment for proteomics research.

PSU's $2.5M microelectronics test facility is highly regarded and heavily utilized by both established and newly formed electronics companies. This is relevant for MMD because the physical and electrical aspects of product and system test are becoming increasingly demanding as system complexity grows and size shrinks.

WEAKNESSES

The research metrics and national rankings/visibility of the university programs of which MMD is comprised are still comparatively weak. Cornell University, for example, has annual nanotechnology funding of approximately $70M and has won multiple multi-year, multi-PI federal NSF research center awards. Oregon has yet to win such a center, yet it must.

Past technology transfer success in MMD (or any high technology field) has been modest. Few Oregon companies have been created, and none survive. Licensing activity has also been modest, and generated revenues are so far well below patenting costs. The recent upsurge in patenting and research focus is a leading indicator of much better future performance.

Basic university funding in Oregon is extremely weak (#50 in US in trend of investment in higher education), at a time when it is becoming clear that strength of innovation is the only way that a high-wage economy is likely to be sustained. This chronic under funding has numerous negative effects on research and technology transfer performance, such as high student loads and burnout levels for faculty; old and/or poorly maintained facilities; lack of matching funds for capital equipment grants; lack of funds for major proposal generation (thereby limiting proposal quality), feasibility studies, and IP protection; lack of ability to recruit "signature" researchers and top quality graduate students; and severe pressure to use research indirect costs to subsidize education.

MARKET OPPORTUNITIES

- Energy efficiency and portable power
    - Fuel cell systems at practical sizes and costs
    - Portable/remote power for wireless electronics and distributed sensor networks.
        - MMD can enable several alternative solutions to this critical problem
    - Man-portable heating and cooling – a critical DOD need
        - Leverage into vehicle heating/cooling systems
    - Miniaturized/distributed/portable HVAC, 50% energy savings

- High Technology
    - Nanometer-scale semiconductor devices, materials, and processing equipment
    - Integrated nanophotonic communication devices in semiconductors
    - Microreactor production of nanomaterials (lower cost and waste than batch methods)
- Biomedical materials and devices
    - Implantable/portable artificial kidney, liver, lung
    - Materials for cartilage replacement and eye surgeries
    - Biosensors for specific substances and general biohazards
- Agriculture – distributed/local production of bioproducts
    - Biodiesel
    - Biodiesel to hydrogen
- Environment – microreactors for on-site/in-situ waste remediation, distributed chemical production

Applications	Estimated WW annual market
Semiconductors	$200B
Semiconductor process equipment	$16B
Electronic Displays	$65B
Inkjet Printing	$35B
Batteries	$3.5B
Heating, Ventilation, Air Conditioning (HVAC)	$20B
Portable power, heating, cooling (future)	$10B approx.
Nanomaterials (2007)	$1B
Medical Implants	$15B
Analytical Instruments and Equipment	$19B
Biosensors and bioelectronics	$1.5B
Alternative fuels, e.g., biodiesel (future)	$100Ms approx.
Vehicular fuel cell systems (future)	$10B approx.

Derived from publicly available market data sources.

It should be stressed that MMD is in most respects a new category. It has potential to disrupt large existing markets (e.g. electronics, HVAC, automobiles) as well as to create or enable new and emerging ones (nanomaterials, distributed sensors) that could become the economic lifeblood of regions that

have become accustomed to the high wage levels that can only be supported by the high added value of innovation.

CHALLENGES

The specific challenges in front of the MMD signature research effort are clearly mirrored in the center's goals:

1. Grow federally funded research, in particular by winning a major center.
2. Build stronger partnerships with Oregon industry via research that is technically world class and commercially relevant, leading to growth in sponsored research, license agreements, and new products/businesses for these companies.
3. Recruit top-quality undergraduate and graduate students into MMD research and degree programs, and place these students in Oregon companies.
4. Launch innovative startup companies

Effective action is beginning to take place in all of these areas, but many other challenges exist: academic culture and traditions (promotion and tenure, publication rights, individualism), the fact that OUS is regulated as a state institution (affecting contract terms and turnaround times), and a comparative lack of venture capital in Oregon. These challenges have been recognized by OCKED and other groups, but not yet boldly addressed by the state.

CONNECTIONS TO OREGON INDUSTRY

Oregon's "Silicon Forest" semiconductor, MEMS, microfluidics, and specialized supplier (instruments, process equipment, design software) base is a major concentration of industrial strength that is easily among the top three such concentrations in the U.S., and arguably number one in the field of semiconductor process R&D and leading edge manufacturing A consistent theme is that Oregon companies in this field (or the Oregon operations of out-of-state companies) have outperformed other operations. The phase I analysis of patents documented one aspect of this strength, but the picture can be enriched by the following few (of many possible) examples:

- Intel Corporation, the world leader in semiconductor technology - in particular the highly profitable CPU segment - has its most advanced technology R&D and production facilities in Washington County, where it recently opened the world's first 300mm production fabrication line running 90nm technology. Approximately half of Intel's most senior people are in Oregon, including the Chief Technology Officer. Also in Oregon are senior managers in Intel Capital, which invests in advanced technologies.

- Hewlett-Packard, the world leader in inkjet printing technology (which is itself the largest application market for MEMS technology) has its most

technologically advanced R&D and manufacturing site in Corvallis and its main printer development facility in Vancouver, WA. Besides inkjet printing, HP Corvallis has entered the digital projector and CD/DVD personalization markets, and is conducting both MEMS and nanotechnology research.

- LSI Logic, the market leader in the $20B Application-Specific Integrated Circuit (ASIC) market, has its last remaining in-house fabrication in Oregon, which was honored as the 2001 "Fab of the Year" by the Semiconductor Industry Association. As is the case with Intel, LSI is doing leading edge process technology and materials work (e.g. low k intermetal dielectrics and high k gate insulators) in order to maintain its technology leadership.

- Hynix Semiconductor (Eugene) is completing a major investment in a memory production facility. Eugene and UO officials have been told on several occasions that this plant outperforms – in terms of quality and productivity – the company's facilities in Korea.

- Xerox's Wilsonville operation is the world leader in solid inkjet printing and, like HP inkjet, the most successful business operation in the company.

- Tektronix is the world leader in many aspects of electronic test and measurement equipment. Tektronix's VP of R&D has identified MMD and Analog Mixed Signal as high-interest areas in Oregon university research.

- Electro Scientific Industries (ESI) in Beaverton is the world leader – with commanding market share - in laser processing for semiconductor memory repair, electronic hybrid trimming, and high-speed precision measurement of electrical impedances.

- FEI Company in Hillsboro is a leading producer of essential nanotechnology analytical tools, including the industry-leading DualBeam FIB and Tecnai TEM tools used by Oregon's leading MMD companies and university programs.

- ETEC (Applied Materials) and Novellus are two very important companies in the semiconductor processing equipment market.

- Other Oregon semiconductor/electronics firms with niche market strength include Lattice Semiconductor, Analog Devices, Maxim Integrated Products, TriQuint Semiconductor, and Microchip.

- In-Focus Systems, Planar Systems, Pixelworks, and Sharp (Clark County, WA) are important players in the electronic display and digital projector markets.

- Wacker Siltronic of Portland is a major supplier of silicon substrates. SEH America in Clark County, WA, is another major supplier.

- Wah Chang-Ormet other metals companies, and the DOE Albany Research Center have strong capabilities in fabricated metals, materials research, alloys and intermetallics, and metallic microstructures.

- Smaller Oregon companies involved in MMD-related product development include Cascade MicroTech, Precision Castparts, Protarus (fuel cell components), Idatech (fuel cell components), Entek International (membranes), Bend Research, Intellichem, MicroHelix, and others.

- There is potential investment activity in Eastern Oregon (e.g. proposed Treasure Valley Biorefinery) related to bioproduct/biofuel production from locally grown crops. These efforts may get a significant boost if the Sun Grant legislation (passed by congress Jan. 2004) is signed into law and funds are appropriated. OSU stands to become one of 5 regional centers with up to $15M/year funding and an emphasis on high-value bioproducts including fuels. MMD is perfectly positioned to further this activity.

Although details remain confidential, small/startup company collaborations (most requiring venture investment) involve microchannel devices and reactors for space heating, water purification, chemical separations, fuel cell system components, and biomedical applications. Though in early stages, most of these have true breakthrough potential. One example that is now public (Feb. 3) is application of MMD microchannel technology to drastically improve size and efficiency of kidney dialysis filters. Startup funding for development must still be raised for this new venture.

At least six MMD companies have been created outside of Oregon based on PNNL technologies similar to those they will be bringing to the MMD collaboration, which illustrates that there is some relevant history for startups in this new field.

1. Innovatek (Richland, WA; fuel reformers; http://www.tekkie.com/index-innovagen.htm)
2. MesoSystems (Kennewick, WA and Albuquerque, NM; biodefense air samplers; http://www.mesosystems.com/)
3. Mesoscopic Devices (Denver, CO; fuel cell “balance of plant” components, including microreactors; http://www.mesoscopic.com/index.htm)
4. Microenergy Technologies (Vancouver, WA; fuel atomization and electronics cooling SBIRs; http://www.microet.com/)
5. Velocys (Columbus, OH; fuel cell and fuel conversion-related microchannel products)

6. Zess Technologies (Spokane, WA; microchannel heat exchangers; http://www.zessindustries.com/)
7. Others are pending.

MULTI-SCALE MATERIALS AND DEVICES SUMMARY

STRENGTHS

Research and contract funding growth
Over 50 Pis
Over 60 issued or applied for
Silicon Forest high tech concentration
>5000 related Oregon industry patents
Entrepreneurial connections and interest
UO/OSU/PSU/PNNL collaboration

WEAKNESSES

Research metrics and ranking relatively weak
Past commercial success limited
Basic university funding weak

OPPORTUNITIES

>$100 billion in diverse markets
Energy efficiency and portable power
High technology materials and processes
Biomedical materials and devices
Distributed sensors

CHALLENGES

Grow competitive research - win federal center
Build stronger industry partnerships
Recruit top faculty and students
Launch successful startups

BRAIN FUNCTION AND DISEASE

Oregon ranks highest in the nation in stroke mortality with 13% of all deaths due to stroke. The state also has the highest rate of Alzheimer's disease, and second highest rate of Parkinson's disease. The state has more people than average over 65 (12.8% vs. 12.4%) and over 75 (6.4% vs. 5.9%). It ranks 7th in suicides (excluding "death with dignity") and 9th in deaths from alcoholism. Oregon holds the distinction of being the fattest state west of the Rockies. More than 20 percent of adult Oregonians are obese and 38 percent more are overweight. Our youth are in trouble, too. The percent of overweight teens in Oregon has tripled in the past 20 years. In the past 35 years suicide among teenagers has multiplied five-fold. On the positive side, Oregon ranks lower than the national average in deaths from cardiac disease although that is still the number one cause of death.

Remarkable advances have been made in understanding how mental events correlate with brain activity in specific areas. Oregon researchers are contributing to these major advances in understanding brain function and how it is affected by disease. At UO researchers can identify early changes in brain function during normal and disease development and localize areas of activity and damage in the brain. At OHSU there are new approaches to the drug treatment of stroke and obesity. UO researchers are looking at diagnosis of brain disorders and at OSU there is a project aimed at alternative methods of treating neurodegenerative disorders. The longest running study of adolescent depression is conducted by Oregon Research Institute.

STRENGTHS

Oregon is very strong in neuroscience research. Both grants analysis and interviews support this finding. An analysis of Oregon neuroscience funding data reveals that there was a total of over $87 million for over 380 grants led by 118 principal investigators (PI's). Most of the funding came from NIH and included the Institutes of Neurological Disorders and Stroke (NINDS), Mental Health, Medical Sciences and others. There were 89 active grants awarded by NINDS to Oregon institutions in 2003, or 9% of the 993 total awards to Oregon institutions from NIH. This compares to 88/2374 NINDS awards in Washington (3.7%), 72/1448 in Colorado (4.9%) and 53/674 in Arizona (7.8%).

Basic research in Oregon includes some leading work in brain function, developmental neurobiology, stroke diagnosis and treatment, neurotoxicology, neuroendocrinology, signal pathways in neuronal cells, and neuronal control of food intake. The areas of focus are summarized below. These areas are well funded and published, and involve a large number of investigators. There have been 37 patents in the area of neuroscience drug discovery, 13% of all academic patents. Many of these are directed towards the treatment of stroke; none have yet proven successful in the clinic. There are at least nine patents relating to

diagnosis and monitoring of neurological disorders. Leading Principal Investigators have a high rate of publications and related citations. Four companies have active neuroscience research and/or products.

Areas of Focus in Oregon

At the University of Oregon, the **Brain, Biology and Machine Initiative** (a multidisciplinary initiative led by Michael Posner, a National Academy of Sciences member,) supports a functional MRI imaging center dedicated to research. The center was partially funded by grants from alumni and received NIH funding of $1.8 million in 2002. The fMRI facility will permit imaging of brain function and tissue that will allow scientists to better understand the brain's anatomy as it relates to thought and behavior. An fMRI is capable of pinpointing brain activity to within one millimeter in humans, thus laying the groundwork for investigating such brain functions as attention, emotion, learning, and memory. Work at the new facility will strive to map *functional* domains of the brain. Much of the current focus in cognitive neuroscience is on language learning. The imaging studies as well as work in biology and neuroscience could lead to therapeutic treatments, e.g. new drugs. The imaging group is writing software for analysis of data that may have commercial applications, e.g. using imaging to identify the best form of treatment for depression or dyslexia. The initiative is led by the Department of Psychology at UO, which is ranked in the top 20 graduate schools in the nation.

Within the **Institute for Neuroscience**, also at UO, faculty research interests include cellular neuroscience, developmental biology and neural systems. Cellular neuroscience focuses on the activity and regulation of membrane currents and ion channels and on the cellular mechanisms of sensory transduction. The developmental biology group has a program of research concerning the molecular, genetic, and cellular analysis of development in the zebra fish and also relates developmental activities to those occurring in Drosophila, yeast and mice. The UO's expertise in zebra fish is decades old and recognized internationally. The study of neural systems investigates how cells receive, process, and relay information, how various factors modulate the functioning of specific neural and muscular systems, and how this changes during the human life span. Additional studies at the **Neuro-Informatics Center** (NIC) include computational analysis of neural systems.

The **Neurological Sciences Institute** (NSI) at OHSU has 23 faculty members who study movement control, neural degeneration, neural development and plasticity and sensory systems. This includes studies of how nerve cells degenerate as a result of genetic disorders, aging, injury or disease, how movement is controlled and how the sensory systems work.

The **Vollum Institute** at OHSU is involved in basic neuroscience research. It has 21 faculty, is directed by National Academy of Science member Richard

Goodman, and has a budget of over $16 million. The Vollum has recently established a new Center for the Study of Weight Regulation and Associated Disorders (CSWR) headed by Roger Cone, a successful entrepreneur who founded Northwest Neurologics and Znomics in Oregon and another company in California. Since 1985, Vollum laboratories have disclosed 130 discoveries to the OHSU Technology and Research Collaboration office, resulting in 170 patent applications and 82 issued patents. In addition, technologies developed at the institute have been licensed to 49 biotechnology and pharmaceutical companies and have formed the basis for two start-up companies, Hedral Therapeutics and Northwest Neurologics. In total, Vollum technologies have generated almost $7 million in licensing revenue to help support the research mission of OHSU. This figure represents nearly 80% of the royalty-based income for the university as a whole.

The **Center for Research on Occupational and Environmental Toxicology** (CROET) at OHSU has been selected as one of five university research centers to pioneer development of the National Institutes of Health Toxicogenomics Research Consortium (TRC). NIEHS has slated a total of $37 million to fund the new consortium for an initial period of 5 years. OHSU will receive $7.25 million. Last year, NIEHS awarded CROET a Superfund Basic Research center grant that will interact with the new TRC initiative. CROET, in concert with OHSU's School of Medicine Department of Pediatrics and Doernbecher Children's Hospital, focuses on neurotoxins and neurotoxicogenomics and child health, studying the role of gene-environment interactions in disease and dysfunction. CROET has 16 faculty members.

The **Oregon Regional Primate Center (ORPRC)** at OHSU is one of eight centers supported by the NIH as a national primate research resource. Scientists at the Center have been responsible for some major discoveries in neuroscience in recent years. For example, they have mapped brain pathways that regulate hunger to help understand the causes of eating disorders and obesity. In preclinical trials with monkeys, they have identified several drugs that suppress appetite.

In the past two decades researchers have recognized depression in children as a serious problem. Researchers at **ORPRC** are furthering our understanding of brain mechanisms underlying the early development of anxiety and depression. By studying depression in children they have identified markers such as blunted growth hormone release and consistent behavioral inhibition.

OHSU/OGI received $300,000 from Intel Corp. to create new ways of using sensing technology to detect cognitive impairment and dementia in elderly adults. The technology may someday help seniors maintain their cognitive abilities.

The **Linus Pauling Institute** at OSU has received a $5.8 million grant to study aging and neurodegenerative diseases and has been designated an NIH center of excellence for Research on Complementary and Alternative Medicine.

The **Oregon Research Institute** (ORI) manages a longitudinal study of more than 850 adolescents, the Oregon Adolescent Depression Project, which has been on-going since 1985. This research study, funded by the National Institute of Mental Health, continues to follow a large group of high school students from adolescence into adulthood. The study also includes the parents, siblings, and children of the original high school participants. The overall goal is to increase current knowledge about the epidemiology of adolescent depression, risk and protective factors. Scientists are especially interested in how adolescent depression affects other aspects of life, such as parenting, health habits, personality, suicidal behavior, substance use, and other mental disorders.

The **Aging and Alzheimer's Disease Clinic** is a multidisciplinary clinic with 11 faculty members offers comprehensive care to patients with Alzheimer's disease and related disorders.

The **Oregon Stroke Center** responds to acute stroke emergencies at four Portland hospitals that are part of a citywide stroke code network. The four Portland hospitals include: Providence St. Vincent Hospital, Providence Portland Hospital, Portland VA Medical Center, and OHSU. The center also carries out research and clinical trials on the causes and treatment of stroke.

The **Parkinson Center of Oregon** (PCO) has an active clinical trials program and performs research on drug and surgical therapies for the disease. The National Parkinson Foundation has designated PCO as a center of excellence because of PCO's research productivity.

WEAKNESSES

The major weakness in Oregon is the lack of a critical mass in translational and clinical research for neuroscience. There are active clinical centers dealing with stroke, Parkinson's disease and Alzheimer's disease. The Neurology department at OHSU is ranked 14th in NIH grants. There is also an active clinical research program studying depression. However, except for pockets of excellence such as these, overall clinical research and treatment in neurological disorders is not competitive. Enhancement of translational clinical research overall, but particularly in neuroscience, is needed for Oregon to become a center for translating the outcomes of basic biological research into clinical practice. It is not likely that start-up companies will have the resources to fully develop the clinical applications of licensed technologies and that many university spin-outs will move out of state. This has already happened in the case of three neuroscience technologies that were the basis of start-ups. In those cases, there was only a

modest return to the state economy (although the Oregon founders are now starting new companies.)

Another area of weakness is the lack of industry-sponsored research in any field. Oregon ranks 40th in the nation in industry-sponsored research. The relatively small bioscience industry in Oregon is concentrated in medical device and diagnostic companies and few companies sponsor biomedical research at universities.

MARKET OPPORTUNITIES

Disease	Patients	Current market ($billion)
Stroke	4.5 million	0.3
Epilepsy	2.3 million	5
Parkinson's	2.7 million	1
Depression	17 million	20
Obesity	40 million	0.3
Diagnosis		1

Derived from publicly available market data sources.

As summarized in the table above derived from our marketing analysis, there are major opportunities in developing products for unmet medical needs. The potential markets for these diseases are much higher. Those most closely related to Oregon's basic research capabilities are:

Stroke – drug discovery, diagnosis, localization of damage, and monitoring of treatment.
Obesity – drug discovery
Neurodegenerative disorders – monitoring and therapies
Mobility disorders –diagnosis, monitoring, rehabilitation, identification of environmental causes of neurotoxicity
Depression and addiction – diagnosis, behavior modification
Epilepsy – diagnosis, monitoring and prediction

Stroke
Stroke is the third leading cause of death in the United States, and a leading cause of long-term disability. An estimated 4.5 million Americans and their families live with the disabling effects of stroke. The death rate in Oregon from stroke is the highest in the nation. Currently the market for stroke drugs is $351 million but the potential market for improved drugs much larger.

There is a clear need for a safe, effective drug for treating stroke. The only approved therapy for acute ischemic stroke, Genentech's Activase, is administered to less than 2% of the incident cases as a result of its strict treatment criteria and risk of hemorrhage. News from the ischemic stroke pipeline in the past three years has been disappointing. Trials of several high-profile investigational neuroprotective drugs have failed.

The most urgent unmet need in stroke therapy continues to be for interventional techniques to prevent or minimize the brain damage from ischemic stroke. Collaborative research at OHSU, Legacy and Virogenomics is focusing on prevention and early treatment of stroke to minimize damage to the brain.

Brain damage resulting from stroke is currently monitored using computed axial tomography (CT) and magnetic resonance (MRI). EGI is developing methods based on multi channel electroencephalography (EEG).

Obesity

More than 60% of the adult population is overweight or obese. Obesity is closely associated with increases in heart disease, diabetes, cancer and even depression - all expensive conditions to treat. According to Datamonitor, research is rapidly moving away from relatively crude neurotransmitter-based appetite suppressants and fat-absorption inhibitors towards very specific agents, targeting the biological core of satiety and caloric consumption. Though recent research has begun to unravel the genetic basis of obesity, most experts believe that susceptibility to obesity is polygenic. Programs at the Vollum Institute and the Oregon Regional Primate Center are addressing weight regulation.

Parkinson's Disease

Parkinson's disease, which affects over 1 million Americans, is a chronic and progressive disorder that results from the death of nerve cells in a critical area of the brain. A drug called l-dopa can be given, but has side effects. New approaches are needed for prevention and control of the disease.

Depression

Thirty-five to 40 million Americans living today will suffer from major depression during their lives. For each person directly suffering, three or four times that number of relatives, employees, associates and friends will also be adversely affected by their suffering.

Epilepsy

Epilepsy is a chronic neurological condition affecting an estimated 2.3 million people in the United States. Of these, more than one third continue to have seizures despite treatment. Inadequate treatment greatly increases the risk of brain damage and death from injuries incurred during a seizure.

Analysis of EEG recordings is the primary method of diagnosis in epilepsy. Unfortunately, the relatively infrequent nature of seizures means that long-term

EEG recording is necessary. The major medical need for epilepsy is a method to predict the onset of convulsions prior to their occurrence. The use of advanced forms of EEG techniques and analysis may in the future provide a means of early diagnosis. EGI is using multi channel EEG to improve prediction and monitor drugs.

Each person with epilepsy has a unique set of seizure patterns and therapy must be tailored to the individual. Complete prevention of seizures is one of the primary goals of treatment. While a number of drugs are approved and more are coming onto the market, up to 30% of patients do not have complete seizure control. Many of the drugs have significant side effects at the dose level needed for the therapeutic benefits.

Neurodegenerative Diseases

Neurodegeneration occurs in a large percentage of the population. Intel and OHSU are studying detection of early impairment. There is no comprehensive clinical test used to diagnose Alzheimer's disease. Currently, doctors use a series of physical, neurological and psychological examinations and medical history for diagnosis.

The market for Alzheimer's disease therapeutics is $1 billion. The leading companies in this segment are Pfizer and Novartis. However the annual health care expenditures for the disease were over $110 billion in 2000 and are increasing rapidly. While there is ongoing clinical support for Alzheimer's patients in Oregon, the research efforts do not appear to be competitive at this time.

CHALLENGES

As mentioned in "Weaknesses" above, there are three major challenges that Oregon faces in commercializing the results of basic research in neuroscience. Oregon needs to:

- Focus some of the basic research efforts on one or more unmet medical needs from the group above in order to reach a critical mass of research that reaches from basic to clinical in the focus area. We would recommend an initial consideration of stroke and/or obesity. Other states and institutions have greater strength than Oregon in the field of neurodegenerative disease. Funding that is directed towards specific applications could drive this. Such funding then could be leveraged with additional federal funding.
- Develop strength in clinical or translational research where the results from basic research laboratories can be tested rapidly in patients.
- Develop a locally based investment community to support start-ups. In the absence of a strong pharmaceutical or biotechnology industry in the state or strong venture capital, there is a need for the innovative technologies to

be developed within research institutions to a point where additional value may be derived for the benefit of the state on a long-term basis. This will involve ongoing collaboration between the university that discovered the technology and the Oregon licensee company that is trying to develop it. Various initiatives are under way in Oregon to improve venture funding. The strength of neuroscience research in Oregon has brought investors to the state before and could do so in the future.

CONNECTIONS to OREGON INDUSTRY

Several companies have been created based on neuroscience technology developed at Oregon research institutions.

Electrical Geodesics Inc. (EGI) in Eugene, founded in 1992, has developed a sensor net, instrumentation and analysis software for an advanced form of EEG (electro-encephalogram) measurement of brain activity. In 2001, the company received clearance from the FDA for the EGI System 200 as a medical device in the U.S. The company also performs research in neuroscience and has received SBIR awards from NIH of $335,000 in 2003 and $482,000 in 2002. EGI has received a total of 17 SBIR awards. EGI is using their dense EEG array system to monitoring and localize brain damage after strokes and also to study epilepsy and sleep.

Virogenomics Inc., a Portland-based drug discovery company, in collaboration with Oregon Health and Science University received federal funding of $99,000 to study a compound that provides significant protection to the brain when it is administered immediately prior to or following a stroke. The company will collaborate with Drs Mary Stenzel-Poore of OHSU and Roger Simon of Legacy Research to define the way the compound works and to determine how to integrate it into a drug development program aimed at treating stroke. Virogenomics has received 3 SBIR awards.

Neurocom International is a leader in the development of computerized tools for the assessment and rehabilitation of patients with balance and mobility disorders. About 34% of people over 65 suffer from these disorders.

Axonyx Inc., a U.S.-based biopharmaceutical company, plans to acquire the controlling interest in OXIS, a Portland-based company. Axonyx develops proprietary pharmaceutical compounds and new technologies useful in the diagnosis and treatment of Alzheimer's disease, human memory disorders, and prion-based illnesses such as Mad Cow disease.

Other neuroscience biopharmaceutical companies founded on Oregon research include **Northwest Neurologic** (founded in Portland, then acquired by Neurocrine Biosciences, California), **Acea** (acquired by CoCensys, both of

California) and **Cambridge Neuroscience** (founded in Massachusetts, then closed due to the failure of its lead drug in clinical trials).

BRAIN FUNCTION AND DISEASE SUMMARY

STRENGTHS

Strong research funding over $85 million
Over 100 PI's
Over 30 issued and pending patents
Some past and new companies
OHSU/Legacy/Virogenomics collaboration

WEAKNESSES

Clinical and translational research weak
Past commercial success limited
Lack of venture funding
Lack of industry funding

OPPORTUNITIES

>$25 billion markets
Stroke
Obesity
Depression

CHALLENGES

Improve clinical research
Launch successful startups
Build stronger industry partnerships

INFORMATION TO KNOWLEDGE

The explosion of data in all scientific disciplines is well recognized. With the widespread use of more automated equipment to collect data, management of information and its conversion into useful knowledge will continue to be a challenge. This is becoming a significant challenge in the whole area of bioinformation from patient records to analysis of genomics and proteomics data. Many scientific applications require large computing resources to process data.

In Oregon, the requirement for computing resources is very broad. The software industry in Oregon consists of over 600 companies that are distributed and could be a major source of jobs in rural communities with high-speed internet access. At the other end of the spectrum, universities and companies are working on the modeling and simulation of complex problems such as analysis of earthquakes, tidal waves and volcano activity, analysis of nerve signals in the brain, genome and proteome analysis and management of patient information in healthcare settings. Access to computing resources is rate limiting in this research.

STRENGTHS

Computational research in Oregon is strong and broadly distributed. OGI, UO and OSU are all ranked in the top 100. Some applications research, such as oceanography at OSU, is ranked in the top 10. Research grants in the state bring in over $100 million to 361 principle investigators. There are over 600 software companies, and over 136 patents issued to companies in Oregon. Oregon is a leader in the development of open source software and has several large companies with major software research efforts in the state, including Intel, HP and IBM.

Areas of Focus in Oregon

Scientific and Environmental Computing

Internet2 is a consortium of universities working with government and industrial partners to build the next generation Internet infrastructure. Internet2 has deployed a very high-speed network backbone, called Abilene, which connects gigaPoPs, or access points, located at various universities throughout the country. This network enables many of Oregon's research institutions to more effectively access the information they need, communicate with one another, and be an integral part of the global research community.

Both OSU and UO were early members of Internet2. Later, the three Portland-area higher education institutions were awarded a grant from the National Science Foundation (NSF) to build a metropolitan area network and connect to the Internet2 via the Pacific Northwest gigaPoP in Seattle. This enabled a

number of projects to proceed including the Virtual Integrated Circuit Test Facility at **PSU**, Medical Informatics distance learning at **OHSU** and transmission of broadcast-quality digital video over computer networks at **OGI**.

There are a number of groups within Oregon and collaborating institutions that have developed special tools for dealing with large amounts of scientific data. The data comes from diverse fields including:

- Volcano and earthquake research
- Wave and ocean research
- Medical informatics
- Genetic data from model organisms and patients
- Genome and proteome data
- Neurological imaging and electrical data

Funded by a $4.8 million National Science Foundation grant, Oregon State's **O. H**. **Hinsdale Wave Research Lab** is the largest tsunami research facility in the world. By combining the latest in information technology with earthquake engineering the lab enables researchers worldwide to participate in real-time experiments using cutting-edge communications technology.

The **College of Oceanic and Atmospheric Sciences** (COAS) at Oregon State University is one of the leading ocean and atmosphere research centers in the United States. The annual budget of the College includes nearly $22 million from approximately 300 grants and contracts from NSF, ONR, NASA, NOAA, and other Federal agencies. In 1997, the last year for which data are available, COAS was fourth on the list of institutions receiving NSF funds for oceanographic research. COAS is one of the 11 members of the Joint Oceanographic Institutions, Inc., the nonprofit corporation that is the prime contractor for the $50 million per year international Ocean Drilling Program.

COAS computer facilities are among the best in the nation. An important and unique part of COAS is the computing expertise and facilities, and COAS is first among all oceanographic institutions worldwide in the application of super computing methodology to global environmental problems. The COAS computer network links about 350 workstations, and includes seven parallel super computers. A realistic "model" of the ocean gives rise to equations that are too complicated to be solved by ordinary mathematical methods. Oceanographers at COAS create approximations to these equations that can be solved numerically on a computer. This procedure is quite similar to that used to create weather forecasts.

The **Departments of Computer Science** and **Geological Sciences** at UO collaborated to develop an environment for performing online computational steering and visualization of parallel seismic tomography application. Use of this

environment has already led to geological discoveries beneath the East Pacific Rise. Because ocean ridges and their interiors are inaccessible to direct study, remote sensing techniques are used. Seismic tomography allows a sampling of the Earth's interior via earthquake or human-made pressure waves recorded by seismic instruments. Just as X-rays are sensitive to density variations of organic tissue, seismic waves are sensitive to density variations of rock. This principle (similar to that used in medical CAT scans) can be used to determine the three-dimensional structure of the Earth's interior. Seismic tomography thus allows geophysicists to image volcanic systems and predict how the heat and magma distribution correlates with surface processes (e.g. hydrothermal activity) or to image the mantle in search of the roots of volcanoes.

According to an NSF report, **OGI** received approximately $7.2 million in federal funds for its computer science research in fiscal 2001, the latest year for which data are available. OGI was awarded about $9 million for computer science research from all funding sources combined. The school was ranked 16th in 2001 in federal funding and 21st in overall funding, leading the Northwest. The Oregon schools all improved significantly in their relative position with OSU at 70th and UO at 75th.

The **Northwest Alliance for Computational Science and Engineering** (NACSE) is a coalition of Pacific Northwest institutions including OSU and UO led by IEEE (Institute of Electrical and Electronics Engineers) Fellow and ACM (Association for Computing Machinery) Fellow Cherri Pancake of OSU, whose goal is to exploit Web technology to make it easier for scientists and engineers to learn about and used network-based scientific resources. OSU and NACSE have a leading IT role in the NSF NEES (Network for Earthquake Engineering Simulation), which recently announced plans to adopt the NACSE interfaces and data model across the entire NEES program, and are experts in Geographical Information Systems, especially for natural resources.

The Oregon **Regional Alliance for Infrastructure and Network Security** (RAINS) is a public-private partnership active in building software for protection, monitoring and management of networks.

Biomedical Research Computing

One of the findings in Phase I analysis of grants was that there was no clear classification for a large number of the grants funded in biomedical research. For a deeper analysis of this data, we selected all grants that referred to proteomics, genomics and genetics. This gave us a new group that relies heavily on information technology to translate the data into an understanding of genes, proteins and pathways involved in basic biological systems. In combination, these grants numbered over 270 and totaled more than $90 million in funding across OHSU, UO and OSU. Many of the grants overlap with neuroscience funding, but there are also many in the cancer area and in basic research.

Overall, all of the Oregon institutions are building regional strength in this research area.

The **OHSU Cancer Center** is making an investment in equipment for functional genomics and proteomics with the associated bioinformatics required. The study of proteins in signal pathways is a major area of focus and earlier studies by Dr Brian Druker led to the identification of a small molecule drug that inhibited a target pathway by affecting a particular protein in the pathway, thus leading to a highly effective cancer drug, Gleevec. Further discoveries in this area could lead to additional drugs targeted to specific cancers.

OHSU Dental School is using modeling to simulate the biomechanics of materials and prostheses and to predict their physical properties.

OSU researchers have developed a new time-of-flight mass spectrometer designed specifically as a workhorse for proteomics studies. The licensee company sold 50 of these instruments to drug and biotech companies in the first year of sales.

Pacific Northwest National Laboratory (PNNL) won a five-year, $10.2 million grant from the National Institutes of Health to support a center for basic research in proteomics, as part of their systems biology initiative. PNNL collaborates with Oregon institutions on proteomics research. The grant designates PNNL as an NIH research resource center and will fund development of advanced instrumentation for studying the large and complex protein sets that constitute biological systems. The ability to measure proteins, especially those present in trace amounts, and to observe changes in them is the key to understanding molecular-level cell function and disease progression, treatment and prevention. Besides instrumentation, the grant will support improved computational and bioinformatics tools for extracting, visualizing and ultimately understanding the data produced in the resource center. The research creates quantities of data that in many cases can be analyzed only with computer programs developed specifically for that purpose.

PNNL is the site of the fifth largest supercomputer in the world, according to the latest Top500 list published in November 2003. They are also developing sophisticated modeling techniques for understanding a number of biological systems. In addition, the Environmental Molecular Sciences Lab (EMSL) has developed methods to enable the web-based use of many of the large scientific instruments to make them more readily available to users at remote locations.

The **Neuroinformatics Center** (NIC) at UO has been formed to bring advanced informatics to brain research. In the near term, NIC will demonstrate the capability of creating a high-resolution finite element model of human head tissues, which will be used in the analysis of brain function by integrating information from EEG and MRI sources. Over the longer term, the NIC will

develop the informatics resources required to integrate structural MRI with dense-array EEG for medical applications such as acute ischemic stroke. Funded in part by the Telemedicine and Advanced Technology Research Command, the NIC is interested in providing access to neuroinformatics technology over the Internet.

The **Zebrafish Information Net (ZFIN)** is a web-based, worldwide resource at UO that serves as a centralized location for the storage and integration of zebrafish genetic, genomic and developmental data.

The **Department of Medical Informatics and Clinical Epidemiology** in the OHSU School of Medicine currently consists of more than 50 faculty. This includes faculty with their primary academic appointments in the division, several from other departments with "joint" appointments in the division, and "clinical" faculty with informatics/outcomes training who work primarily for companies and institutions outside the university. The division currently receives over $2 million per year in competitively awarded externally funded research. Medical Informatics is the field concerned with the acquisition, storage, and use of information in health and biomedicine. Clinical epidemiology is the application of the logical and quantitative concepts and methods of epidemiology to problems (diagnostic, prognostic, therapeutic, and preventive) encountered in the clinical delivery of care to individual patients.

WEAKNESSES

The computer science schools in Oregon are relatively small. Although OGI was ranked 21st in the country in 2001 in overall funding, OSU was 70th and UO 75th. A major weakness in comparison to other schools is the relative lack of industry funding.

Equally concerning is that while there is a strong presence in Oregon by leading computing companies, and a substantial number of smaller independent software companies, these companies sponsor very little research in Oregon and do not appear to have strong relationships with the university departments of computer science.

While there are cases of faculty starting small companies (in many cases for research purposes), and examples of research of interest to major software companies (e.g. spreadsheet error detection and Microsoft), we found no significant examples of technology development or spinout plans that are likely to create growth companies or appreciable numbers of new jobs. There should be opportunities to complement computer science research with partnerships with companies and industry groups targeting major new market opportunities such as RAINS and security.

Another reported weakness is the lack of high-end computing resources that can be used to tackle large computing problems. There is a call for a state resource that could be based on a grid computing approach to using under utilized computing availability.

MARKET OPPORTUNITIES

A study released by the Rural Internet Access Authority, a North Carolina economic development group with industry backing, estimated that deployment of an advanced computing grid in the state would add more than $10 billion to the state's output and result in a net gain of 24,000 jobs through 2010 (www.e-nc.org/pdf/grid_report_oct-28-03.pdf). The North Carolina legislature backed an initiative to give everyone in the state access to the internet by 2001 and high-speed access by 2003. Several industry leaders interviewed support such an approach for Oregon.

The global software market was $152 billion, a decline of 5% from the previous year according to Ovum. The Ovum analysts predict that web services, business intelligence, security, portals, content management and records management will be growth areas in the next year. However International Data Corporation (IDC) analysts report a slow growth of 1.5% in 2002 and predict that software spending will grow by 4% in 2003.

The top three companies in software are Microsoft ($25.9 billion software sales), IBM ($13.1 billion) and Oracle ($6.9 billion). Of the top ten leaders, IBM has a software research presence in Oregon.

Application development is expected to be the fastest growing segment at over 11%. IDC reported that the total High Performance Technical Computing (HPTC) market for calendar year 2002 was $4.7 billion and HP was the worldwide market leader with a 34% revenue share. HP also has a presence in Oregon.

This report complements the ratings on the TOP500 Supercomputer Sites list published in November 2003. The list shows that HP leads with 165 sites, followed by IBM with 159 and SGI with 41. The number of systems in the TOP500 list using Intel processors grew from 119 to 189, signifying a major shift in this marketplace. With this increase, the Intel processor family is now the dominant processor used in HPC systems. HP and IBM follow Intel. In terms of total performance of all the installed systems, the latest TOP500 edition still shows IBM as the clear leader with 35.4 percent, ahead of HP with 22.7 percent and NEC with 8.7 percent.

Linux continues to dominate the growing market for Web servers. According to IDC, a leading IT research consultancy, Linux market share within the Web server sector stands at approximately a third and will grow to 41 per cent by 2005. Embedded Linux has risen from relative obscurity to recognition as one of

top two or three OS choices for new designs of smart devices and embedded systems.

Life science applications are very broad and include all of the computer applications in medicine and biological research. A study by Alta Biomedical in 2003 projected that the bioinformation global market is expected to be over $175 billion in 2005.

Overall the opportunities for converting large amounts of complex information into usable knowledge are many and varied. The challenge for Oregon will be to identify appropriate economically viable opportunities for focus.

CHALLENGES

Oregon has an extensive network of fiber optic cable and the major university locations have access to Internet 2. However there is a need for additional computational resources for university research. Several executives interviewed proposed the development of a widely accessible super-computing resource by aggregating the excess capacity of existing State computer hardware (utilizing networked distributed computing clusters) that would create statewide economic development and job opportunities and facilitate profitable collaborations with private industry. In addition there is a need for improved connectivity for software and other businesses.

CONNECTIONS to OREGON INDUSTRY

Three companies with a major presence in Oregon are the leaders in high performance computing – **HP, IBM** and **Intel**. These large companies are represented in several areas of specialization.

Open Source Development Lab, Portland - home to Linus Torvalds, the creator of Linux - is dedicated to accelerating the growth and adoption of Linux in the enterprise. Founded in 2000 and supported by a global consortium of IT industry leaders, OSDL is a non-profit organization that provides state-of the-art computing and test facilities in the United States and Japan available to developers around the world. OSDL's founding members are IBM, HP, CA, Intel, and NEC.

There is an active software industry in Oregon with over 600 companies. The major areas of specialization are:

Electronic Design Automation
Mentor Graphics, Cadence and Synopsis are the three leading EDA companies; Mentor and Synopsys have sizable operations in Oregon. Recent patents issued to Oregon inventors and assigned to these three companies are 24, 1 and 14, respectively.

Financial Solutions
Timberline Software was founded in 1971. Others include **Corillian**, **Harland Financial Solutions** and **Summit Information Systems**.

Educational and Training Software
This group is represented by **Inspiration Software**, **Vernier Software & Technology** and **Learning.com** as well as others (see Education and Behavior section in this report).

Security
This group is represented by members of RAINS, such as **Symantec, Network Associates, Digimarc** (which has a very large patent portfolio) and **Tripwire**.

Information Technology
This is a large group of developers and users of software in many organizations throughout the state. A new company involved in mining of complex data is **Thetus**.

INFORMATION TO KNOWLEDGE SUMMARY

STRENGTHS
Very strong applications funding
Over 300 PI's
Over 130 industry software patents
Leading computer company presence
Many software companies

WEAKNESSES
CS metrics and ranking relatively weak
Past commercial success from universities limited
Few CS-related patents or protected IP
Few/no university-based startups

OPPORTUNITIES
Large software/IT market - over $150B
Open source (Linux) software and services
Large scale scientific computing solutions

CHALLENGES
Build high performance grid computing
World-class research
Build stronger industry partnerships
Recruit top faculty and students
Launch successful startups

ANALOG AND MIXED SIGNAL CIRCUITS

Analog and mixed-signal integrated circuits is an increasingly important and profitable segment of the overall semiconductor market. *Analog* refers to signals with continuous values, e.g. waveforms to drive audio speakers, and *mixed-signal* refers to the combination of digital and analog circuitry on a single chip to produce a more highly integrated system. The latter is one of the most interesting developments in integrated circuits, not least because it is key to the development of recent and emerging high-growth products such as power switching devices (e.g. on-board inkjet print heads), digital cameras and camcorders (imaging chips), cellular phones, medical electronics (e.g. for pacemakers), smart MEMS, sensors, wireless PDAs and laptops, GPS (Global Positioning System), and RFID (radio frequency identification systems). "AMS" circuitry is particularly important for enabling wireless applications with both high performance (bandwidth), low cost (integrating multiple functions on one chip), and minimum power consumption (a serious issue for almost all mobile electronic product categories).

Wireless connectivity for mobile computing is the "current next thing" in PCs and PC chip sets, with growth rates several times higher than the rest of the PC market. Mobile computing represents 20% of the market and is expected to reach 35% within three years. Wireless base station installations have been growing at about 40%/year and are expected to reach 180,000 units by 2005, while wireless network cards for laptops have been growing at 70% with a 2005 forecast of 10 million units (Nautilus Group).

The 802.11a,b,g (Wi-Fi) WLAN (Wireless Local Area Network) standard has most of the mobile wireless data market today, and is ideally suited for home networks and wireless local area networks, e.g. in corporate or academic buildings and public "hot spots" such as Starbucks stores. There are also emerging higher speed wireless data standards such as UWB (Ultra Wide Band). However, longer range/wide area functionality would be very valuable as one means of addressing the "last mile" problem for high-speed internet connections, especially if interference problems could be solved such that line-of-sight is not required. (Forest-dwelling Oregonians would be among the most appreciative beneficiaries). The 802.16a,e (Wi-Max) standard addresses these needs, and is expected to grow rapidly (with stationary applications preceding mobile usage) as implementation cost is reduced.

RFID (Radio Frequency Identification) is another example of a wireless application that is experiencing high growth and driving new applications. Small and inexpensive RFID chips with integrated antennas can replace bar codes and hand-operated scanners to make inventory tracking and retail transactions more automated, efficient, and information-rich. The announcement by Wal-Mart, the world's largest retailer, that it would require its top 100 suppliers to implement

RFID is expected to drive rapid penetration of the technology in retail, and will itself drive the production of as many as 1 billion tags. In addition to retail, there are also numerous other applications for RFID such as security, personal identification, healthcare, and replacement of magnetic strip credit/debit cards with non-contact methods.

The combination of low-power AMS designs, GPS functionality, wireless communications standards, MEMS/MMD, and research in other disciplines could lead to very interesting applications such as sensor networks for environmental quality, agricultural moisture and chemical optimization, transportation fleet management and tax levying, and infrastructure monitoring. Semiconductor companies, including both large and small ones in Oregon, are very eager to identify new high volume, high value/silicon area markets.

Finally, an important related set of concerns and opportunities has to do with security. The concerns include network security (especially as the number of remote and mobile users grows), privacy (e.g. enhanced tracking capability by employers, retailers, service providers) and identity theft (e.g. non-contact credit card transactions). The opportunities include standards and technologies to solve these problems and security products for both businesses and governments (e.g. the U.S. Department of Homeland Security).

As a result of these considerations, the "Analog and Mixed Signal Circuits" cluster and related commercial opportunities is considered to include research and development efforts in integrated circuit design and test, wireless device and network technologies, and network security.

STRENGTHS

Although the analog and mixed signal circuit research figures are comparatively small, there is an extraordinarily high fraction (about 50% as opposed to a more typical 3-5% for Oregon university research overall) of this funding coming from industry and industry associations. There is also high interest on the part of local and national employers in the graduates from these programs, particularly out of the OSU analog and mixed signal group. Faculty productivity in both research and degree production is very high (e.g. ~60 AMS graduate students at OSU for 5 core faculty).

One program – OSU Analog and Mixed Signal - has a credible claim to a national ranking in the top 10 in its field.

Though smaller than AMS research, wireless applications research (largely at OSU) is even more concentrated toward industry projects and applications.

Though highly competitive worldwide, these fields are a good fit for Oregon due to the strong presence of the semiconductor, electronic design automation, and

electronics test industry (electronics industry "location quotient" of 2.63 for Portland, 2000).

Areas of Focus in Oregon

AMS Integrated Circuit Design and Integrated Circuit Test

Oregon State University's analog and mixed signal circuit design group is considered to be one of the top 6 in the U.S. (the peer group includes MIT, Stanford, UC Berkeley, Georgia Tech., UCLA, UC Davis, and Texas A&M), and has been acknowledged as one of the top programs by Dr. David Hodges, UCB Engineering Dean Emeritus and integrated circuit design technology pioneer. The OSU AMS group has 5 core faculty doing over $1.5M/year research – resulting in a very high faculty productivity ratio. This core group includes 1 IEEE Fellow, 1 IEEE Third Millennium Medal winner, 3 NSF Career/Young Investigator awardees, and the current editor of the IEEE Transactions on Computer Aided Design. The group has authored 5 books and over 500 conference and journal papers, and has produced over 200 graduate degrees. The latter statistic is quite significant because AMS is a highly sought after integrated circuit design specialty under normal market conditions. This is because it requires more in-depth knowledge of the underlying physical science and technology. AMS-trained engineers are therefore likely to be more versatile, which is often a prerequisite for valuable innovation.

Of this research, industry and industry consortia fund two-thirds, so industry interest and regard for this program is extraordinarily high compared to most Oregon university efforts. The OSU AMS group is internationally known for their work on state-of-the-art analog-to-digital and digital-to-analog converters, the key interface between sensors/RF and digital computers. Among the recent key AMS technologies coming out of OSU AMS is the "substrate coupling" simulation method enabling more accurate simulations of digital noise in AMS chips. Major semiconductor and EDA companies are adopting this method. Current interdisciplinary research efforts include such investigations as low power/low weight GPS/wireless transmitters which can be attached to the legs of birds. OSU has facilities for integrated circuit and device probing from DC to 13.56 GHz and has invested more than $1.5M in funding to build up the world class testing facility.

OSU's claim to leadership in AMS is also supported by the national breadth of its academic and industry research partners, which include Intel, National Semiconductor, Texas Instruments, Analog Devices, Cypress Semiconductor, AKM, Boeing, Lucent Technologies, Semiconductor Research Corporation, Crystal Semiconductor, Motorola, DARPA, Honeywell, Tektronix, Sandia National Laboratory, Cadence, MIT, U. Illinois, Stanford, UC Berkeley, and U. Washington.

Portland State University's $2.5M Integrated Circuit Design and Test Laboratory is highly regarded and heavily utilized by both established (e.g. Intel, LSI Logic, Credence) and newly formed electronics companies (joint research and space provision for testing technology startup Octavian Scientific resulted in Oregon's first transaction in which a public university received equity in a public company in exchange for technology). The ICD&TL has 4 PhD faculty, 384-pin 150MHz digital test capability, rack test electronics for analog measurements up to 22GHz, and a 200mm wafer prober with a temperature range of –40C to 120C. PSU has published research in the area of test coverage and productivity.

Wireless Applications

OSU's Industrial and Manufacturing Engineering group has a wireless networks and RFID group that is very strong in applications. Over the last few years, OSU has hired (from U. Pittsburgh) national-level experts in industrial barcode and RFID systems, and has one of the nation's top RFID technologists, Dr. David Porter, who also serves on the ANSI Committee for RFID standards (NSITS-T6). In the last year, this group has won approximately $2M in new research and service contracts, and is highly sought after for testing and optimizing (e.g. placement of transceivers in buildings) wireless networks. OSU also won over $0.5M out of a $1.6M ODOT federal contract to investigate the use of wireless technology for Vehicle Mileage Tracking (VMT), a concept that is used in truck fleets today, and which may serve in the future as a more rational basis for tax funding of roads and bridges. Oregon leads the nation in developing the VMT application, which could become a very large longer-term opportunity, pending social and political acceptance of a new concept for infrastructure funding.

OHSU/OGI recently received a $300,000 grant from Intel to develop sensors with on-board data processing and wireless communication capability for monitoring and responding to cognitive impairment in elderly people.

Network Security

PSU also has expertise and valuable industry connections in the area of wireless networks, network security, and computer forensics. PSU is the only university in the Pacific Northwest to hold an NSA certification for its computer security educational program.

OHSU's OGI School of Science and Engineering has done some NSA-sponsored research (amount unknown) in the areas of software reliability and safe/secure distributed systems.

WEAKNESSES

The research metrics and faculty sizes for these programs are quite small by most standards, although student numbers are quite respectable. Although

funding from industry is significant (particularly in the last few very difficult years for semiconductor companies) it is not at a level that makes for a “wealthy” program or department.

Though facilities at OSU and PSU have some good equipment, they are relatively small compared to leading universities. It is at least a perceived weakness that a major integrated circuit design program is not associated with a wafer fabrication facility, however the researchers have used this to their advantage by fabricating devices in TSMC, Texas Instruments, National Semiconductor, and other fabrication facilities. This has broadened the impact of the research as well as enabled the researchers to identify significant research problems relevant to industry that would not have been possible if they had a captive fabrication facility. Additionally, it is our belief that university ownership of a general-purpose fabrication facility (as opposed to specialized/unique facilities) would be a mistake, and that fabrication partnerships with industry (e.g. OSU with National Semiconductor) will continue to be the most effective way to build integrated circuit designs.

The other side of faculty productivity is a high faculty student load that works against having time to raise significant additional research funding and spin out new technologies. As with the MMD field, Oregon’s very poor support of higher education is a fundamental limiting factor.

MARKET OPPORTUNITIES

Applications of Analog and Mixed Signal Circuit technologies are too numerous to list exhaustively, but some of the most notable ones are:

- Cellular phones and towers, and the emerging 3G and 4G standards
- Wireless network cards for PDAs and laptops
- Wi-Fi (wireless fidelity, 802.11) and UWB (ultra wide band) networks for homes and businesses
- Wi-Max (802.16) networks for longer range, e.g. “last mile” broadband internet connections
- Multimode PC chips (cellular, wi-fi, bluetooth)
- Outdoor wireless standards, solutions to interference issues
- VMT - Vehicle mileage tracking, possibly replacing fuel taxation as a method for funding transportation infrastructure
- VOWLAN/VOIP – Voice Over Wireless LAN, Voice Over Internet Protocol - computer telephony, intranet applications
- Wireless network optimization, installation, testing, and management
- RFID tags and systems for retail and other applications
- GPS-based products
- Wireless sensor networks – environment, infrastructure, agriculture
- Infrastructure and network security for businesses and Homeland Security

- Inkjet printheads and other intelligent MEMS devices
- Imaging chips – scanners, camcorders, cameras, PDAs, cell phones, security
- Power semiconductors – consumer, lighting, automotive
- Medical devices for diagnostic, monitoring, portable and implantable functions

The market size for AMS ICs is highly dependent on what definition is used for AMS, i.e. what is considered an analog function, and how much analog functionality must be present on a chip for it to qualify as AMS. A reasonable figure at present is $30B/year, or 15% of the total semiconductor market. This percentage is expected to grow substantially.

The 802.11 WLAN (wireless local area network) market is expected to grow to $3.0B by 2007 (Dell'Oro Group), and 802.16a equipment is expected to reach $1.0B in sales by 2008, with accelerating growth beginning a few years from now.

GPS equipment sales are expected to finish 2003 at $16.5B, growing at a CAGR of 29% since 1999 (US GPS Industry Council)

RFID equipment and solutions are a $1B market in 2003, and expected to reach $3.0B in 2007 – a 23% CAGR (Wireless Data Research Group).

According to a Business Communications study, the market for microelectronic implantable medical devices is estimated to be $9 billion in 2003. The majority of the market is in cardiac devices but the neurological segment is growing rapidly.

Cybersecurity is a large market already - $17B in 2001, growing to $45B in 2006 (21.5% CAGR) – with the largest growth expected in security-related hardware (International Data Group). A separate market forecast for overall cybersecurity software has not been found, but this could be a very significant opportunity depending on actions taken/mandates and grants issued from the U.S. Department of Homeland Security. $1.9B is currently targeted for local responders, and the RAINS group of companies hopes that the already-deployed RAINS-Net can be sold to providers receiving these grants. It is also significant that at a time when software jobs are highly mobile, work in matters of national security should be less likely to be sent overseas.

Some selected specific market size estimates serve to illustrate the breadth and depth of this field:

Applications	Current market ($billion)
Total Semiconductors	$200B
Processors	$52B
Analog and mixed signal circuits	$30B
Application Specific Circuits	$20B
Automotive electronics	$80B (~15% is semiconductors)
Cell phones/wireless handsets	$65B (~33% is semiconductors)
Electronic Design Automation	$2.76B
Image sensor chips	$1.7B
RFID equipment and solutions	$1B (very fast growth)
RFID Tags (2007)	$460M (very fast growth, no end in sight)
Wireless data services - 2005	$18B (very fast growth)
Firewall hardware (network security)	$2B (fast growth)
Firewall software	$1B

Derived from publicly available market data sources.

CHALLENGES

AMS and wireless applications programs are deserving of more focus by OUS, and are attractive opportunities for expansion in at least the next 5 years as these fields grow rapidly. Funds (e.g. ETIC) for recruiting more top faculty and for providing faculty released time to prepare major research proposals would be well spent.

Partnerships with Oregon industry in integrated circuit design could be enhanced by providing more time for department heads and faculty to visit and interact with industry on practical problems and emerging applications. This is an important activity for building relationships and crafting successful partnerships, especially in fast-moving opportunities like this one.

CONNECTIONS to OREGON INDUSTRY

Oregon's semiconductor operations are generally best known for their process development capabilities and manufacturing technology, but analog and mixed signal circuit capability is an increasingly important technology for any semiconductor company as single chip systems become more complex. ASICs (such as those provided by LSI Logic) increasingly include analog functions and non-volatile memory, and microprocessors are increasingly integrating wireless functionality and antennas on-board. Thus, Oregon's industrial strength in

AMS/wireless should tend to track its impressive strength in semiconductors. Oregon does have significant representation from companies in the AMS market, including 2 of the top 10 analog suppliers.

Examples of Oregon industrial activity in AMS/wireless include:

- The Intel (Washington County) Centrino™ family
- Intel Capital investments and interest in wireless communications and networking companies, including some in Oregon
- LSI Logic Mixed Signal ASICs
- Lattice Semiconductor (Hillsboro) is a leading supplier of Field Programmable Gate Arrays and Programmable Logic Devices
- Hewlett-Packard inkjet printheads include analog/digital/power circuits coupled with MEMS technologies
- Microchip (Gresham) PICmicro™ processors with AMS circuitry
- Agilent Technologies (Corvallis), a world leader in imaging chips, especially for mobile devices; very successful optical mouse chip
- Analog Devices - #5 worldwide supplier of analog integrated circuits and a leader in MEMS products
- Maxim Integrated Products (Beaverton/Hillsboro)- #7 worldwide supplier of analogs
- Triquint Semiconductor (Hillsboro) is a major producer of high performance compound semiconductor integrated circuits for wireless communications
- Mentor Graphics (Wilsonville) EDA software with analog-mixed-signal emphasis
- Advanced Power Technology (Bend) manufactures high voltage/currents for power conversion and control
- Tektronix (Beaverton) is a/the leading supplier of RF/wireless test equipment
- Pixelworks (Wilsonville) is a leading supplier of integrated circuits for control of data projectors
- Numerous small/startup semiconductor test and wireless companies (Network Elements, Teseda, Accelerant, Mobilian, Octavian Scientific, Eleven Wireless, VeriWave).
- Biotronik (Lake Oswego) has just announced (12/4/03) a major sales contract for its wireless cardiac rhythm management monitor for home healthcare application. This is believed to be the world's first wireless communication system for remote monitoring of implantable pacemakers and defibrillators.
- Inovise (Newberg) is a well-funded (~$40M) startup that is commercializing high information content extensions to electrocardiography by measuring and interpreting sonic signals
- Roughly 15% of recent Portland area VC-funding events have been in the AMS/IC/wireless area (e.g. Accelerant Networks, Eleven Wireless,

Mobilian, Network Elements, Pixelworks, Octavian, Teseda), and another 11% have been in the information security area (e.g. Fios, GeoTrust, TechTracker, TripWire, TrueDisk).

- PSC Scanning (Eugene) is a leader in barcode scanning systems for retail applications- a market that is beginning a transition toward RFID
- Oregon RAINS (Regional Alliances for Network Security) is a collaborative group of mostly software companies with technologies that are expected to be important for complying with upcoming Homeland Security requirements.

ANALOG AND MIXED SIGNAL CIRCUITS SUMMARY

STRENGTHS

Probable top-10 AMS program at OSU
High % industry-sponsored research
Silicon Forest industry concentration
RFID applications research

WEAKNESSES

Research metrics and ranking relatively weak
No recent Oregon startups
Few university patents and protected IP
Basic university funding weak

OPPORTUNITIES

$30B AMS semiconductor segment growing
Wireless data communications growth
RFID applications growth
Wireless network security

CHALLENGES

Grow competitive research
Recruit top faculty and students
Launch successful startups

EDUCATION AND BEHAVIOR INTERVENTION

Education is a major concern in Oregon. The state spent just over the national average per student in the period 1999-2000 and achieved high rankings in 8th grade math and reading. Over 90% of schools have internet access and there is one computer for every 4.3 public schools students.

In the area of e-learning, more than 50 percent of U.S. high schools currently offer online courses or are exploring them for the future. The increase applies particularly in rural states where students do not have access to specialized teachers. The U.S. market for the online higher education industry is expected to grow from $1.2 billion in 1999 to $7 billion in 2003. The total e-learning market is expected to grow to $100 billion.

Behavior modification as a business has been largely focused on tobacco, alcohol and substance abuse and obesity as related to diet and exercise. There are also programs for the prevention of violence in schools, including one managed by UO. The substance abuse behavior modification market is estimated at over $1 billion in 2003.

Oregon has a world-class research effort in education and behavior modification that could enable the state to become a leader in these emerging markets. The commercial applications are not immediately obvious and the industry currently is small, but we have chosen to include this cluster as an emerging core competency.

STRENGTHS

Oregon universities have over $65 million in research funding. A total of 193 investigators have 229 grants. The University of Oregon's graduate program in education was ranked in 2003 as second nationally among public schools of education, according to US News and World Report. Its faculty was ranked as most productive in the nation. OHSU's graduate nursing program was ranked number six in the nation. This level of excellence in education training and research could create additional economic opportunities for Oregon.

Areas of Focus in Oregon

The UO **College of Education** received two five-year federal grants, each approximately $4.5 million to establish two national research centers to improve student behavior and reading. UO is the only school to receive funding for two centers. The UO has consistently ranked in the top ten of graduate colleges of education and is the best in the Northwest. It is the fourth ranked public school and third-ranked in special education.

The **Center for Improving Reading Competence Using Intensive Treatments School-wide** (CIRCUITS) will develop intervention programs and methods of delivery for students with reading disabilities in grades K-3. The researchers believe that they have a solid, scientific knowledge base for improving the teaching of beginning reading.

The **Center on School-wide Behavior Support** aims to increase the capacity of schools, families, and communities to support and educate children with significant problem behaviors. Their school wide approach (which they call Effective Behavioral Support) defines, teaches, and encourages appropriate behavior in children in elementary and middle schools. "Effective Behavioral Support" is based on the fact that about 85% of students have the social skills to do quite well if placed in a reasonable environment.

More than 90 schools will take advantage of a proven ability to identify children as young as three who are at risk for delinquency and target these students for early intervention. Hill Walker, associate dean of the College of Education at the University of Oregon, has piloted an early intervention program in Eugene, Oregon. Called FIRST STEPS, the program enlists school staff and peers to teach and reinforce pro-social behavior. Parents learn to teach their children how to succeed at school.

Many elementary, middle, and high schools in America have instituted peer conflict-resolution programs. Research data, partly from the UO, are accumulating that show peer conflict-resolution programs reduce discipline referrals; improve the school climate; and increase self-esteem, confidence, and responsibility in the students who go through training.

ORI recently received $4.1 million in grants from NIH to focus on alcohol and substance abuse in adolescents. For more than 20 years, ORI has conducted research to help prevent smoking in adolescents.

Oregon Social Learning Center (OSLC) focuses on researching what parenting methods are most effective for raising well-adjusted children. They received a $4 million grant from NIMH to study delinquency.

OHSU has a program on the impact of managed care on behavioral health care and a nursing program that was ranked 6th in the nation overall for 2003 by U.S. News and World Report.

WEAKNESSES

The research at Oregon schools has little connection with, and virtually no funding from, industry. While some of the research could have commercial applications, for example in e-learning and distance learning as well as behavior modification, there has been little movement in that direction. The Oregon-based

educational and behavior companies do not collaborate with researchers as far as the interviewing team could discern.

MARKET OPPORTUNITIES

IDC predicts that the on-line education market will grow to $100 billion. However analysts and educators agree that it is still a nascent industry and many start-ups in the market have failed. According to the figures published by Learnframe, the global education and training market has a size of $2 trillion, out of which the U.S.A has a share of $740 billion. Approximately 10% of this is "for-profit" business (comparable with IDC's $100 billion).

A new report from eMarketer agrees with these projections and raises the following points:

- The market has been subject to overestimated projections; however indications now are for a rapidly growing sector.
- The current generation has grown up with the Internet and video games and students will respond to online educational opportunities.
- The percent of US schools with Internet access has grown from 56% in 1999 to 76% in 2002.
- In 2002, US educational testing spending was a $925 million market; online and computer-based assessment accounted for $50 million.

The major opportunities appear to be in the development of programs, videos and other channels to disseminate the research knowledge. The challenge will be for Oregon to develop appropriate products for this burgeoning marketplace.

CHALLENGES

Major challenges for the creation of an industry sector based on research currently being performed at Oregon institutions include a lack of focus on potential commercial products and a lack of interaction between researchers and the e-learning industry. Without an external stimulus, such as directed funding for focused projects, this connection is not likely to occur.

CONNECTIONS to OREGON INDUSTRY

Existing Oregon companies active in the Educational Market:

Inspiration software produces software and expects to have revenue of $18M in 2003.
Study Dog, Inc. produces online reading systems.
Learning.com produces online instructional services for K-12.
Learning Services produces software and multimedia products for educators.

International Society for Technology in Education is a non-profit organization that produces tools for educators.
JamStart produces and publishes advertising-free periodicals for children. The periodicals aim to help children learn to read.

Existing Oregon companies active in behavioral science:
Oregon Center for Applied Science produces videos for behavior modification.
Applied Behavior Science Press publishes books and videos on smoking cessation.
Deschutes Research produces behavior modification products for smoking cessation.

EDUCATION AND BEHAVIOR INTERVENTION SUMMARY

STRENGTHS
Strong funding over $65 million
About 200 PI's
High ranking academic programs
Some new companies

WEAKNESSES
Little connection to commercial applications
Low interinstitutional collaboration
No industry funding
No university-based startups

OPPORTUNITIES
>$100 billion future markets
Online education
Educational testing
Educational games

CHALLENGES
Focus on commercial applications
Build stronger industry partnerships
Launch successful startups

ADDITIONAL AREAS OF RESEARCH STRENGTH

The following research groups were not selected to be included in the top five Core Research Competencies. The reasons for this are included in the descriptions below. In most cases there is excellent research but the direct connection to incremental, high-wage economic development in Oregon is not clear. Agriculture and forestry are mature industries in Oregon. Many of the large forestry companies and food processors are not headquartered in the state. In the case of basic biomedical research, there is significant breadth, but no single cluster from a market perspective. Intersections with market opportunities addressed by Oregon industry for each of these three areas have been included in the top five Core Research Competencies.

AGRICULTURE and FOOD PRODUCTS

Agriculture has been a major industry in Oregon and was approximately $3 billion in 2001. In addition there was at least $2 billion in value-added food products. The two largest agricultural sectors were livestock production and nursery production. The state has led the nation in the production of some specialty crops such as grass seeds, mint and some fruits and nuts, although some of these are now declining for Oregon due to international competition. Oregon also is a leader in horticulture, cut greens and flowers and the production of Christmas trees. Many of the most successful farms in Oregon are moving their emphasis towards a greater degree of integration. They are developing and selling higher value products based on crops that would otherwise be sold at the farm gate, at prices set by the processors and other channels.

Governor Kulongoski has expressed the need for a strategy for the development of sustainable agriculture that minimizes the impact on the environment and water quality. He also called for investment in agricultural research and incentives to support sustainable agriculture and to develop markets for the products of agriculture. In regard to food processing the governor has called for the industry to be considered as an integrated regional cluster that can work together to take advantage of technological advances.

Oregon has a good base of both agricultural research and food research at OSU. OSU received over $27 million in funding in 2003 for agriculture and food science. Funding has been increasing over the last three years. The majority of this funding comes from the USDA, with about 12% coming from private industry. The challenge is to identify large commercial opportunities arising from the research. These connections were not found to be obvious in interviews or grants analysis.

There are five federally supported **USDA** agriculture research centers in Oregon. These had R&D expenditures of over $29 million in 2000.

The OSU **Center for Innovative Food Products** in Portland supports producers in designing food products. They provide science-base research and educational information to agricultural producers and food processors that seek to develop value-added products for new markets.

An area of increasing emphasis relates to "integration" of agriculture or production and marketing of high value-added products. **Bear Creek Corporation** in Medford is one of Oregon's leading employers. Many large farming operations have moved to value products ranging from beef and lamb, including some range-fed and organic, to mint oil, jams and juices and cut flowers.

While food-processing technologies from OSU have been licensed and utilized by the industry in the past, these licenses are now mature. Large new market opportunities arising from the research base in agriculture or food processing are not obvious at this time.

Although there has been a lot of successful breeding in many plant species at OSU, research in horticulture does not appear to have major economic impact on the Oregon agriculture industry. One notable opportunity for the future is **OSU's** selection as one of five national centers for research, education and outreach programs in "bioenergy" under a congressional Sun Grant initiative. This plan calls for up to $75 million a year in funding, of which OSU would receive 20% representing a nine-state Western region. The new program is designed to reduce U.S. reliance on imported fossil fuels and enhance energy security.

FORESTRY and SUSTAINABLE ECOSYSTEMS

Approximately 28 million acres of Oregon's total of 61.5 million is forested and forestry continues to be an important industry for Oregon. However, there have been major declines in the timber harvested over the last thirty years. Oregon's primary and secondary wood-processing industries annually generate approximately $10 billion in sales, which supports nearly 75,000 direct jobs.

OSU is a national leader in ecosystems research relating to forestry. Funding was approximately $18 million in 2002, with the majority of funding from federal programs, and about 12% from private industry. This research is applicable to the design and certification of sustainable forests and there is increasing consumer demand for such certification. This certification indicates that the wood is derived from sustainable forest ecosystems. However, this requirement is not universally accepted by the industry. While Oregon research has been important in determining how sustainability is assessed, it is difficult to project how this might change or increase the industry in Oregon, so the translation of this research into commercial opportunities and employment growth is not clear at this time.

The Ecological Society of America recently determined OSU **College of Forestry** to be the best in the nation in the field of forest ecology. In the Phase I analysis of publications, we found that forestry and ecosystems had over 1100 publications.

Areas of potential intersection between eco-research and industry that may bear exploring in Oregon include the use of nature (micro-organisms, fungi, enzymes and plants) to neutralize pollutants, and promoting ecological design in apparel.

BASIC BIOMEDICAL RESEARCH

Overall, the findings indicate that the most concentrated field of biomedical research is directed towards a functional understanding of the brain and nerve cells. Underlying the strength in neuroscience research is a growing strength in biomedical research in Oregon. State research institutions, led by OHSU, have increased NIH funding by 75% in the four years between 1998 and 2001. While this growth appears impressive, Oregon ranked 32nd in terms of percent change, just ahead of the national average of 70%.

In overall R&D expenditures at research universities Oregon ranked 18th in per capita federal funding and 11th in per capita support of R&D from state and local sources but only 26th in total funding, reflective of a lack of industry sponsored research.

The range of biomedical research is large. While the greatest concentration is in neuroscience research, there is also strength in cancer, enhanced by the research funding associated with the Oregon Cancer Research Center. The Center has an important collaboration with PNNL in the field of proteomics. In a specific, high-profile drug development success, Dr Brian Druker at OHSU performed pivotal research in the discovery of a new drug, Gleevec, which had one of the fastest approval times of any drug in recent history, but was owned and developed by a company outside of Oregon.

OHSU has a well-recognized strength in endocrinology. In recent years much of this strength, partly concentrated at the Oregon Regional Primate Center, has been directed towards neuroendocrine research. There is also some excellent research in infectious and genetic diseases.

Overall, Basic Biomedical Research has significant breadth, but no single cluster from a market perspective. Its intersections with market opportunities addressed by Oregon industry have been included in several of the top five Core Research Competencies – Multi-Scale Materials and Devices, Brain Function and Disease, and Information to Knowledge.

ONGOING ANALYSIS

The information presented in this report is partially based on quantitative data including information on patents, grants to universities and publications collected from a variety of sources. We were asked to suggest a process by which such information could be gathered and analyzed on an ongoing basis

Some of the data analyzed during this project has been previously presented in Phase I and Phase II interim reports. The following appendices contain the data used as a partial basis for this report and a list of the people interviewed during the course of the study.

Appendix 1 *Oregon Patent Data* lists the identified patents by company and sector.
Appendix 2 *Oregon Grant Data* shows federal grant funding by cluster and department.
Appendix 3 *Starlight Analysis of Oregon University Grant Data*
Appendix 4 *Publication Topics by Cluster*
Appendix 5 *Starlight Technical Literature Clusters* shows the results of a Starlight cluster analysis of Oregon publications.
Appendix 6 *Citation Results* shows the results of some directed citation searches.
Appendix 7 *List of people interviewed*
Appendix 8 D*ata Collection Methods* describes the proposed data collection in more detail.

Based on the experience gained in performance of this project, and the desirability of conducting similar analysis on a regular basis in the future, we believe the following information should be collected every two years or so:

1. Counting and rough classification of patents issued to Oregon inventors and assignees. Further details are given in Appendix 1, but essentially this will involve several hundred searches of the U.S. Patent and Trademark Office database using the names of companies and research institutions having a presence in Oregon. The resulting patent counts, when sorted by technology categories gives one indication of R&D strength/investment by industry segment. By taking the ratio of recent (e.g. last 8 years) patents as compared to longer term (last 25 years) patents in each category, emerging/growing fields can be roughly distinguished from aging/mature fields.
2. Analysis of research grants received by Oregon universities and research institutions. Details are given in Appendix 2, but this analysis should be done in three parts in order to assemble the most comprehensive picture:

a. Federal scientific grants analysis – NIH and NSF. Unfortunately, only NIH consistently provides both numbers and amounts of awards.

b. Analysis of grants data provided by the institutions themselves. Ideally, this information will be categorized not just by college and department, but also by thematic research cluster, as OSU's College of Engineering is beginning to do.

c. Starlight™ analysis, provided by PNNL, of grants to Oregon institutions by all federal agencies. This "crunching" of several thousand awards returns a display of the data organized into thematic clusters, and as such is more of a visualization tool rather than a counting method. It is useful as a verification of the two prior analyses, or as a means of capturing important themes/emerging research competencies that they missed.

3. We recommend discontinuing detailed analysis of publications and citations. This is laborious, and in our experience, did not contribute any essential new information. It did, fortunately, tend to mirror the grants findings.

4. Human knowledge. The greatest insights in this study were gained by interviews with leaders and experts in academia, industry, and the business professions. Private knowledge, networking knowledge, and current events (e.g. the 21st Century Nanotechnology Research and Development Act) come into play here. We know of no way at this time to automate this process or to render it suitable for analysts without a research and/or technology background. It was exactly this form of "expert analysis" which led to the selection of Multi-scale Materials and Devices as the first signature research concept, and which our findings confirm as the best choice. It is unlikely that the patent and grants analyses alone would have led to the identification of this opportunity, although they were essential for identifying the deeper research competencies and future opportunities.