Overview of the Silicon Forest

Regional Connections
Working Paper 1

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Working Paper

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REGIONAL CONNECTIONS

An Overview of the Silicon Forest

By Joseph Cortright & Heike Mayer

Metro Portland's cluster of electronics firms have emerged as a fast growing, high paid, nationally important high tech center. The Silicon Forest, composed of more than 2,000 firms, directly employing 70,000 workers and indirectly driving demand for other businesses in the regional economy, has prospered. Portland's electronics industry has significantly outperformed that of the rest of the nation during the 1990s, growing at an average annual rate of 8 percent, nearly triple the national average. The high tech firms of the Silicon Forest are now the principal drivers of the metropolitan economy; accounting for a majority of the region's exports, providing among its highest wage jobs, and producing a stream of new start-up firms. The Silicon Forest is not a low cost production center or a random sampling of electronics firms: it is composed of firms in a series of related specialties, who perform critical parts of their research and development activities locally. Growth of the industry has been fueled by innovation and entrepreneurship.

Silicon Forest is the name given to the emerging cluster of electronics and related businesses in the Portland area during the 1980s. Over the past decade, the metropolitan area has emerged as a significant national center for the production of a variety of high technology products and services. The high technology industry has been a major force in driving the metropolitan area's growth during the 1990s.

The Silicon Forest consists of more than 2,000 firms producing semiconductors, computers, electronic products, and computer software, and a wide array of related and

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Regional Connections work products include a technical report—Progress of a Region: The Metropolitan Portland Economy in the 1990's—briefings on the regional economy and a series of working papers summarizing the project's studies of the region's industry clusters, including high technology, metals, creative services and nursery products.

For more information about Regional Connections, contact Ethan Seltzer at 503-725-5170 or visit our website at www.upa.pdx.edu/ims/regcon/regecon.html.

supporting industries. While larger firms like Intel and Tektronix are well-known, the region is home to dozens of smaller firms that also sell their products world-wide.

More than 70,000 persons are employed by Silicon Forest businesses. Average pay for employees in electronics and software firms is about two-thirds higher than the average for all jobs in the region--more than $50,000 annually.

Portland's high technology industries have significantly outperformed the US high tech industry. Overall, Silicon Forest businesses have grown about three times faster over the past five years than their counterparts nationally--more than eight percent per year compared with about 2.6 percent per year for the nation.

Silicon Forest firms have distinctive specialties. Portland is an important center for microprocessor design, silicon wafer making, wafer fabrication, semiconductor test and measurement equipment, electronic design automation (EDA) software, display technology, and high frequency, mixed signal integrated circuits.

The development of the Silicon Forest was triggered in large part by the phenomenal success of homegrown Tektronix, which accounted for a majority of Oregon's high tech workers in the 1960s and 1970s. Industry growth was stimulated by investments (and subsequent expansions) by Intel and Hewlett Packard in the late 1970s, and a wave of Japanese investment in the 1980s. Throughout the 1980s and 1990s, the expansion of the Silicon Forest was fueled by new start-up firms, many of them spin-offs of the ideas, expertise, and personnel of the region's larger firms. In the mid 1990s, Intel and several other firms collectively planned investments of about $10 billion in new semiconductor production capacity.

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Introduction: What is the Silicon Forest?

Over the past decade, the Portland Metropolitan Economy has grown rapidly. But the economy the region has today is not simply a larger version of the economy it had a two decades, or even a decade ago. It has changed in fundamental ways. One of the most striking changes has been the emergence of high technology firms as the leading source of employment and economic growth in the Portland area. The purpose of this paper is to define and describe the composition, size, and growth trends of the Portland metropolitan area's computer, electronics and software cluster, commonly referred to as the "Silicon Forest." [1]

This paper is divided into five major parts. Part 1 describes the broad outlines of high technology industries in the Portland metropolitan area, and describes the number of firms, their employees, wage rates and firm sizes. We also identify the region's largest high technology employers. Part 2 looks at the distinctive specializations of metro Portland high tech firms, including silicon wafer productions, semiconductor manufacturing, printers, and semiconductor manufacturing equipment and electronic design automation software. Part 3 measures the growth of the Silicon Forest over the last decade, a period of time when local high tech firms have outstripped their national counterparts and nearly doubled the number of high tech workers in the region. Part 4 examines the region's high tech support infrastructure: the firms that provide supplies and services essential to high tech manufacturing. Finally, part 5 offers some rough estimates of the regional economic impact of the industry.

Accurately describing any high tech industry is a real challenge: economic data are always retrospective, and technology firms are always changing, often defying categorization by data gatherers. Compiling this snapshot of the industry owes considerable thanks to the hard work undertaken by the Regional Connections research team--Heike Mayer, Matt Witt and John Schwab--and a grateful acknowledgement of the advice and insights of dozens of industry experts interviewed for the project.

This is the first in a series of papers presenting the research findings of the Regional Connection's project's examination of the Metropolitan Portland high technology industry cluster. Subsequent papers in the series present our analysis of other aspects of the cluster, including its geographic characteristics, interfirm linkages and the dynamic processes that drive the region's growth.

[1] The term 'Silicon Forest' was first coined by Lattice Semiconductor in the early 1980s [Richey-Noll, 1999]. It has subsequently been used as a common description of the agglomeration of high tech firms in the Portland area. Unlike many silicon wannabes, Silicon Alley (New York), etc., Portland actually is a major center for the production of both silicon wafers and silicon based semiconductor devices.

1. Measuring the Silicon Forest

While there are a range of definitions for "high technology"--many of which include telecommunications, pharmaceuticals, aerospace and defense, research laboratories and other industries, we focus on firms that are closely related to the manufacture of computers, instruments, electronic devices and software. These industrial categories identify the firms most closely related to high technology in the Portland metropolitan area, and account for the bulk of the region's high tech jobs. The definition developed by the Oregon employment Department for defining the high technology sector consists of four Standard Industrial Classification Codes:

SIC 357: Computers
SIC 36: Electrical Equipment
SIC 38: Instruments
SIC 737: Software and Data Processing
SIC 50*: High Technology Wholesaling (* selected segments)[2]

Much of the analysis in this report is based on this definition and on employment and payroll data collected by the Oregon Employment Department and the Bureau of Labor Statistics.

1.1 Employment

Directly and indirectly the businesses that form the Silicon Forest employ more than 70,000 workers in the Portland metropolitan area and have an annual average payroll of more than $3.7 billion. While high technology activity is concentrated in semiconductors, electronics and software firms, there are closely-related and supporting activities in other industry sectors, notably, metals, plastics, wholesaling, engineering and others.

Table 1 shows the distribution of the region's firms, employment and payroll by major industry classification. Metropolitan Portland, including Clackamas, Columbia, Multnomah, Washington and Yamhill Counties in Oregon and Clark County, Washington, has more than 2,000 businesses with a payroll that are classified as being in one of five industries that are part of the region's high technology cluster. The data in Table 1 are drawn from Oregon and Washington state employment data for 1997. (Because of confidentiality restrictions, the Washington data could not be shown by industry; all of the Clark County data are combined and shown separately).

[2] Our analysis of firm level data shows that many of the region's electronics and software firms are classified as wholesale firms. These include firms in SIC 5045 (Computers, peripherals and software), SIC 5065 (Electronic parts and equipment, and SIC 5084 (Industrial machinery and equipment). Many of the firms classified as wholesalers are the research, development, product support and engineering staffs of firms headquartered in other regions that work closely with Oregon manufactuers.

Table 1: Employment in Portland Area High Technology Firms

Segment	Firms	Employment
Computers	25	4,206
Electronic & Electrical Machinery	137	23,530
Instruments	106	10,378
High Tech Wholesaling	972	11,607
Software and Computer Services	742	11,856
Total, Oregon Portion of Metro Area	1982	61,577
Clark County, WA (1996)	340	8,820

Source: Oregon Employment Department, 1997 Covered Employment and Payroll Data. Clark County Data from Washington Employment Security Department.

1.2 Average Pay

Average pay levels in all segments of high technology are much higher than for the region as a whole. In 1997, the latest year for which such data are available, average annual payroll per worker in for high technology was over $50,000, compared with a regional average pay per worker of slightly more than $30,000.

Table 2: Employment Pay in Portland Area High Technology Firms

Segment	Employment	Payroll	Average Pay
Computers	4,206	205,063,362	48,755
Electronic & Electrical Machinery	23,530	1,359,350,892	57,771
Instruments	10,378	555,589,461	53,535
High Tech Wholesaling	11,607	571,003,557	49,195
Software and Computer Services	11,856	613,916,964	51,781
Total, Oregon Portion of Metro Area	61,577	3,304,924,236	53,671
Clark County, WA (1996)	8,820	395,149,045	44,801

Source: Oregon Employment Department, 1997 Covered Employment and Payroll Data. Clark County Data from Washington Employment Security Department.

1.3 Firm Size

While the region's high technology industry consists of more than 2,000 firms, data on Oregon employers shows that a relatively few firms account for the bulk of high technology employment. In 1997, 13 firms with more than 500 employees each, accounted for about 40 percent of all high technology employment in the Oregon portion of the metropolitan area.[3]

[3] Firm level data for Clark County, Washington, employers was not available for this analysis. Data in this section differs slightly from totals shown in other tables as data on employment and firms for a single quarter, rather than annual average data, is used.

Table 3: Employment and Firms by Firm Size, 1997

Firm Size	Firms	Employment
500 plus	13	25,743
250-499	18	6,170
100-249	58	8,915
50-99	63	4,268
20-49	156	4,734
10-19	229	3,096
5-9	304	2,008
Under 5	1,139	2,108
Total	1,980	57,042

Source: Computed from firm level employment data provided by the Oregon Employment Department, Fourth Quarter, 1997

As Table 4 shows, the typical size of firms varies by industry segment. Firms with more than 100 employees account for four-fifths or more of all employment in computers, electronics and instruments. Software and wholesale firms tend to be much smaller. Firms with more than 100 employees account for less than half of all employment in these sectors.

Table 4: Employment and Firms by Firm Size and Industry Segment, 1997

	Computer	Electronics	Instruments	Software	Wholesale	Total
Distribution of Firms						
Over 100	6	28	16	19	20	89
20-99	4	37	17	79	82	219
Under 20	13	72	73	644	870	1,672
Total Firms	23	137	106	742	972	1,980
Distribution of Employment						
Over 100	3,913	19,952	9,085	4,501	3,377	40,828
20-99	156	1,706	674	3,130	3,336	9,002
Under 20	60	477	446	2,393	3,836	7,212
Total Employment	4,129	22,135	10,205	10,024	10,549	57,042

Source: Computed from firm level employment data provided by the Oregon Employment Department, Fourth Quarter, 1997

1.4 Largest Firms

There are about 40 firms in the Portland metropolitan area engaged in high technology with more than 250 employees. Collectively, these firms account for about 40,000 employees—slightly more than half of all of the region's high tech employment. A list of these firms in shown in Table 5 on page 7.

Table 5: Portland Area Electronics Firms with 250 or more employees, 1998.

Rank	Firm	Segment	Employment	City
1	Intel	Semiconductors	11,000	Hillsboro
2	Tektronix	Electronics	5,100	Wilsonville
3	Sequent Computer Systems Inc	Computers	2,500	Beaverton
4	Hewlett-Packard Co	Printers	2,000	Vancouver
5	Epson Portland Inc	Printers	1,800	Hillsboro
6	SEH America Inc	Wafer Maker	1,800	Vancouver
7	Wacker Siltronic Corp	Wafer Maker	1,700	Portland
8	Merix Corp	PCB Supplies	1,100	Forest Grove
9	Precision Interconnect	Cable	1,000	Tigard
10	A-Dec Inc	Instruments	905	Newberg
11	Planar Systems	Displays	900	Beaverton
12	Electro Scientific Industries Inc	SME	800	Beaverton
13	AVX/Vancouver	Electronics	795	Vancouver
14	FLIR Systems Inc	Displays	700	Tigard
15	Fujitsu Microelectronics Inc.	Semiconductors	630	Gresham
16	Maxim Integrated Products Inc	Semiconductors	580	Beaverton
17	NEC America Inc	Electronics	550	Hillsboro
18	In Focus Systems Inc	Displays	500	Wilsonville
19	RadiSys Corp	Computers	500	Hillsboro
20	Sentrol / SLC Technologies	Electronics	500	Tualatin
21	Williams Controls Inc	Electronics	500	Tigard
22	Lattice Semiconductor	Semiconductors	500	Hillsboro
23	Fujitsu Computer Products	Computers	450	Hillsboro
24	Protocol Systems Inc	Electronics	400	Beaverton
25	Credence Systems Corp	SME	400	Beaverton
26	TriQuint Semiconductor Inc	Semiconductors	386	Hillsboro
27	Sharp Microelectronics/Sharp Labs	Semiconductors	370	Camas
28	LSI Logic Corp	Semiconductors	370	Gresham
29	Wafertech, LLC	Semiconductors	350	Camas
30	EFTC Northwest	PCB Services	350	Newberg
31	ADC Kentrox	Electronics	330	Beaverton
32	America Kotobuki Electronics Ind	Electronics	310	Vancouver
33	Integrated Device Technology Inc	Semiconductors	300	Hillsboro
34	Micro Systems Engineering, Inc	Semiconductors	290	Lake Oswego
35	FEI Company	SME	285	Hillsboro
36	Laughlin-Wilt Group Inc	PCB Services	280	Beaverton
37	Maxtek Components Corp	Semiconductors	280	Beaverton
38	Integrated Measurement Systems	SME	265	Beaverton
39	Sun Microsystems Data Center	Computers	250	Beaverton
40	OECO Corp	Electronics	250	Milwaukie

Sources: Quanix Data Services, Vancouver Business Journal, Portland Business Journal
Note: In 1999, the printer manufacturing division of Tektronix was sold to Xerox and Sequent Computer Systems was purchased by IBM.

2. Silicon Forest has distinctive specialties

The Silicon Forest is not a random assortment of electronics firms, or a mirror image of the kinds of businesses one would find in Silicon Valley, CA, or Austin, TX. The Silicon Forest has especially high concentrations of firms involved in Silicon wafer manufacturing (the raw material for chip production), semiconductor design (equipment and software to design, produce and test chips), and in display technologies.

Table 6: Portland's Distinctive Specializations

Specialization	Leading Firms
Silicon Wafer Manufacturing	Wacker Siltronic, SEH-America, Komatsu, Mitsubishi (Salem)
Semiconductor Manufacturing	Intel, Fujitsu, IDT, LSI, Lattice, TriQuint, Maxim, Maxtek, Linear Technology, Sharp,
SME/EDA Software	ESI, IMS, FEI, Mentor Graphics, Synopsys, Tektronix
Display/Imaging Technologies	In-Focus, Sharp, Planar, Pixelworks, FLIR Systems, Flight Dynamics
Printers	Tektronix, Hewlett Packard, Epson

2.1 Silicon Wafer Manufacturing

Silicon wafers, the six inch and eight inch metallic disks of pure silicon that are the platform for manufacturing integrated circuits, are manufactured in great numbers in the Portland metropolitan area. The region is one of the largest clusters of wafer production in North America, and is home to four major production facilities, all subsidiaries of multinational corporations: Wacker Siltronic (Portland), Mitsubishi Metals (Salem), SEH America (Vancouver) and Komatsu (Hillsboro). These firms all "grow" pure polycrystalline silicon ingots and then slice the ingots into wafers for use in chip manufacturing. The processing has to occur in ultra-clean environments, and uses relatively large amounts of electricity and water.

2.2 Semiconductor Manufacturing

The Portland area is a principal center for the design and production of semiconductors. In 1997 (the latest year for which data are available) Oregon firms (nearly all of which were located in the Portland metropolitan area) accounted for more than ten percent of all the semiconductors produced in the United States (Bureau of the Census, 1999). Oregon ranked fourth in the total output of semiconductors, behind only Texas, California and Arizona. Firms in the Portland area produce a wide range of mass market and specialized integrated circuits that are used in a wide range of industries, including microprocessors (like Intel's Pentium chips), computer memory (Fujitsu makes D-RAM), and a variety of other specialized chips used in communication devices, computer networking, computers, instruments, and other purposes.

While there is a widespread popular perception that Portland's wafer fabrication facilities are simply factories for large scale production of microchips designed elsewhere, the majority of chip company workers are not directly involved in production. Nearly all of the region's firms are integrated producers, designing and manufacturing their own products. Among semiconductor firms, fewer than half the region's employees are production workers. The bulk of the others are engineers, designers, managers and other technical and professional workers. Nearly all of these firms have critical research and development functions in the Portland area; private sector R&D spending in the Portland area has more than quadrupled in the past decade, driven primarily by the electronics industry.(National Science Foundation, 1999) A majority of all of Intel's US patents over the past five years have been awarded to researchers located in Oregon.(US Patent & Trademark Office, 1999).

Nor should one harbor the notion that semiconductor manufacturing is a simple, routine process; making microchips is not like operating a silicon cookie cutter. Wafer fabs produce their final product in an ultra-clean environment that uses a complex combination of electricity, chemicals, photography and metals. Each silicon wafer must pass through as many as 30 separate machines or "tools" between the time it enters the plant until it is diced up into separate chips for assembly. A considerable amount of experimentation and adjustment of machinery, processing sequences and materials is needed to get acceptable yields (numbers of usable "die") from each wafer. Engineers and line workers are responsible for continuously refining and improving the process to raise yields, a chore that requires considerable expertise. And as the technology improves, they are continually pressed to fit more transistors and smaller lines on a chip, forcing more exacting manufacturing changes. The importance of production efficiency in microchips should not be underestimated; a major reason why US firms lost most of the DRAM market to the Japanese in the early '80s was the lower yields and poorer quality of most US manufacturing; Intel's Aloha DRAM facility distinguished itself as the Intel plant with the highest yields.[4]

While Intel is clearly the region’s largest semiconductor producer, there is a significant concentration of other firms in the region that design and/or produce semiconductor products. These firms include multinational firms (Fujitsu, Sharp Microelectronics, Wafertech), subsidiaries of Silicon Valley firms (LSI Logic, Integrated Device Technology (IDT), Linear Technology, Maxim) and homegrown spin-offs and startups (TriQuint Semiconductor, Lattice, Maxtek).

[4] Jackson, 1995. According to Intel's manager of technology and manufacturing "During the 80s ... our competitors were achieving higher yields, transferring and ramping new technologies faster than us and overall running their factories more efficiently."(Splinter, 1998) The centerpiece of Intel's efforts to raise yields is its "Copy Exactly" strategy. Rather than develop production processes and recipes at the leisurely pace and small scale of a research lab (and then struggle to duplicate them in a full-scale, high speed production environment), Intel develops its new processes in a fully-sized production fab. Once the developmental work gets acceptably high yields, the production process is copied exactly--everything from the make and model of equipment, to the length and number of bends in process pipes, to the temperature of chemicals, to the paint on the walls, to the sequence of steps production workers follow. This has enabled Intel to quickly get high yields from new designs and get to market quickly, a critical edge with tough competition and declining prices. (McDonald, 1998)

The traditional model of semiconductor production has been one in which a single company both designs and manufactures its own integrated circuits. More recently, with the growing cost and complexity of manufacturing equipment and processes, the industry has seen the emergence of two new "dis-integrated" semiconductor firms: the "fabless" semiconductor producers and the "foundries." Fabless semiconductor makers are firms that design their own chips, but contract for their production in other firms facilities. Foundries are firms that do not design their own circuits, but rather manufacture designs developed by others. Splitting the two functions enables firms to specialize: fabless firms focus on designs, foundries build competence in manufacturing processes. In addition, some firms offer custom or semi-custom manufacturing, helping customers design specialized chips, often drawing on proprietary "libraries" of component designs.

2.3 Semiconductor Manufacturing Equipment/Electronic Design Automation Software

Designing, testing and manufacturing semiconductors is an increasingly complex process; the number of transistors on a single chip is now counted in the millions, the lines on the highest density chips have shrunk to .18 microns. During the 1980s, as semiconductor design and manufacturing moved from manual to automated systems, Portland area businesses drew on their backgrounds in building test and measurement equipment, lasers, semiconductors and software to build a number of enterprises making the capital equipment or software to design, manufacture and test semiconductors. Today, a number of Oregon firms are among the leaders in the development of equipment to design, manufacture and test electronic circuits.

Semiconductor manufacturing equipment (SME) is the hardware used to manufacture, test, and repair semiconductors. Electro-Scientific Industries (ESI), FEI, Integrated Measurement Systems (IMS), ETEC and Cascade Microtech, all make equipment to produce and/or test and in some cases repair microcircuits. Tektronix makes a wide range of electrical test and measurement equipment which are used in manufacturing and other settings.

Electronic Design Automation (EDA) software is the programs that engineers use to design, test and refine the layout of integrated circuits and printed circuit boards. Mentor Graphics, Synopsys, Genedax, ORCAD (recently purchased by Cadence), and others make software tools to design, refine and virtually test microcircuits and other electronic devices.

Both SME and EDA firms must constantly upgrade their products to keep pace with changes in semiconductor manufacturing. Firms in these fields must coordinate the development of their products with key customers.

2.4 Display and Imaging Technologies

To be useful to end users, the information generated by computers is typically displayed in some visual form. Portland area firms are particularly innovative in the development of new display technologies. Tektronix pioneered fundamental advances in information displays, first with its oscilloscopes and later with graphic computer display terminals. More recently, firms in the region have been developing advanced technologies including electroluminescent flat panel displays (Planar Systems) liquid crystal display projectors (In Focus, Lightware), customized display circuitry (Pixelworks), and "heads up" displays for aerospace (Flight Dynamics). In addition, Sharp Labs of America, located in Camas is an important research and development center for Sharp's LCD display products. A related, but distinct technology, infrared imaging, is incorporated in products manufactured by FLIR Systems.

2.5 Printers

The Portland metropolitan area is home to production facilities for three firms that are among the world's leading producers of printers for personal computers: Tektronix produces color laser printers in Wilsonville (an operation recently purchased by Xerox), Epson produces inkjet printers in Hillsboro, and Hewlett Packard produces inkjet printers in Vancouver, WA. This market segment has been extremely competitive, and important restructuring is affecting Portland area firms: The printer manufacturing division of Tektronix has been sold to Xerox in September, 1999, and Hewlett Packard's inkjet production operation has been scaled back in the past year. Hewlett Packard also plans to split its operations in the coming year.

2.6 Software

The Portland metropolitan area is home to a wide range of software producers and related computer services companies. The sheer number, small average size, and rapid rate of change in the region's software businesses means that they tend to defy easy categorization. As noted, the region has a strong presence in Electronic Design Automation (EDA) software, which is closely linked to the design and production of integrated circuits. Outside this specialty, there is an enormous diversity of software firms, ranging from financial and accounting software (CFI Pro Services, Timberline, ADP Dealer Services), to multimedia (Creative Media, Oaktree) to electronic commerce (Webtrends, 800.com, Digimarc).

2.7 Other High Technology Manufacturing

While most of the region’s high technology employment can be grouped into the major categories listed above, there are a large number of firms that produce other kinds of high technology products. These include precision cables, medical devices, communications technologies, and manufacturing services.

3. The Growth of the Silicon Forest

One of the most remarkable aspects of the high technology industry in the Portland metropolitan area during the 1990s has been its rapid growth. Collectively, high technology firms have added more than 25,000 jobs over the past decade, significantly outpacing the nation as a whole in high tech job growth. Job growth has been accompanied by dramatically increased high tech exports and a multi-billion dollar wave of investment in semiconductor manufacturing facilities.

3.1 Employment Growth

High technology employment has expanded rapidly in the Portland metropolitan area over the past decade. In 1988, roughly 34,000 people worked in high technology jobs; by 1998, the total was more than 61,000. The composition of high technology employment in the metropolitan area in each of the years between 1988 and 1998 is shown in Table 7.

Table 7: Portland Area High Technology Employment, 1988-1998

Year	Computers SIC 357	Electrical Equipment SIC 36	Instruments SIC 38	Software SIC 737	Total
1988	3,300	11,700	13,300	5,500	33,800
1989	3,900	12,800	12,600	6,300	35,600
1990	4,200	14,400	11,600	7,400	37,600
1991	5,300	14,800	10,600	6,700	37,400
1992	5,200	15,400	9,900	6,900	37,400
1993	6,000	16,400	9,300	7,700	39,400
1994	6,400	18,400	9,200	8,500	42,500
1995	7,100	22,300	8,300	9,400	47,100
1996	7,900	25,400	9,000	10,900	53,200
1997	8,800	27,800	9,300	12,200	58,100
1998	8,200	29,700	9,400	13,800	61,100

Source: Oregon Employment Department, Non-Agricultural Wage and Salary Employment Estimates. Portland-Vancouver Metropolitan Area. Note: Excludes high technology wholesaling.

Most of the gains in the last decade were recorded in the five-year period between 1992 and 1997. In that time, high tech employers in the Oregon portion of the metropolitan area added more than 20,000 jobs. The bulk of the job gains came in SIC 36 (electronics) and SIC 737 (software).

Using the more detailed data available from the Oregon Employment Department (and including high technology wholesaling firms in the definition of included industries), allows us to examine the composition of gains (and losses) by industry sector. These data are shown in Table 8. There were significant increases in employment in each of the major component industries, except instruments. The decline in instruments employment is due largely to restructuring and downsizing at Tektronix, one of the region's largest electronics firms.

Table 8: Employment in the High Technology Cluster, 1992-97

Segment	Employment		
	1992	1997	Gain
Computers	2,839	4,206	1,367
Electronic & Electrical Machinery	12,624	23,530	10,906
Instruments	11,091	10,378	(713)
Software and Computer Services	6,455	11,856	5,401
High Tech Wholesaling	7,779	11,607	3,828
Total	40,788	61,577	20,789

Source: Oregon Employment Department, 1992 and 1997 Covered Employment and Payroll Data. Oregon Portion of the Portland Metropolitan Area only.

3.2 Comparisons to the Nation

Over the past five years (1992 to 1997) Silicon Forest industries have grown much more rapidly than the regional economy. Significantly, these sectors have all grown faster than their counterparts nationally. Overall, between 1992 and 1997, employment in the core sectors of the region's electronics industry has grown three times faster than the comparable sectors of the US economy, about 8 percent per year in Portland, compared to about 2.7 percent growth nationally. The fastest growth has been in electronics (SIC 36), including semiconductors, and software and computer services (SIC 737), both of which have grown more than 12 percent annually over the past five years. Table 9 also shows the location quotient for the electronics industry. The location quotient measures the relative concentration of an industry in a particular location. Metro Portland's overall high tech location quotient of 1.5 suggests that high technology is about 50 percent more concentrated in the metropolitan area than in the nation as a whole.

Table 9: Growth & Location Quotients for Metro Portland's High Technology Cluster

	Location	Growth Rate, 1992-1997*	
	Quotient	Metro	US
Computers	1.45	7.86%	-1.93%
Electronic & Electrical Machinery	1.94	12.45%	2.07%
Instruments	1.71	-1.33%	-2.12%
Software and Computer Services	1.18	12.16%	9.73%
Total High Tech Cluster	1.50	8.10%	2.66%

Source: Oregon Employment Department, 1992 and 1997 Covered Employment and Payroll Data.

Another way of gauging the growth of the Silicon Forest is to look at metropolitan Portland's share of national employment in the high technology industries in 1992 and 1996 (Table 10). The metropolitan area increased its share of national employment in four of the five sectors of high technology (the exception was instruments).

Table 10: Metro Portland's Share of National High Technology Employment

	Metro Share of US		
	1992	1996	Shift
Computers	0.73%	0.99%	0.25%
Electronic & Electrical Machinery	0.83%	1.32%	0.49%
Instruments	1.19%	1.16%	-0.03%
High Tech Wholesaling	0.73%	0.84%	0.11%
Software and Computer Services	0.77%	0.80%	0.03%
Total: High Tech Cluster	0.84%	1.02%	0.17%

Source: Oregon Employment Department, 1992 and 1997 Covered Employment and Payroll Data.

3.3 Exports

One of the key forces driving the expansion of the Silicon Forest has been the dramatic increase in high technology exports during the 1990s. As shown in Table 11, high technology exports from Portland totaled more than $3.6 billion in 1997, and were up nearly 17 percent per year.

Table 11: Portland Metro High Tech Exports, 1993 and 1997

Segment	1993	1997	Change	% Increase
Electric & Electronic Equipment	463,699,737	1,685,529,013	1,221,829,276	32.3%
Industrial Machinery & Computers*	1,028,793,797	1,432,568,427	403,774,630	8.3%
Scientific & Measuring Instruments	371,609,357	535,289,873	163,680,516	9.1%
Total High Tech	1,864,102,891	3,653,387,313	1,789,284,422	16.8%

Source: U.S. Department of Commerce, EL data series. (Note data for industrial machinery and computers includes items not classified as high technology in other tables).

The published statistics may actually understate the volume of high technology exports from Oregon. Export data are estimated from customs documents, and the reliability of data on the origin of manufacture of many products is unreliable. The American Electronics Association estimates that in 1998, Oregon high tech firms exported about $5.4 billion, a number far higher than the $3.6 billion in exports estimated by the Commerce Department.(American Electronics Association, 1999).

3.4 New Investment

Another factor accelerating the region's employment growth during the 1990s was the announcement and construction of a series of very expensive new electronics manufacturing facilities. Between 1994 and 1996, ten companies announced eleven major investment projects that would collectively spend about $11 billion on new plant and equipment in Oregon and Southwest Washington. (Two projects, Hyundai's Eugene DRAM Fab and Mitsubishi's expanded Salem silicon wafer production facility, are outside the Portland metro area). All of this investment was related to the production of semiconductor devices and silicon wafers. (See Table 12). While several of the larger investments (LSI Logic, for instance) represent multi-phase, multi-year investment plans, as of 1999, initial construction was complete on each of these projects and all were in

operation. One industry source estimated that Oregon captured 32 percent of the new North American chip capacity announced in 1994 and 1995. (Strategic Marketing Associates, 1995)

Table 12: Announced New Semiconductor Investment in Oregon & SW Washington, 1994-1996

Firm	Location	Products	Investment	New Jobs
LSI Logic	Gresham	Semiconductors	$4,000 million	2,000
Intel (Ronler Acres)	Hillsboro	Microprocessors	$2,200 million	1,400
Hyundai Electronics	Eugene	DRAM Memory	$1,300 million	1,000
Wafertech	Camas	Semiconductors	$1,200 million	800
Fujitsu Microelectronics	Gresham	DRAM Memory	$1,032 million	445
Integrated Device Technology, (IDT)	Hillsboro	Semiconductors	$800 million	975
Intel (Aloha D1E)	Hillsboro	Microprocessors	$705 million	355
SEH America	Vancouver	Silicon Wafers	$700 million	600
Komatsu Microelectronics	Hillsboro	Silicon Wafers	$450 million	300
Mitsubishi Silicon	Salem	Silicon Wafers	$340 million	400
Wacker Siltronic	Portland	Silicon Wafers	$240 million	300

Source: Portland Development Commission

4. Related and Supporting Industries

While computers, electronics, instruments and software firms form the core of the region's high tech cluster, the presence of these businesses creates demand for the provision of supplies from other segments of the economy. Some of the inputs to high technology firms are in common supply in every metropolitan area (electricity, water, office supplies) but other products and services are highly specialized. Many of the businesses that are counted as part of other segments of the Portland economy (for example in metals, plastics or business services) are effectively part of the Silicon Forest industry cluster because they sell all or most of their output to firms in the high technology industry.

The Silicon Forest is a set of businesses connected by buyer-seller relationships, similar technology and similar labor force needs. Portland has a wide range of highly specialized producers and service providers. The interactions between the firms ensures they can meet the ever changing and increasingly demanding needs of firms in the industry cluster. The region hosts specialist firms that build and outfit cleanrooms, print labels for electronic devices, and provide testing services. There are several hundred specialized wholesaler firms and manufacturers representatives that sell electronic components and machinery to businesses in the Silicon Forest, often providing engineering services and customer support in the process.

Table 13 identifies some of the major concentrations of supplier and supporting industries that sell a large portion of their output to the region's high technology firms. We based our analysis of related and supporting industries on a review of input-output data for electronics firms, examination of industry directories used by high tech firms, and selected interviews with industry participants.

The region's critical mass of manufacturing firms has made it attractive for a number of supplier firms, especially Japanese firms, to establish US subsidiaries in the Portland area. Recent additions include makers of diffusion furnaces (Tokyo Electron), photo masks for semiconductors (Dupont Photo Masks), crucible makers (Hereaus Shin-Etsu) and providers of photolithography chemicals (OHKA American). While supplier firms may be attracted by the strong local market afforded by the region's base of semiconductor manufacturers, most also serve clients outside the state as well.

The abundance of suppliers in turn, increases the region's attractiveness to semiconductor and electronics manufacturers. Knowing that there is a well developed base of expert supplier firms is a critical factor in choosing a location for new semiconductor fabrication facilities.(Smith, 1999).

Table 13: Related and Supporting Industries

Related Industry	Product/Service Supplied	Typical Firms
Ceramics/Glass	Crucibles, Carriers	Weiss Scientific, Hereus Shin-Etsu, Toshiba, Fujimi
Temporary Staffing Services	Contract Workers for production, professional and clerical functions	Manpower, SOS Staffing, Express Technical, Sources Services
Metal Fabricators and Finishers	Cases, chassis, metal parts for electronic products	Delta Engineering, Crystal Lite, AccraFab, Anodizing
Chemicals Suppliers	Gases and specialty chemicals for processing	BOC Gases, Air Liquide, OHKA America
Engineering & Construction Firms	Specialists in building and equipping high tech factories	IDC, Harder Mechanical, EC
Professional Services	Advertising, Public Relations, Legal, Accounting, Venture Capital	KVO, Waggener Edstrom, Ater Wynne, KPMG, Shaw Venture Partners, ZIBA
Plastics	Plastic Injection Moldings	Puget Plastics, TriQuest Plastics, SPM
Labels	Labels for Products, Chips, Assemblies	Labelgraphics, HiTech Graphics,
Testing Laboratories	Product testing and certification, instrument calibration	Braun Intertec, Northwest EMC

The region's large concentration of high technology firms does more than simply generate additional demand for the supplier businesses located in the metropolitan area—it generates quantitative and qualitative changes in those businesses. The presence of silicon wafer manufacturers like Wacker Siltronic leads chemical supply firms to expand and diversify the products and services they provide locally. Public relations firms that start out serving large local clients develop the capacity to serve national clients and help new startups. Suppliers who meet the demanding delivery and quality standards of Intel are better prepared to compete for business from other sophisticated high tech firms.

In addition to the employment at firms in the supplier industries shown in Table 13, we estimate that there are approximately 7,000 to 10,000 persons on the payroll of temporary staffing agencies that work for high tech firms or their suppliers. Statewide, the American Electronics Association reports that member firms statewide employed more than 9,000 temporary workers in 1998 and 11,350 temporary workers in 1997. In addition, there are large numbers of persons working in construction, maintenance, professional and creative services, metal machining and finishing, and other fields, who primarily supply or provide services to firms in the industries listed above.

5. Regional Economic Impact of the Silicon Forest

Silicon Forest firms play an important role in the regional economy because the majority of their products are sold to customers in other states and nations. These sales generate new income in the region, some of which is paid as wages and salaries to local employees and re-spent in the local economy. The high average wages in the high technology industry means that this industry has a particularly high multiplier effect.

While we have not undertaken an input-output study of the Silicon Forest, it is possible to estimate the rough magnitude of the multiplier effects from Portland area high tech. The economic consulting firm ECONorthwest prepared an economic impact study of Intel's Oregon operations, estimating that Intel alone had direct impacts of $640 million and indirect impacts of $244 million on regional income. The induced impact (from the re-spending of this personal income in the metro economy) was to generate a further $302 million.

The ECONorthwest impact model implies each dollar in personal income generated by the high technology industry generates approximately 34 cents in personal income in other sectors of the regional economy. The model also estimates that about one job is created for every $27,500 in induced personal income.

We estimate that the total direct payrolls of the Portland area high technology industry are around $3.7 billion annually (see Table 1). Applying the Intel multiplier to this total, implies high tech generates an additional $1.3 billion ($3.7 billion times .34) in personal income in the regional economy, and approximately 47,000 jobs ($1.3 billion divided by 27,500) in induced economic activity. While the exact multiplier effect for spending in other segments of the high tech industry is likely to be different than it is for Intel, these data provide a rough approximation of the indirect economic impact that is likely attributable to the Portland area high technology industry.

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