ARIZONA OPTICS: A TARGETED INDUSTRY SUMMARY REPORT

Prepared for the

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INTRODUCTION

Once upon a time the field of optics was pretty straightforward, limited to a fairly narrow range of applications, constituted primarily of lenses and mirrors, and the basic materials thereof. Although these technologies and applications remain a component of the industry, the sector has taken on an entirely different character. This new field of optics is so young and dynamic that it lacks a universally accepted title. Referred to almost interchangeably as Optics, Photonics, Electra-optics or Optoelectronics, the field encompasses a range of physical and digital technologies that are loosely associated by their basis in light and its application and manipulation to perform useful tasks.

Much of Arizona's optics industry grows from the region's status as a center of world-class astronomy and The University of Arizona's pre-eminence in that and the broader field of optical sciences during the 1950s and 60s. This sector's strength, a large and diverse array of small, innovative, technically rich, scientist/entrepreneur-based firms, is also its weakness for it lacks a counterpart share of large production-oriented; vertically-integrated firms that are necessary for a well-balanced regional industry.

> Optics defined:
>
> *Optics is the field of science and engineering encompassing the physicalphenomena and technologies associated with the generation, transmission, manipulation, detection, and utilization of light.'*

Given the inevitable acceleration in the commercial application of optics-based technologies *the potential* economic benefit to the State of Arizona, and southern Arizona in particular, is very substantial. However, realizing these benefits is far from inevitable because other regions of the United States and elsewhere in the world are gearing up to take advantage of this emerging sector. Whether or not Arizona plays a prominent role in the long term future of optics may ultimately depend on a shared development strategy between the Arizona Department of Commerce, Greater Tucson Economic Council and other local economic development agencies, and the Arizona Optics Industry Association.

The information in this paper is based upon a variety of sources, drawing extensively from *Harnessing Light: Optical Science and Engineering for the* 21st *Century,* an excellent publication from the National Research Council (see Endnotes) and some recent unpublished work by the UA Office of Economic Development. Additional information is drawn from the U.S. Bureau of the Census and Bureau of Labor Statistics, as well as some proprietary database services. Industry surveys in 1995 and 1999 and a series of recent interviews with Arizona industry and university managers and scientists, coupled with a decade of the UA Office of Economic Development's industry monitoring provide a basis for the Arizona-specific overview.

UNDERSTANDINGTHE OPTICS FIELD, MARKET AND INDUSTRY

The role of light in our lives has expanded enormously over the last several decades, but that change is barely underway in contrast with the acceleration that will occur over the next 10-20 years. The application of optics-related technologies will play an enabling role in the advance of telecommunications, the practice of medicine, national defense capabilities, computing technologies and innumerable other industrial applications and avenues of scientific inquiry.

Coherent and Incoherent Light

The evolution of optics from a tool for manipulating light to a technology that applies light as a tool, began with the invention of the laser in 1960. The "coherent" beam of light generated by the laser has properties that allow its direction, focus and propagation unlike all other (incoherent) light sources. Applications of incoherent light technologies also continue to advance the frontiers of science and industrial processes.

- Laser technologies are found in all manner of consumer and industrial devices today, ranging in size from large manufacturing devices to semiconductor-based diodes no larger than a grain of rice.
- Coherent light applications have made possible fiber-optics communications, laser surgery, compact disks, more efficient and precise manufacturing processes and innumerable other advances.

- Incoherent light technologies drive ultra-high resolution optical lithography, adaptive optics for astronomy, infrared and other non-visible light remote-sensing applications and higher efficiency alternatives to conventional illumination technology.

The Diversity of the Industry

An exhaustive inventory of optics products would not be possible, but it's useful to generally understand the products of this industry on two levels, the basic optical components and the equipment and systems that include them. Note that the finished products may or may not be considered an optical good. Consider also the enabling effect that some of these components have had individually or in combination. The markets for lasers and fiber optics were growing relatively modestly until those components were refined and combined, at a cost of several hundred millions of dollars, resulting in a $1 trillion digital communications network today.

Examples of optical components:

- Lenses
- Mirrors
- Prisms
- Diffraction gratings
- Light sources
- Lasers
- Modulators
- Detectors
- Displays (liquid crystal, flat-panel, video, etc.)
- Optical fibres and connectors
- Windows
- Eyeglasses and sunglasses
- Coatings for heat-reflecting or W-blocking

Examples of optical equipment, instrumentation, subsystems or systems:

- Sensors (image, thermal, distance, size, shape, etc.)
- Imaging systems (video, digital and film cameras), including image analysis software and hardware
- Optically-based information storage systems (CD, DVD, etc.)
- Xerographic copiers
- Laser and LED printers
- Video-based guidance and tracking systems
- Ground-based or space-based telescopes
- Microscopes (analog and digital)
- Photolithography equipment
- Fiber optics
- Laser communications systems
- Digital and bar code scanners
- Laser-based cutters, welders and markers
- Rapid-prototyping equipment
- Medical diagnostic and surgical instruments
- Remote sensing and surveillance instruments and systems

Market Scale and Growth Projections

The optics market and the many markets that incorporate optics are headed into a very strong growth period over the next decade, driven by a combination of laser, imaging, display and image/signal processing technologies that enable new devices, instruments, and systems within markets ranging from healthcare to communications to aerospace."

- The global optics market was estimated to be more than $55 billion in 1998, with the U.S. representing about 60-70 percent of that figure. Annual growth rates are estimated to be 10-20 percent.
- In the optoelectronics subsector (devices that integrate optical components and electronics, e.g. lasers), global production was $12.5 billion in 1995, with U.S production representing slightly over half. Based on anticipated annual growth rates of 10 percent, the global optoelectronics market could reach $500 billion by 2013.

- Between 1975 (fifteen years after development of the laser) and 1995, the estimated annual international market for laser devices increased from $72 million to $1.2 billion. U.S. firms hold about 35 percent of this market.
- Fiber transport capacity, computer processing power and digital storage density are advancing by a factor of 100 per decade, moving towards "terabit-per-second" bandwidth on long-haul networks.
- A count of optics companies that appear in international commercial directories showed an increase from 1,300 in 1975 to 4,100 in 1997. About 70 percent are U.S. firms."'

The Optics Workforce
More than 125,000 engineers and scientists, and a larger number of specialized technicians are employed in the optics field on behalf of the public and private sectors. As the industry and its markets grow, the supply of adequately skilled scientists, engineers and technicians has not kept pace, and qualified individuals are becoming harder to find and hire.

Optics training could only be found in 23 U.S. academic institutions in 1986; the number increased to 132 in 1998, an almost six-fold increase in twelve years. Despite this increase, there is still a lack of optics-specific training and many firms must hire electrical or mechanical engineers, for example, who have not had significant training or exposure to optical technologies in the classroom or lab. To further an understanding of what distinguishes an optics-prepared engineer, scientist or technician, The International Society for Optical Engineers (SPIE) developed these occupational definitions:'"

- Optical Scientist - Conducts research into the aspects of optical phenomena, materials, techniques, and devices; develops theories and laws based on observation and experiments; and devises methods to apply laws and theories to industry and other fields.

  Minimum occupational requirements should be a BS in optical science or engineering, or other technical field such as electrical or mechanical engineering, or a related area. If the degree is a related technical discipline there should be at least a year of lab and classroom work in optics-related subjects, such as lasers, quantum electronics, optoelectronics, optical analysis or design, imaging systems, optical instrumentation, etc. *Desired occupational requirements* include a MS or PhD degree with advanced classes in optical theory and applications, with laboratory work wanted for all but pure theoretical jobs.

- Optical Engineer - Designs, develops, tests or supervises the manufacturing and installation of optical materials, equipment, instrumentation, components, subsystems, electro-mechanical or optoelectronic systems incorporating optical components or subsystems for commercial, industrial, medical, military, or scientific use.

  Minimum and desired occupational requirements for the optical engineer were the same as those identified for the optical scientist.

- Optical and Electra-optical Technician - Applies skills, optical theory, and related knowledge to polish, coat, or otherwise fabricate, setup, align, or install optical materials, equipment, instrumentation, components, subsystems, or systems for subsequent evaluation and use by scientific or engineering staff in making decisions relating to the use of optical technologies or products for commercial, industrial, medical, military or scientific use.

  Development of the *preferred skills and background* necessary for the optical technician is encouraged to begin in secondary school, if possible, with vocational courses in the areas of electronic digital signal circuits, circuits and microprocessors, machining/materials processing, and computer application software. This training should be supplemented with additional applied physics and mathematics courses.

The Challenge of Tracking and Measuring the Optics Industry
Obtaining comprehensive information about the contemporary optics industry from secondary sources is for the most part impossible because the sector cannot be discretely identified within the Standard Industrial Classification (SIC) system, an intricate hierarchy used to organize almost all business and industry statistics.

Prior to the development of the laser and advanced digital technologies, traditional optics manufacturing was generally encompassed in SIC 3827, *Optical Instruments and Lenses.* Although not insignificant in absolute terms, the growth and technical diversification of the industry means that only a fraction is represented by this sub-sector. In terms of Federally-generated statistical information, contemporary optics-related industrial activity is largely hidden within the industries that utilize it as a production process or as a subcomponent of final products that are not classified as optical goods.

Many of the "optics" companies in Arizona can be identified with seemingly unrelated industry sectors. Raytheon makes missile-based ordinance, Veeco makes instrumentation, Gruber Industries makes communications equipment, Breault Research Organization is a software firm, OptoPower makes semiconductor devices, and others use optical technologies in automotive parts, various printing and photolithographic applications, etc.

The obscurity of available optics-related industrial data prevents an encompassing description of the industry in terms of total number of U.S. firms, revenues, employment, etc. But, it is useful to examine the behavior and potential of industries that utilize optics-related technologies or consume optical subcomponents, as predictors of demand and industrial behavior. Relocation and site preference data, organized by SIC/NAICS codes, is presented later in this report.

Table one identifies a group of SIC manufacturing codes that encompass a majority of optics-related industrial activity. It also provides a cross-reference for the new 1997 North American Industrial Classification System (NAICS), which has begun to replace the 1987 SIC system There are only three SIC/NAICS categories in the chart that are exclusively optics-related - optical instruments and lenses, ophthalmic goods, and fiber optics cable manufacturing - the rest typically involve optics as a minority component.

Optics diffused:

"Although optics is pervasive in modern ***life, its role is that of a technological enabler:*** *It is essential, but typically it plays a supporting role in a larger system . . .*

...In the diversity andpervasiveness of optics lies great strength, but these same qualities similarly pose a daunting hurdle to concise assessments and simple prescriptions. "[v]

Table 1. Optics-related SIC/NAICS code correspondence table.

1987 SIC codes		1997 NAICS codes	
Code	**Industry description**	**Code**	**Industry description**
*3357	Drawing and insulating of nonferrous wire (fiber optic cable-insulating only)	335921	Fiber optic cable manufacturing
3646	Commercial, industrial, and institutional electric lighting fixtures	335122	Commercial, industrial, and institutional electric lighting fixture manufacturing
3647	Vehicular lighting equipment	336321	Vehicular lighting equipment manufacturing
3648	Lighting equipment, NEC	335129	Other lighting equipment manufacturing
3669	Communications equipment, NEC	33429	Other communications equipment manufacturing
3695	Magnetic and optical recording media	334613	Magnetic and optical recording media manufacturing
*3699	Laser welding and soldering equipment, NEC	333992	Welding and soldering equipment manufacturing
3823	Industrial instruments for measurement, display, and control of process variables; and related products	334513	Instruments and related products for measuring, displaying, and controlling industrial process variables
3826	Laboratory analytical instruments	334516	Analytical laboratory instrument manufacturing
3827	Optical instruments and lenses	333314	Optical instrument and lens manufacturing
3829	Measuring and controlling devices, NEC	334519	Other measuring and controlling device manufacturing
3841	Surgical and medical instruments and apparatus	339112	Surgical and medical instrument manufacturing
3845	Electromedical and electrotherapeutic apparatus	334510	Electromedical and electrotherapeutic apparatus manufacturing
3851	Ophthalmic goods	339115	Ophthalmic goods manufacturing
3861	Photographic equipment and supplies	333315	Photographic and photocopying equipment manufacturing
* Indicates the SIC code describes a broader industry than the corresponding NAICS designation.			

Source: U.S. Census Bureau

Although there is a lack of secondary information about the national industry or that of other states, this report is able to measure the industry in Arizona on the basis of the primary data generated by two optics industry surveys, conducted four years apart, in 1995 and 1999. Although company-specific information is categorically limited due to the narrow scope of the 1999 survey, there is a thorough review of the Arizona industry and its makeup in this report.

Global Industry Trends and Arizona Optics

A contemporary picture of the optics field can be illustrated through six major areas.“[vi] Each is followed by a brief related discussion of the Arizona industry.

Information and Telecommunications is very possibly the strongest sector for optical technologies over the next decade as applications broaden and the demand for communications bandwidth increases exponentially. Optics has become the dominant technology for all forms of long distance digital information transfer, and is increasingly utilized for short-distance digital communication. This is the result of technical innovations started by laser-powered fiber optics and currently driven by advances in fiber transport capacity, computer processing power and memory storage capacity. The explosion of internet use and movement towards a fiber-to-the-home national communications infrastructure will be significant drivers for this industry over the foreseeable future.

Interestingly, almost every key interview conducted for this report pointed out the importance of this sector, but lamented its relative absence in Arizona. Apparently an unrecognized phenomenon, Arizona’s industry includes a significant share of fiber optics and communications activity; about 10 percent of the firms and 12 percent of employment are involved in some aspect. There also seems to be a building momentum among Arizona firms to re-orient their product lines to serve this industry. Telecommunications is not considered to be one of the UA Optical Science Center’s relative research or instructional emphases, although considerable research has been done on optical data storage, a counterpart technology.

Health Care and the Life Sciences have made major advances through the integration of laser, fiber-optics and digital imaging technologies, manifested through the production of optics-related medical diagnostic and laboratory equipment, surgical devices and the X-ray, MRI and CAT-associated imaging systems. The use of optics technologies for non-invasive diagnostic methods and monitoring of body chemistries has tremendous potential. Ophthalmic science continues to advance through optical technology as more alternatives are developed for visual correction.

Arizona, particularly Tucson, has several companies that utilize optical technologies for medical applications, ranging from medical imaging to laser-based surgical equipment. A relatively strong research area with the potential to become much stronger, a variety of cross-disciplinary activities are taking place on the UA campuses to develop optics-based medical procedures and/or equipment. Toshiba has made a very significant multi-year investment in medical imaging, a particular area of strength involving researchers at the UA College of Medicine and Optical Sciences Center.

Optical Sensing, Lighting and Energy is a broad category of optics-related enterprise with a strong growth projection. More efficient lighting technologies are being driven to the marketplace by the enormous energy efficiencies they provide. For example, the conversion of the country’s stoplights to red LED lights is projected to save $175 million alone. Optical sensors are becoming more commonly integrated in industrial, consumer and military applications. The collection and interpretation of remote sensing data continues to advance and the entire data collection aspect of visible light astronomy is dependent on this category of the optics field. The development of cost-effective light-based renewable energy technologies such as photovoltaics continues to be hampered by relatively low prices for non-renewable forms of energy. Any significant upward trending in energy prices will stimulate this industry and signal an opportunity to promote formation or relocation of these types of firms.

An important component of the Arizona optics industry, this broad industry segment is well supported by Optical Science and Astronomy programs that develop and use light sensing technologies. Much of this research is still supported by Federal money, The research and the instrument needs of the astronomy community can be linked to the existence of a number of companies specializing in CCD-cameras and other light-based sensors. Several firms are involved in the development of energy-efficient display lighting. There is a moderate level of photovoltaic development and possibly fabrication in southern Arizona, but not the level logically associated with Arizona’s solar energy potential.

Optics Applied to Manufacturing Processes, one of the less obvious application areas, has had a profound economic impact in the course of improving industrial efficiencies. Applications can be divided into two categories: 1) the use of light to perform manufacturing, including the use of lasers in material preparation, assembly and finishing, and optically-based rapid prototype manufacturing; and 2) the use of optics to control manufacturing, including optical sensors, metrology and machine vision systems used in robotics.

This application area is significant to Arizona’s optics sector, relating to the development and manufacture of sensors, imaging systems, and laser-based welders, cutters and markers. Optical metrology, precision measuring devices such as interferometers, is key to many industrial processes and is a traditional area of strength in Arizona; the UA Optical Sciences Center and Mirror Lab have been technology drivers for this field in particular. In fact, the current Head of the Optical Sciences Center, James

Wyant, founded and recently sold WYKO (now VEECO), a leader in the interferometer industry. The decision by Edmund Scientific (an established supplier of industrial optics equipment) to locate their first remote sales and engineering office in Tucson can be viewed as a vote of confidence in the local industry.

National Defense remains a very significant application area for optics technologies. Defense expenditures have, over time, been the greatest economic driver of advanced optics technologies and almost every weapons system reflects that investment. Defense-related optics applications include imaging systems for remote sensing, battlefield surveillance, target acquisition and missile guidance systems. As the concepts of science fiction become reality, light-based directed energy weapons are being tested and refined. It can be expected that the development of optics-based defense applications will continue to offer civilian spin-offs as well, given the greater emphasis on commercial partnerships with the National Laboratories and the increasing tendency to blend commercial and military technologies in the face of decreased defense research funding.

Optics has long played a significant role in Arizona's defense industry, dominated historically by Hughes and, currently, Raytheon. Because much of the guidance and target acquisition capabilities of the various missile systems are optically based, this work has required the involvement of a strong optical engineering staff. After consolidation of some optics-related development programs from other Raytheon sites to Tucson, the optical engineers and scientists at Raytheon's Tucson facility represent one of the largest working groups of its kind in the United States. A number of smaller firms and consultancies in the community remain largely dedicated to defense assignments. Insofar as most of this work involves classified information, the nature and extent of this activity is difficult to assess.

Research and Education represents another aspect of optical technologies ' "identity crisis" due to its lack of a recognized academic or disciplinary home on almost every university campus. Similar to the workplace, optics technologies are often integrated with other academic disciplines like electronics, medicine or materials science. Some argue that the scientific advancement of the technology is constrained when utilized in disparate research as a tool rather than pursued as a focussed discipline. An alternate perspective, though not necessarily contradictory, is that interdisciplinary pursuit of optics research offers the most powerful vehicle for technological progress.

Both of the preceding perspectives are reflected in Arizona's most significant comparative advantage, the presence of a major academic and research unit dedicated exclusively to optical sciences at The University of Arizona that in turn amplifies and raises the standards of the extensive cross-disciplinary research woven through the University's science, medical and engineering faculties. In form and in scale, this sets the UA apart from every other university in North America'. In addition to providing a common identity and anchor for related research on campus, the Optical Sciences Center's international stature creates a rallying theme and a "cachet by proximity" for Arizona's optics industry.

Unfortunately, the throughput of graduates at all degree levels remains insufficient to meets the needs of Arizona industry but it has been suggested that this is as much a function (i.e. incoming students) as it is one of program capacity. The difficulty of finding qualified candidates to enter degree programs illustrates the need to promote these careers to younger age groups (currently underway through the Arizona Optics Industry Cluster's school-to-work programs). Additionally, the speed of change within the science indicates the need to develop continuing professional education programs for those who make optics their careers. Indeed, programs that routinely bring optical scientists and engineers to Arizona for training provide great exposure for the community and can influence business location decisions.

[1] It is acknowledged that The University of Arizona has a unique global prominence in optics-related education and research, and that knowledge of this activity is more available to the author of this report. However, the absence of information regarding optics-related inquiry and training at Arizona State or Northern Arizona Universities should not be interpreted to mean these technologies are absent on those campuses, although it can be said that they are not organized under a discrete optical sciences curriculum. The scope of this report did not require or permit a comprehensive examination of the optics-related research and training assets of the entire Arizona University system.

DEFINING THE ARIZONA OPTICS COMMUNITY

Arizona's core optics community, including public and non-profit astronomy and education organizations but exclusive of (non-optics) suppliers, is estimated to consist of about 160-175 companies/organizations and 6,500-6,750 employees at the midpoint of 1999. These estimates are based upon recent survey results, with allowances for firms that did not receive or return surveys.

The following industry characterization does not involve estimates and is based on primary data obtained through two surveys of the known Arizona optics community, during 1995 and 1999.[v11] A significant amount of information is presented here. For the sake of brevity, most of the tables will be considered self explanatory without extensive supporting discussion.

Size and Growth

Based on mid-1999 survey results, the Arizona optics industry reports a total of 136 firms and other organizations, employing 6,245 full-time equivalency (FTE) positions. This represents a substantial increase (65 percent) from the 3,793 FTE positions reported 1995 survey. The preponderance of this growth results from employment increases within existing firms, plus the addition of nine companies formed since 1995 and the inclusion of thirteen firms in 1999 that did not report in 1995.

Table 2. Arizona optics industry employment, 1995-1999.

	1995 employment	1999 employment	Percent change from 1995
Total reported employees	3793	6245	64.6%
Average employees per organization	33	51	54.5%
Median employees per organization	6	12	100.0%

Source: The University of Arizona Office of Economic Development, 1999.

There were substantial changes in organization-specific employment:

- Among organizations that responded to both surveys, in 1995 and 1999, employment grew dramatically from 3,716 in 1995 to 5,289 in 1999, a net workforce increase of 1,573 employees, or 42.3% over a period of four years. This is very robust growth for an industry sector that is dominated by manufacturing and pre-manufacturing services.
- 44.1% of the organizations surveyed in 1995 and 1999 increased the size of their workforce, by a median figure of 90.1% and an average of 3.5 times.
- In 37.3% of the organizations surveyed in 1995 and 1999, the employment remained the same.
- 18.4% of the organizations surveyed in 1995 and 1999 decreased the size of their workforce, eliminating 148 positions. Among organizations cutting back on workforce, median reduction was -33.3% and the average was -40.6%.
- During the period of 1995 and 1999, employment gain due to newly established companies was 78 workers. This represents about three percent of observed employment growth.
- Median firm employment doubled from six to twelve FTE between 1995-1999, indicating significant expansion at the "micro firm" level.

Arizona Industry Structure

By Functional Category -- Because it can be classified on so many different levels, this analysis categorizes the Arizona optics industry in several different forms. Table three breaks the industry down into six functional categories, as indicated below. Unlike the more complicated classification systems that follow, this simple hierarchy can be applied to include all of the reporting firms that provided product or service descriptions.

Table 3. Distribution of Tucson, Phoenix and Arizona optics firms/organizations by primary enterprise functions.

Primary enterprise categories	Number of firms/ number of firms providing employment data	Number of employees in 1999/ share of region's optics employment	Share of state optics employment
Metropolitan Tucson			
Manufacturing	33/29	1105/28.7%	33.8%
Consulting, research and development, prototyping	32/28	1414/36.7%	98.7%
Astronomy (primarily non-commercial)	5/5	945/24.5%	92.6%
Sales and distribution	5/4	10/0.3%	8.5%
Total	80/69	3853/100.0%	61.7%
Metropolitan Phoenix			
Manufacturing	36/35	2135/98.3%	65.2%
Consulting, research and development, prototyping	2/2	19/0.8%	1.3%
Astronomy (primarily non-commercial)	0/0	NA	NA
Sales and distribution	8/7	105/4.6%	89.7%
Total	48/46	2275/100%	36.4%
Non-Metro			
Manufacturing	4/4	34/29.1%	1.0%
Consulting, research and development, prototyping	1/1	6/5.1%	0.4%
Astronomy (primarily non-commercial)	2/2	75/64.1%	7.4%
Sales and distribution	1/1	2/1.7%	1.7%
Total	8/8	117/100%	1.9%
Arizona			
Manufacturing	73/65	3274 /52.5%	100%
Consulting, research and development, prototyping	34/30	1433/23.0%	100%
Astronomy (primarily non-commercial)	7/7	1020/16.3%	100%
Education (primarily non-commercial)	2/2	327/5.2%	100%
Sales and distribution	14/12	117/1.9%	100%
Software	3/3	68/1.1%	100%
Total	136/123	6245/100%	100%

Source: The University of Arizona Office of Economic Development, 1999.

Impressive Rate of Growth in Arizona Optics Manufacturing --Table four elaborates on the manufacturing component of the Arizona optics industry. Optics manufacturing employment is compared with total durable goods manufacturing employment at the state and metropolitan levels. It is interesting to note that 60 of every 1,000 manufacturing workers in Tucson are involved with optics enterprise, but in Phoenix the rate is only about 13 per 1,000. The table also compares the growth rate of optics manufacturing employment to the overall increase in durable goods manufacturing employment. This is a very striking contrast, with optics manufacturing employment nearly doubling in Tucson. In reality, it has more than doubled, insofar as the number of employees (literally hundreds) recently hired by Raytheon is not documented for this report.

Table 4. Optics manufacturing employment as a component of total durable goods manufacturing sector employment.

	Durable goods manufacturing employment (April 1999)	Optics-related manufacturing employment* (August 1999)	Optics share of durable goods manufacturing employment	Growth in durable goods manufacturing employment, 1995-1999	Growth in optics-related manufacturing employment* 1995-99
Metropolitan Phoenix	131300	2135	1.63%	8.7%	71.4%
Metropolitan Tucson	23400	1459	6.24%	4.8%	93.2%
Arizona	167000	3627	2.17%	11.9%	76.5%

* It is assumed that the entirety of optics-related manufacturing falls within the "durable goods" subcategory.

Source: The University of Arizona Office of Economic Development, 1999.

Arizona Optics Industry Classified by Optical Equipment or Systems - Table five is included to help define the Arizona optics industry on the basis of optical equipment or systems. It is a fairly inclusive hierarchy; roughly two-thirds of the organizations and 85 percent of the employment can be assigned to a category. Note the wide variance in four-year employment growth between categories, without taking the proportional change too seriously when it involves less than five firms.

Table 5. Distribution of Arizona optics firms by primary product area, indicating various employment characteristics and age of firm.

Optical equipment or systems	Number of firms/ number of firms providing employment data	Number of employees in 1999/ share of total optics employment	Average/ median number of employees	Percent growth in employment 1995-99	Average year established
Sensors (image, thermal, distance, size, shape, etc.)	14/13	578/9.3%	44/25	124.9%	1982
Imaging systems (video, digital and film cameras), including image analysis software and hardware	17/13	484/7.8%	37/12	16.3%	1990
Optically-based information storage systems (CD, DVD, etc.)	3/3	121719.5%	406/14	193.9%	1987
Ground-based or space-based telescopes	16/15	1056/16.9%	70/15	10.8%	1978
Microscopes (analog and digital)	9/9	150/2.4%	17/7	92.3%	1986
Photolithography equipment	3/3	65/l.0%	22/4	18.1%	1986
Fibre optics	12/12	746/12.0%	62/18	161.8%	1988
Laser-based cutters, welders and markers	3/3	230/3.7%	77/15	132.3%	1992
Medical diagnostic and surgical instruments	3/2	253/4.1%	127/na	0.8%	1983
Remote sensing and surveillance instruments and systems	2/2	74/l.2%	37/na	10.4%	1980
Light sources	7/7	388/6.2%	55/9	24.8%	1994
Software	3/3	66/1.1%	22/12	120.0%	1989
Ophthalmic	3/2	28/0.4%	14/na	833.3%	1981
Not otherwise classified	40/36	905/14.5%	25/5	84.7%	**1988**

Source: The University of Arizona Office of Economic Development, 1999.

Arizona Optics Industry Classified by SIC and NAICS Codes - Table six shows the distribution of Arizona optics organizations by SIC and the counterpart NAICS codes. The "poor fit" between these classifications systems and the modem optics industry is suggested by the fact that about 40 percent of the firms and at least one-third of the employment cannot be clearly assigned to a four-digit SIC or six-digit NAICS code.

Table six. Distribution of Arizona optics firms, by optics-related SIC and NAICS codes, with firm characteristies.

SIC and NAICS Codes (in corresponding pairs) most likely to contain optics-related enterprise — Code	Description	Number of firms/ number of firms providing employment data	Number of employees in 1999/ percent share of total employment	Average/ median number of employees in firm	Percent growth in employment 1995-99	Average year established
*3357 335921	Drawing and Insulating of Nonferrous Wire Fiber optic cable manufacturing	2/2	393/6.3%	173/NA	754.4	1989
3646 335122	Commercial, Industrial, and Institutional Electric Lighting Fixtures Commercial, Industrial, and Institutional Electric Lighting Fixture Manufacturing	1	9/0.1%	NA	80.0	1994
3647 336321	Vehicular Lighting Equipment Vehicular Lighting Equipment Manufacturing	2/2	290/4.6%	37/NA	33.6	1993
3648 335129	Lighting Equipment, NEC Other Lighting Equipment Manufacturing	8/8	497/8.0%	62/15	36.9	1989
3669 33429	Communications Equipment, NEC Other communications equipment manufacturing	7/7	337/5.4%	48/20	48.5	1985
3695 334613	Magnetic and Optical Recording Media Magnetic and Optical Recording Media Manufacturing	1	1200/19.2%	NA	200.0	1978
*3699 333992	Laser Welding and Soldering Equipment, NEC Welding and Soldering Equipment Manufacturing	2/2	21/0.3%	11	50.0	1991
3823 334513	Industrial Instruments for Measurement, Display, and Control of Process Variables; and Related Products Instruments and Related Products for Measuring Displaying, and Controlling Industrial Process Variables	14/12	514/8.2%	43/28	145.3	1980
3826 334516	Laboratory Analytical Instruments Analytical Laboratory Instrument Manufacturing	6/5	88/1.4%	18/12	224.1	1988
3827 333314	Optical Instruments and Lenses Optical instruments and lens manufacturing	25/22	437/7.0%	20/5	1.0	1987
3829 334519	Measuring and controlling devices, NEC Other measuring and controlling device manufacturing	5/5	77/1.2%	15/4	541.7	1987
3841 339112	Surgical and Medical Instruments and Apparatus Surgical and Medical Instrument Manufacturing	1	No info	No info	No info	1980
3845 334510	Electromedical and Electrotherapeutic Apparatus Electromedical and Electrotherapeutic Apparatus Manufacturing	1	250/4.0%	NA	0.0	1983
3851 339115	Ophthalmic Goods Ophthalmic Goods Manufacturing	3/2	28/0.4%	14/NA	833.3	1985
3861 333315	Photographic Equipment and Supplies Photographic and Photocopying Equipment Manufacturing	3/3	5/0.1%	2/2	-73.7	1982
No Code	**Firms/organizations not attributable to the above SIC or NAICS codes**	**53/51**	**1498/33.6%**	**42/10**	**40.1**	1979

Source: The University of Arizona Office of Economic Development, 1999.

Astronomy

The fundamental relationship between astronomy and the optics community is not a function of what astronomers observe, but of the technologies they employ to make their observations. Though astronomy is not typically considered a growth industry, there are a number of new observatory facilities on the drawing board for local mountains. Astronomy is an area of major economic activity in southern Arizona, playing a formative role in the integration, dissemination and advancement of optical technologies. Although astronomy is a major program at the University, the local astronomy community is made up largely of visiting scholars and technicians. The enormous sum of technologies and concepts that are brought from around the globe to support this scientific inquiry in southern and northern Arizona are inevitably disseminated and absorbed into the larger scientific community. It is a subtle and primarily informal process, but a potentially powerful source of technical cross-fertilization that cannot be overlooked. The relationship between optics and astronomy is fundamental - to properly support optics in this community requires that the astronomy sector's needs be satisfied as well. About all they ask from the community is dark skies and clean air.

The University of Arizona

The Optical Sciences Center (OSC) is at the heart of optics-based research and instruction on The University of Arizona campus. OSC is considered a national asset for technical leadership in developing new technologies and application for optics in the fields of data storage, medicine, manufacturing, telecommunications, military guidance systems and others.

As noted earlier in this report, cross-disciplinary optics research is occurring all over campus because the enabling optics technologies tend to migrate into the areas of application rather than the reverse. However, even when optics-related research is not conducted under direct OSC auspices, the Center plays an important role as a de facto clearinghouse for tracking the many facets of UA optics-related research.

To illustrate, the University's recent success in recruiting two world-class scientists and their entire post-doctorate staffs has resulted in the development of the Optical Materials and Technology (OMAT) laboratory. This 12,000 square foot laboratory at the UA Science and Technology Park is at the cutting edge of science, pioneering the use of lasers to construct molecular-level physical structures, among other applications. Rather than an appointment to OSC, these researchers are actually members of the Chemistry faculty.

Other campus units involved in optics-related research include (but are not limited to) the Departments of Electrical and Computer Engineering, Chemistry, Computer Science, Materials Science, the Colleges of Medicine and Pharmacy and various life science faculties in the College of Science, Physics, Applied Mathematics and others.

In addition to the OMAT facility, The University of Arizona Science and Technology Park (UASTP) is home to at least four optics-related enterprises, including IBM, Raytheon and NP Photonics, a small firm founded by a UA faculty member. UASTP is also the site for the Tucson Technology Incubator (TTI), scheduled to open later this year (Fall, 1999). The TTI will be an excellent launching pad for optics-related business startups.

Major Arizona Optics Organizations

Without additional explanation, Table eight indicates the top 30 optics employers in Arizona. Due to uncertainties regarding some firms' permission to publish specific employment data, 1999 employment is indicated by range. This list is inclusive of all Arizona optics organizations reporting 50 or more FTE positions.

Table 8. Top 30 Arizona optics employers.

Rank	Optics organization	Community	1999 employment*	Activity
1	IBM Storage Systems Division	Tucson	1000+	**CRDP
2	Raytheon	Tucson	N/A	Manufacturing
3	UA Optical Sciences Center	Tucson	250-499	Education
4	GSI Lumonics	Glendale	250-499	Manufacturing
5	National Optical Astronomy Observatories	Tucson	250-499	Astronomy
6	UA Steward Observatory	Tucson	250-499	Astronomy
7	Durel Corporation	Chandler	250-499	Manufacturing
8	Spectrum Astro, Inc.	Gilbert	250-499	Manufacturing
9	Acoustic Imaging	Phoenix	250-499	Manufacturing
10	UA Lunar & Planetary Laboratory	Tucson	250-499	Astronomy
11	Gruber Industries Inc.	Phoenix	100-249	Manufacturing
12	Opto Power Corporation	Tucson	100-249	Manufacturing
13	Three-Five Systems Inc.	Tempe	100-249	Manufacturing
14	Veeco Metrology Group	Tucson	100-249	Manufacturing
15	Vanguard Automation	Tucson	100-249	Manufacturing
16	Lincoln Laser Company	Phoenix	100-249	Manufacturing
17	Roper Scientific	Tucson	100-249	Manufacturing
18	Tomar Electronics Inc.	Gilbert	50-99	Manufacturing
19	Polymicro Technologies Inc.	Phoenix	50-99	Manufacturing
20	Integrated Technology Corporation	Tempe	50-99	Manufacturing
21	Phase Shift Technology	Tucson	50-99	Manufacturing
22	ETEC Systems, Inc	Tucson	50-99	Manufacturing
23	IPRO Inc.	Phoenix	50-99	Manufacturing
24	Hoffman Engineering Corporation	Phoenix	50-99	Manufacturing
25	Lowell Observatory	Flagstaff	50-99	Astronomv
26	Medoptics Corporation	Tucson	50-99	Manufacturing
27	MER Corporation	Tucson	50-99	**CRDP
28	Fred Lawrence Whipple Observatory	Amado	50-99	Astronomy
29	Dataforth Corporation	Tucson	50-99	Manufacturing
30	Breault Research Organization	Tucson	50-99	Software

* Employment by ranges because not all firms gave permission to publish actual figure.
**Consulting, research and development and prototyping services.

Source: The University of Arizona Office of Economic Development, 1999.

LOCATIONAL ISSUES

Arizona Interviews

Interviews conducted for this report focussed on Arizona as a place to conduct optics business. It was interesting to note that several firms had very opposite perspectives or experiences in some of these areas, though both viewpoints are included here. Some of the remarks could only be interpreted as recommendations and they are included to provide industry insight, but *should not be construed as the recommendations of this report.*

Positive

1. Arizona is easy to recruit to, in part because many UA optical science graduates seek to remain in, or return to the state.
2. Basic quality of local workforce is outstanding.
3. Technicians easy to obtain, flooded with resumes every time they advertise.
4. The University of Arizona's role in this industry is fundamental and cannot be understated; in several cases indicated as the sole reason for an Arizona location (Tucson and Phoenix responses).
5. Phoenix workforce has very strong technical underpinnings.
6. Dark skies and clean air (southern and northern Arizona, important to astronomy community).

Negative

1. Inconvenient airport connections from Tucson and outlying rural areas, particularly to the West Coast.
2. Arizona personal property tax burdensome on capital-equipment.
3. Lack of funding and public support for the Arizona Optics Industry Association (AOIA), and related economic development initiatives.
4. State and community political leadership doesn't understand or appreciate the interface between industry, economic development and education.
5. Skies becoming less dark, and air less clean in southern Arizona (astronomy).
6. Lack of adequate support services (machining and electronics assembly).
7. Difficult to find qualified marketing and sales people, technician-level workers, technical compliance expertise and specialized legal services (Tucson).
8. Basic quality of untrained workforce is only fair-to-average;
9. Lack of an in-place community college-based technician training program (all locations);
10. Local community has no understanding, respect or appreciation of the astronomy community.

Interview Recommendations

1. Invest more in workforce development.
2. Face reality and stop pretending that the lack of infrastructure will slow growth; this attitude is not compatible with the intellectually action-oriented people companies want to recruit.
3. Develop more Centers of Excellence at the University that not only pursue optics technologies, but provide assistance in other business-related and legal disciplines.
4. The Optical Sciences Center needs to adjust its curriculum to give more emphasis to the optics-oriented manufacturing environment and fiber optics technologies.
5. Provide state funding to subsidize executive director positions for AOIA and the other GSPED clusters.
6. Perform an in-depth assessment of other optics-related cluster initiatives throughout the industrialized world and develop recommendations for Tucson.

National Industry Site Preference Factors

The industry site preference factors for fifteen optics-related SIC codes in Tables nine and ten are based on a proprietary targeted industry model commissioned for this assignment. The model includes 51 specific site location factors in eight major categories. These include a mix of cost-driven, quantitative and qualitative site factors. The model draws on a mixture of quantitative analysis and observations to assign relative importance values to each of the 51 site location factors. The model describes the typical importance of various factors for the fifteen optics-related SIC codes. However, variations in the site location process among companies within each industry may be substantial.

As discussed earlier in this report, each of the SIC codes represents an industry sector that includes some optics-related enterprise but, with the exception of Optical Instruments and Lenses and Ophthalmic Goods (SIC codes 3827 and 3851) most of these sectors are dominated by non-optics-related industrial activity.

Table 9. Industry site preference factors for various optics-related SIC codes.

Site Factors	SIC 3357 Nonferrous Wire-Drawing & Insulating	SIC 3646 Commercial Lighting Fixtures	SIC 3647 Vehicular Lighting Equipment	SIC 3648 Lighting Equipment NEC	SIC 3669 Communications Equipment	SIC 3695 Magnetic & Optical Recording Media	SIC 3699 NEC, including Laser Welding Equipment	SIC 3823 Process Control Instruments
Access to Markets								
Geographic Proximity	Medium	High	High	High	Low	High	High	High
Transportation Svcs Cost-Goods	Medium	High	High	High	Medium	High	High	Medium
Transportation Svcs Avail-Rail	Low	Low	Low	Low	Low	Low	Low	Low
Transportation Svcs Avail-Truck	Low	Low	Low	Low	Low	Low	Low	Low
Transportation Svcs Avail-Water	Low	Low	Low	Low	Low	Low	Low	Low
Transportation Svcs Avail-Air	Low	Medium	Medium	Medium	Low	Low	Low	Low
Telecommunications Services	Low	Low	Low	Low	Medium	Low	Low	Medium
Access to Resources								
Energy Dependability	High	High	High	High	High	High	High	High
Energy Cost	Low	Low	Low	Low	Low	Low	Low	Low
Water Availability/Cost	Low	Low	Low	Low	Low	Low	Low	Low
Raw Materials	Low	Low	Low	Low	Low	Low	Low	Low
Intermediate Mfg Products	High	High	High	High	Medium	High	High	Medium
Business/Prof/Tech Svcs	Low	Low	Medium	Medium	High	Medium	Medium	High
Work Force								
Executive, Administrative & Managerial	Low	Low	Low	Low	High	Low	Low	High
Professional Specialty	Low	Low	Low	Low	Medium	Low	Low	Medium
Technical	Low	Low	Low	Low	High	Medium	Medium	High
Sales	Low	Low	Low	Low	Low	Low	Low	Low
Administrative Support	Low	Low	Low	Low	Low	Low	Low	Low
Service	Low	Low	Low	Low	Low	Low	Low	Low
Farming, Forestry & Fishing	Low	Low	Low	Low	Low	Low	Low	Low
Precision Production & Repair	High	High	High	High	High	High	High	High
Operators & Assemblers	High	High	High	High	High	High	High	High
Transportation & Material Moving	Medium	Low	Low	Low	Low	Low	Low	Low
Handlers, Equipment Cleaners & Laborers	High	Low	Low	Low	Low	Medium	Medium	Low
Effective Cost of Skilled Labor	Medium	High	High	High	High	High	High	High
Effective Cost of Unskilled Labor	Medium	High	High	High	High	High	High	High
Reliability	High	High	High	High	High	High	High	High
Space								
Land Availability	High	Low	Low	Low	Low	Low	Low	Low
Land Cost	Medium	Low	Low	Low	Medium	Medium	Medium	Low
Built Space Availability	Medium	Medium	Medium	Medium	High	Medium	Medium	Medium
Built Space Cost	Medium	Medium	Medium	Medium	High	High	High	Medium
Construction Costs	Medium	Low	Low	Low	Medium	Medium	Medium	Low
Financial Capital								
Seed	Low	Low	Low	Low	Low	Low	Low	Low
Debt	Low	Medium	Medium	Medium	High	Medium	Medium	Medium
Venture	Low	Medium	Medium	Medium	High	Medium	Medium	Medium
Public Sector Impacts-Invest								
S/L Government Quality	Low	Low	Low	Low	Low	Low	Low	Low
Secondary Education Quality	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Higher Education Quality	Low	Low	Low	Low	Low	Low	Low	Low
Local Transport/Commuting	Medium	Low	Low	Low	Medium	Medium	Low	Low
Water/Wastewater Systems	Low	Low	Low	Low	Low	Low	Low	Low
Business Incentives	Low	Low	Low	Low	Medium	Medium	Low	Low
Public Sector Impacts-Costs								
Regulatory Policies	High	High	High	High	Medium	Medium	Medium	Medium
Worker Compensation Costs	Medium	Medium	Medium	Medium	High	High	High	High
Unemployment Insurance Costs	Medium	Medium	Medium	Medium	High	High	High	High
Business Taxes	Medium	High	High	High	Medium	Low	Low	Medium
Quality of Life								
Cost of Living (e.g. Housing)	Low	Low	Low	Low	Low	Low	Low	Low
Housing Costs	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Personal/Property Security	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Climate/Physical Environment	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Recreational/Cultural Opportunities	Low	Low	Low	Low	Low	Low	Low	Low
Area Image	Low	Medium	Medium	Medium	Medium	Medium	Medium	Medium

Source: Applied Economics, 1999.

Table 10. Industry site preference factors for various optics-related SIC codes (continued).

Site Factors	SIC 3826 Laboratory Analytical Instruments	SIC 3827 Optical Instruments & Lenses	SIC 3829 Measuring & Controlling Devices, NEC	SIC 3841 Surgical & Medical Instruments	SIC 3845 Electro-medical Equipment	SIC 3851 Ophthalmic Goods	SIC 3861 Photographic Equipment & Supplies
Access to Markets							
Geographic Proximity	High	Medium	High	High	Low	Medium	High
Transportation Svcs Cost-Goods	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Transportation Svcs Avail-Rail	Low	Low	Low	Low	Low	Low	Low
Transportation Svcs Avail-Truck	Low	Low	Low	Low	Low	Low	Low
Transportation Svcs Avail-Water	Low	Low	Low	Low	Low	Low	Low
Transportation Svcs Avail-Air	Low	Low	Low	Low	Low	Medium	Low
Telecommunications Services	Medium	Low	Medium	Low	Low	Low	Medium
Access to Resources							
Energy Dependability	High	High	High	High	Medium	High	High
Energy Cost	Low	Low	Low	Low	Low	Low	Low
Water Availability/Cost	Low	Low	Low	Low	Low	Low	Low
Raw Materials	Low	Low	Low	Low	Low	Low	Low
Intermediate Mfg Products	Medium	High	High	High	Medium	High	High
Business/Prof/Tech Svcs	High	High	High	High	Low	High	Medium
Work Force							
Executive, Administrative & Managerial	High	High	High	Medium	Medium	Low	Medium
Professional Specialty	Medium	Medium	Medium	Low	Low	Low	High
Technical	High	High	High	Medium	Medium	Medium	Medium
Sales	Low	Low	Low	Low	Low	Low	Low
Administrative Support	Low	Low	Low	Low	Low	Low	Low
Service	Low	Low	Low	Low	Low	Low	Low
Farming, Forestry & Fishing	Low	Low	Low	Low	Low	Low	Low
Precision Production & Repair	High	High	High	High	High	High	Medium
Operators & Assemblers	High	High	High	High	High	High	High
Transportation & Material Moving	Low	Low	Low	Low	Low	Low	Low
Handlers, Equipment Cleaners & Laborers	Low	Low	Low	Medium	Medium	Low	Low
Effective Cost of Skilled Labor	High	High	High	High	High	High	High
Effective Cost of Unskilled Labor	High	High	High	High	High	High	High
Reliability	High	High	High	High	High	High	High
Space							
Land Availability	Low	Low	Low	Low	High	Low	Low
Land Cost	Low	Low	Low	Low	High	Low	Low
Built Space Availability	Medium	Medium	Medium	Medium	Low	Medium	Medium
Built Space Cost	Medium	Medium	High	High	Medium	High	Medium
Construction Costs	Low	Low	Low	Low	High	Low	Low
Financial Capital							
Seed	Low	Low	Low	Low	Low	Low	Low
Debt	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Venture	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Public Sector Impacts-Invest							
S/L Government Quality	Low	Low	Low	Low	Low	Low	Low
Secondary Education Quality	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Higher Education Quality	Low	Low	Low	Low	Low	Low	Low
Local Transport/Commuting	Low	Low	Low	Low	Medium	Low	Low
Water/Wastewater Systems	Low	Low	Low	Low	Low	Low	Low
Business Incentives	Low	Low	Low	Low	Low	Low	Low
Public Sector Impacts-Costs							
Regulatory Policies	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Worker Compensation Costs	High	High	High	High	High	High	Medium
Unemployment Insurance Costs	High	High	High	High	High	High	Medium
Business Taxes	Medium	High	High	High	Medium	High	High
Quality of Life							
Cost of Living (ex Housing)	Low	Low	Low	Low	Low	Low	Low
Housing Costs	Medium	Medium	Medium	Medium	Low	Medium	Medium
Personal/Property Security	Medium	Medium	Medium	Medium	Low	Medium	Medium
Climate/Physical Environment	Medium	Medium	Medium	Medium	Low	Medium	Medium
Recreational/Cultural Opportunities	Low	Low	Low	Low	Low	Low	Low
Area Image	Medium	Medium	Medium	Medium	Low	Medium	Medium

Source: Applied Economics, 1999.

New and Expanded Facility Development

The extent and location of new facility development and facility expansion in optics-related industry sectors can be used to gauge industry mobility and geographical location patterns. Tables eleven and twelve indicate facility establishment and expansion announcements, respectively, during the one-year period of August 1998 - July 1999, for a series of 15 optics-related NAICS codes (recent data was only available by NAICS designation; see Table one for SIC/NAICS comparability). Information is organized by state. Included in these tables are new and expanded facilities of 20,000 square feet or more and plant investments of $1 million or more.

Table 11. New facility announcements (8/98 through 7/99), organized by optics-related NAICS codes and listed by state.

NAICS code	State	Quantity	Average plant investment (in US$ millions)	Average plant employment	Average plant size (thousands of square feet)
333314 - Optical instruments and lens manufacturing	Florida	1	1.2	0.0	25.0
333315 - Photographic and photocopying equipment manufacturing	Virginia	1	0.0	0.0	53.0
333992 – Welding and soldering equipment manufacturing	Kentucky	1	3.4	55.0	0.0
	Michigan	1	3.2	60.0	0.0
	Total	2	6.6	115.0	0.0
33429 – Other communications equipment manufacturing	California	1	0.0	100.0	0.0
	Georgia	1	0.0	50.0	0.0
	Total	2	0.0	150.0	0.0
334510 – Electromedical and electrotherapeutic apparatus manufacturing	Minnesota	3	85.0	1050.0	219.3
	Ohio	2	1.1	94.5	90.0
	Massachusetts	1	20.7	0.0	200.0
	New York	1	117.0	0.0	0.0
	Pennsylvania	1	0.0	50.0	0.0
	Washington	1	0.0	0.0	40.0
	Total	9	323.7	1194.5	549.3
334513 - Instruments and related products for measuring displaying, and controlling industrial process variables	California	1	0.0	600.0	300.0
	Michigan	2	2.2	50.0	48.5
	Total	3	2.2	650.0	348.5
334516 - Analytical laboratory instrument manufacturing	**Arizona**	**1**	**0.0**	**0.0**	**47.0**
334519 - Other measuring and controlling device manufacturing	Alabama	1	0.0	100.0	0.0
	Arkansas	1	2.0	125.0	0.0
	Michigan	1	0.0	0.0	22.0
	New York	1	0.0	0.0	27.0
	Total	4	2.0	225.0	49.0
334613 - Magnetic and optical recording media manufacturing	New York	1	10.0	150.0	0.0
335921 – Fiber optics cable manufacturing	(No Data)				
335122 - Commercial, industrial, and institutional electric lighting fixture manufacturing	North Carolina	1	30.0	125.0	155.0
	California	1	0.0	0.0	108.0
	Florida	1	0.0	53.0	34.0
	Total	3	30.0	178.0	297.0
335129 -- Other lighting equipment manufacturing	California	1	0.0	0.0	105.0
	North Carolina	1	2.0	60.0	106.0
	Total	2	2.0	60.0	211.0
336321 – Vehicular lighting equipment manufacturing	(No Data)				
339112 - Surgical and medical instrument manufacturing	Florida	2	7.3	135.0	34.0
	North Carolina	2	1.5	55.0	0.0
	Indiana	1	9.6	0.0	160.0
	Michigan	1	1.0	0.0	30.0
	New Jersey	1	16.0	0.0	0.0
	South Carolina	1	0.0	600.0	200.0
	Tennessee	1	0.0	120.0	0.0
	Total	9	35.4	900.0	434.0
339115 - Ophthalmic goods manufacturing	California	1	0.0	0.0	41.0
	Illinois	1	1.7	50.0	0.0
	Michigan	1	1.0	0.0	0.0
	Virginia	1	125.0	600.0	405.0
	Total	4	127.7	650.0	446.0

Source: Conway Data, Inc., 1999

Table 12. Facility expansion announcements (8/98 through 7/99), organized by optics-related NAICS codes and listed by state.

NAICS code	State	Quantity	Average plant investment (in US$ millions)	Average plant employment	Average plant size (thousands of square feet)
333314 - Optical instruments and lens manufacturing	(No Data)				
333315 - Photographic and photocopying equipment manufacturing	New York	1	0.0	400.0	0.0
333992 – Welding and soldering equipment manufacturing	Michigan	2	1.2	27.5	12.5
	Florida	1	2.0	0.0	52.0
	Illinois	1	0.0	0.0	40.0
	Total	4	3.2	27.5	104.5
33429 – Other communications equipment manufacturing	Florida	2	0.0	166.0	0.0
	North Carolina	2	2.8	0.0	50.0
	Pennsylvania	2	18.0	110.0	0.0
	Total	6	20.8	276.0	50.0
334510 – Electromedical and electrotherapeutic apparatus manufacturing	Minnesota	1	2.0	0.0	20.0
	Pennsylvania	1	2.2	0.0	0.0
	Total	2	4.2	0.0	20.0
334513 - Instruments and related products for measuring displaying, and controlling industrial process variables	California	1	0.0	300.0	104.0
	Indiana	1	2.0	0.0	0.0
	Maryland	1	20.0	270.0	0.0
	Michigan	1	1.1	0.0	0.0
	Oklahoma	1	0.0	0.0	24.0
	Total	5	23.1	570.0	128.0
334516 - Analytical laboratory instrument manufacturing	North Carolina	1	1.6	0.0	0.0
334519 - Other measuring and controlling device manufacturing	Michigan	2	1.4	0.0	0.0
	North Carolina	2	3.6	0.0	0.0
	Ohio	1	5.0	0.0	0.0
	Total	5	10.0	0.0	0.0
334613 - Magnetic and optical recording media manufacturing	California	1	0.0	0.0	431.0
335122 - Commercial, industrial, and institutional electric lighting fixture manufacturing	North Carolina	1	0.0	50.0	0.0
335129 - Other lighting equipment manufacturing	California	1	0.0	700.0	704.0
	Georgia	1	0.0	0.0	50.0
	Total	2	0.0	700.0	754.0
335921 – Fiber optics cable manufacturing	North Carolina	2	0.9	56.0	0.0
	Pennsylvania	1	0.0	75.0	40.0
	South Carolina	1	29.7	130.0	40.0
	Total	4	30.6	261.0	80.0
336321 – Vehicular lighting equipment manufacturing	(No Data)				
339112 - Surgical and medical instrument manufacturing	California	1	16.0	350.0	0.0
	Georgia	1	0.0	50.0	0.0
	Illinois	1	0.0	0.0	107.0
	Indiana	1	3.0	0.0	0.0
	Iowa	1	1.0	0.0	0.0
	North Carolina	1	5.8	200.0	0.0
	Total	6	25.8	600.0	107.0
339115 - Ophthalmic goods manufacturing	Florida	1	3.2	0.0	85.0
	Texas	1	20.0	0.0	400.0
	Total	2	23.2	0.0	485.0

Source: Conway Data, Inc., 1999.

COMPETITIVE FORCES

Arizona has been exemplified as an example of a state with an economic development strategy that is integrated with the cluster process. Many would argue that this strategy has been very successful, and it is not the point of this report to argue this either way.

Groups have traveled long distances to Arizona and Tucson, and still do, to observe this process in action. The attention has spawned a number of imitators, and they have taken lessons from our experiences - building on successes and learning from mistakes. These activities warrant cautious attention because lessons can be learned from the experiences of other regions, but an immediate observation can be made that most of these community-, regional-, state-, or nation-based initiatives seem to have a key ingredient - funding - that is prominently lacking in Arizona's cluster strategy. Very significant public investments are being made in other parts of the U.S. and world, which may lead to even more significant results. Arizona runs the risk of being perceived as a great place to get an optics education, but not in the mainstream of industrial and commercial activity.

The scope of this report did not include a review of these new cluster-based optics clusters and their various initiatives, but the list that follows indicates those that have come to the attention of the author. These organizations and programs need to be examined in more detail as Arizona formulates a promotional strategy for its optics industry.

The Competition

Colorado Photonics Industry Association
Connecticut Photonics Industry Cluster
Florida Electra-Optic Industry Association
Massachusetts Association for Optical Industry
New Mexico Optics Industry Association
Optoelectronic Industry and Technology Development Association (national/U.S.)
Photonics Industry Association of New York
Scottish Optoelectronics
Other possible locations.. .

- St. Louis, Missouri
- El Paso, Texas
- Rochester, New York
- Vancouver, British Colombia
- Singapore
- Morocco

ENDNOTES

[i] Harnessing light: Optical Science and Engineering for the 21st Century. National Research Council (U.S.). Committee on Optical Science and Engineering. Washington, D.C.: National Academy Press, 1998.
[ii] Correspondence from James E. Pearson, then Executive Director of The International Society for Optical Engineers to Katherine K. Wallman, Chief Statistician, Office of Management and Budget, October 8, 1998.
[iii] *ibid.*
[iv] *ibid.*
[v] Harnessing light: optical science and engineering for the 21st century. National Research Council (U.S.). Committee on Optical Science and Engineering. Washington, D.C.: National Academy Press, 1998.
[vi] *ibid.*
[vii] The 1995 survey was administered by the UA Office of Economic Development as the basis for the publication *1996 Arizona Optics Industry Resource Directory and Industry Analysis.* The 1999 Arizona optics industry survey involving a much narrower question set was conducted in large part under the auspices of the Arizona Optics Industry Association; a subset of that survey population is used in this report. Employment and other information from the 1999 survey were confirmed by the UA Office of Economic Development during August 2-3, 1999.