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UNIDO Global Report -- Semiconductors
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I. RECENT TRENDS AND THE CURRENT SITUATION

The worldwide semiconductor industry has always been extremely cyclical in nature. In the past, demand surges were inevitably followed by demand lulls which, in turn, were inevitably followed by demand surges. As a result, worldwide semiconductor production has been erratic, to say the least. Figure 1 shows that in 1984, worldwide semiconductor production grew by 47% to $32.75 billion. One year later, production fell 12%. Such is the nature of the global semiconductor industry.

Figure 1: Worldwide semiconductor production

Year	Production ($ b)	Percent increase
1974	$5.905	14%
1975	4.890	-17%
1976	6.655	36%
1977	7.935	19%
1978	10.160	28%
1979	13.015	28%
1980	16.645	28%
1981	17.445	5%
1982	17.805	2%
1983	22.235	25%
1984	32.750	47%
1985	28.855	-12%
1986	34.760	21%
1987	41.900	21%
1988	56.710	35%

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

There are many reasons why the semiconductor industry routinely undergoes such wild business fluctuations. The industry, though more than two decades old, is still far from achieving maturity. In addition, many of the major customers of semiconductors -- in particular, computer companies -- are far from being mature themselves. During the personal computer (PC) boom of 1984, PC companies were double and triple ordering semiconductors, just to assure themselves of a continuous supply of the vital components. The multiple ordering caused the semiconductor makers to overestimate the market and ramp up production excessively, which ultimately led to the severe semiconductor recession of 1985.

To complicate matters, government meddling has also wreaked havoc with demand and supply. Many industry analysts blame the 1986 U.S.-Japan semiconductor trade agreement, which set arbitrary price floors on certain chips that were exported from Japan into the United States, for the severe memory chip shortage last year.

Thus, forecasting semiconductor demand is an inexact science at best. Nonetheless, several signs indicating an imminent slowdown have recently arisen. And many market researchers fear that the global semiconductor industry, after growing by more than 30% in 1988, may enter into a mild recession by the end of next year.

One of the most important economic indicators in the semiconductor industry is the so-called book-to-bill ratio, considered by many to be the best bellwether of the industry. The book-to-bill ratio measures orders booked versus orders shipped. Thus, a ratio below 1.00 usually indicates industry contraction while a ratio above unity indicates expansion. Last September, the U.S. ratio fell below unity for the first time in 22 months. And recently, the book-to-bill ratio has remained below unity (see Figure 2), which many industry analysts feel portends a recession later this year.

Figure 2: Book-to-bill ratio for the U.S. semiconductor market

1988	
Jan.	1.15
Feb.	1.17
March	1.15
April	1.18
May	1.18
June	1.16
July	1.09
Aug.	1.02
Sept.	0.99
Oct.	0.94
Nov.	0.95*
Dec.	0.93*
1989	
Jan.	1.00*

*preliminary data

Source: World Semiconductor Trade Statistics

There are several reasons for the recent slip in demand. Perhaps most importantly, the markets for many end-products that use semiconductors have slowed. For example, sales of personal computers, which had grown 20% to 30%

annually in the past, will slow to only 13% this year, according to the market researcher International Data Corp. of Framingham, Mass.

In addition, much of last year's demand surge was due to nervous customers who were worried about being able to obtain a continued supply of semiconductors. Memory chips, in particular, were in short supply during most of 1988. Consequently, as prices soared for certain types of scarce semiconductors, many customers stocked up inventories. This year, however, semiconductor makers are beginning to build larger quantities of chips in either new facilities or facilities that were recently expanded to meet the last year's demand surge. Thus, customers are no longer worried about a shortage this year and have stopped stockpiling semiconductors. In fact, some customers are currently burning off excess inventories, which has led to the current book-to-bill ratio of less than one. Semiconductor manufacturers are now aware of the demand lull and many will begin cautiously cutting back on capital expansions.

As a result, worldwide semiconductor production is forecast to grow by only 3.1% to $58.5 billion in 1989 (see Figure 3). Last year, worldwide production grew by 35.3%. Next year, production may actually decrease by 3.3% to $56.5 billion. But Integrated Circuit Engineering Corp. of Scottsdale, Ariz., predicts that worldwide production will recover in 1991. Figure 3 also includes a breakdown of semiconductors into two major categories: discrete semiconductors (simple semiconductors like rectifiers and thyristors that perform just one function) and integrated circuits (semiconductors like microprocessors that perform multiple functions). Integrated circuits (ICs) are commonly called chips.

Figure 3: Worldwide semiconductor production ($ m)

	1986	1987	1988	1989	1990	1991
Discrete semiconductors	$7,190	$8,085	$10,420	$10,620	$10,725	$11,260
Integrated circuits	27,570	33,815	46,290	47,850	45,800	50,600
Total	$34,760	$41,900	$56,710	$58,470	$56,525	$61,860
(Percent growth over previous year)	(20.4%)	(20.5%)	(35.3%)	(3.1%)	(-3.3%)	(9.4%)

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

Not surprisingly, as demand and supply have fluctuated, prices have also vacillated. The average selling price of a semiconductor is forecasted to fall 4.2% to $0.39 in 1989. Last year, the ASP increased 18.6% as a result of the shortage mentioned earlier (see Figure 4).

Figure 4: Semiconductor average selling prices

	Average selling price	Percent increase over previous year
1983	$ 0.289	0.7%
1984	0.332	14.9%
1985	0.289	-13.0%
1986	0.322	11.4%
1987	0.343	6.5%
1988*	0.407	18.6%
1989**	0.390	-4.2%

* estimated
** forecast

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

There are four main geographical regions of semiconductor consumption and production: the United States, Western Europe, Japan and the rest of world (ROW). For the ROW, countries most active in consuming or producing semiconductors include South Korea, Taiwan, China, Malaysia, Singapore, Hong Kong, India, Brazil and Australia.

Figure 5 shows that Japan leads the world in semiconductor production with the United States a close second. In terms of semiconductor consumption, the United States leads the world with Japan a close second. It is interesting to note, however, that the fastest growth region in terms of both production and consumption is the ROW.

Figure 5: Worldwide semiconductor consumption* and production

	Consumption ($ m)		Production ($ m)	
	1988	1987	1988	1987
World total	$54,800	$41,100	$54,100	$43,600
United States	21,100	16,500	22,200	18,500
Western Europe	8,500	6,400	6,100	5,200
Japan	19,100	14,300	23,500	18,700
ROW	6,100	3,900	2,300	1,200

Current largest consumer countries in the world (1988)

1.	United States	$21,100 m
2.	Japan	19,100
3.	West Germany	2,346
4.	Great Britain	1,844
5.	France	1,292

Current largest producer countries in the world (1988)

1.	Japan	$23,500 m
2.	United States	$22,200

Source: Dataquest Inc., San Jose, Calif.; Integrated Circuit Engineering Corp., Scottsdale, Ariz.

Within Western Europe, West Germany leads in semiconductor consumption (see Figure 6). The country purchased $2.35 billion of semiconductors last year, accounting for 27.6% of the total market in Western Europe. Great Britain was second with a consumption of $1.84 billion, representing 21.7% of Western Europe's total market.

Figure 6: Western Europe's semiconductor consumption (total 1988 = $8.50 billion)

1.	West Germany	27.6%
2.	Great Britain	21.7%
3.	France	15.2%
4.	Italy	12.5%
5.	Scandinavia	7.2%
6.	Others	15.8%

Source: Motorola Inc.; Dataquest Inc., San Jose, Calif.

1987 marked the first year in which ROW semiconductor production topped the $1 billion mark (see Figure 7). Last year, the ROW production surged to $2.3 billion. The strong growth in this geographical sector is mainly due to South Korea which accounted for 65% of the total ROW production last year. In fact, next to Japan, South Korea has become the semiconductor success story of Asia. As a result of governmental policy stressing the development of certain industries, South Korea has recently emerged as a significant player in the worldwide electronics industry. In particular, the country has targeted semiconductors, because chips are the foundation of electronic products.

From 1986 to 1987, South Korea's semiconductor production grew more than 70%, from $335 million to $577 million. In 1988, the country's production grew by an astounding 156% to $1,475 million.

Figure 7: ROW semiconductor production

Country	Production ($ m) 1986	1987	1988
1. South Korea	$335	$577	$1,475
2. Taiwan	155	265	400
3. China	122	145	165
4. Others*	133	183	235
Total	$745	$1,170	$2,275

*Includes Hong Kong, India, Brazil, Australia, etc.

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

ROW semiconductor consumption is also led by South Korea, which last year purchased $1,590 million, an increase of 44% from the year before (see Figure 8). This year, the country is expected to consume nearly $2 billion of semiconductors. Taiwan is a close second to South Korea. Due to Taiwan's extensive production of personal computers, the country last year consumed $1,480 million of semiconductors, up 41% from 1987. This year, the island republic should purchase $1,810 million of semiconductors.

Figure 8: ROW semiconductor consumption

Country	Consumption ($ m) 1987	1988	1989
1. South Korea	$1,100	$1,590	$1,970
2. Taiwan	1,050	1,480	1,810
3. Hong Kong	590	810	980
4. Singapore	510	700	840
5. China	340	450	540

Source: Dataquest Inc., San Jose, Calif.

Obviously, the main reason why the ROW countries are consuming an increasing number of semiconductors is because those countries are producing more and more electronic end-products -- such as TVs, VCRs, and personal computers -- that use semiconductors. Figure 9 shows how electronic equipment production in ROW countries has increased dramatically during this decade. ROW countries accounted for 11% of the world's total electronic equipment production in 1984. Last year, the figure grew to 17% and Integrated Circuit Engineering Corp. (ICE) of Scottsdale, Ariz., predicts the figure will rise to 21% in 1993.

The gain will be at the United States' expense. The U.S. produced 55% of the world's total electronics output in 1984 but will only account for 35% in 1993, according to ICE's forecast. Western Europe's electronics output has held steady at around 20% of worldwide production. Meanwhile, Japan's growth has somewhat slowed. In 1984, Japan accounted for 18% of total worldwide production and that figure grew to 23% last year. However, ICE predicts the country will only manage to increase its percentage to 24% in 1993, in part, due to the negative effects of the high-valued yen.

Figure 9: Electronic equipment production

	1984	1988	1993
Total worldwide	$275 b	$490 b	$740 b
Percent of total			
U.S.	55%	40%	35%
Western Europe	18%	20%	20%
Japan	16%	23%	24%
ROW	11%	17%	21%

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

Several recent trends and events promise to have a serious impact on the semiconductor production of various geographical regions. First of all, several ROW countries -- in particular, the Four Tigers: South Korea, Taiwan, Singapore and Hong Kong -- have targeted electronics as key industries. As a result, the governments of those countries have nurtured and supported the local development of such targeted industries. For example, the South Korean government has helped fund a number of semiconductor R&D projects (to be discussed in greater detail later).

Furthermore, several ROW countries have been wooing U.S., Japanese and Western European companies to relocate their manufacturing operations. Malaysia, in particular, has been active. The Southeast Asian country gives various tax breaks to foreign corporations and it also allows manufacturing equipment, and many materials to be imported duty-free. Consequently, many U.S. corporations have been expanding their manufacturing operations there. Previously, Malaysia was used as a manufacturing site for just assembly and test work, the so-called back-end of manufacturing. Recently, however, National Semiconductor, Motorola and Fujitsu announced that they would augment their Malaysian operations by adding wafer fabrication, the so-called front-end of manufacturing in which electronic circuitry is etched onto silicon wafers which are then sawed into individual semiconductor dies.

Fujitsu's expansion in Malaysia is also due to the soaring value of the yen, which makes overseas manufacturing investments comparatively cheaper. Although the high yen value has not forced the Japanese to relocate substantially their manufacturing offshore yet, any further appreciation of the currency's value would increase the already strong pressure to do so.

Another factor pushing the Japanese offshore is the growing protectionist sentiment in the United States and Western Europe. Indeed, after the U.S. slapped imported chips memory chips from Japan with price floors via the 1986 U.S.-Japan semiconductor trade agreement, virtually every major Japanese semiconductor maker increased its manufacturing operations in the United States (see Figure 10).

And Europe 1992 has also given the Japanese, as well as U.S. companies, reason to worry. Earlier this year, the European Commission announce tough "local content" rules which stated that for a chip to achieve "European" status -- and thus be free from any import duties -- the chip will need to be virtually built from scratch within EEC borders. Previously, foreigners could get away with just assembling their semiconductors in the European Economic Community.

Many U.S. companies are already preparing for Europe 1992. For example, Motorola recently invested $70 million to expand its manufacturing operations in East Kilbride, Scotland. And even the smaller U.S. chip makers are getting on the ball. MIPS Computer Systems, developer of an innovative microprocessor using RISC (reduced instruction set computer) technology, announced last January that it would grant West Germany's Siemens the right to manufacture MIPS's microprocessors.

The Western European and U.S. governments have also taken steps to bolster local semiconductor manufacturing by supporting a number of research consortiums. After years of declining semiconductor prominence, Western Europe, in particular, appears to be making a final stand by anteing up huge sums of money. Two projects of special note are ESPRIT, with a total budget of more than $750 million; and the Megaproject, with a budget of close to $2 billion. (Western Europe's R&D drive will be discussed in greater detail later.)

The U.S. government has also taken steps to protect local industry. Two years ago, the government helped establish Sematech, a 6-year consortium established to restore America's leadership in semiconductor manufacturing technology. The consortium's $200 million annual budget is being paid roughly half from taxpayer dollars. Whether Sematech will actually stoke semiconductor manufacturing in the United States has yet to be seen.

Figure 10: Major Japanese semiconductor fabs in the U.S. and Europe

Fujitsu	San Diego, Calif.; Gresham, Ore.; Tallaght, Ireland
Hitachi	Irving, Texas; Landshut, West Germany
Mitsubishi	Durham, North Carolina

NEC	Roseville, Calif.; Mountain View, Calif.; Livingston, Scotland; Ballivor, Ireland
Toshiba	Sunnyvale, Calif.; Braunschweig, West Germany

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

Trade

Because of the dollar's devaluation since 1985, many U.S. semiconductor companies are now beginning to realize that their products have become price-competitive in overseas markets. In particular, the dollar has dropped in value from Y240 in 1985 to Y130 this year. But only recently have U.S. semiconductor companies taken advantage of this by increasing their export efforts to Japan. One reason for the delay is that many Americans had long written off Japan as a closed market and the stigma resulted in many U.S. semiconductor companies remaining leery of the market even after the dollar plummeted in value vis a vis the yen. Now, however, several U.S. companies are renewing their efforts in Japan. A few companies, like Intel Corp. and Texas Instruments Inc., have even begun to win sales to Japan's consumer electronics giants. Previously, winning orders into Japanese consumer electronics products like televisions and VCRs was though virtually impossible for foreign companies.

The yen's rise in value, however, seems to have little effect on Japan's export prowess. By whittling down manufacturing costs at every corner, the Japanese kept prices in check and exports have remained robust. Indeed, Japan's semiconductor exports soared from $2.4 billion in 1984 to $6.2 billion just four years later (see Figure 11). Figure 11 also shows the current magnitude of Japan's semiconductor trade surpulus: $4.5 billion in 1988.

ROW countries achieved the most dramatic increase in exports, from $70 million in 1984 to $700 million in 1988. Meanwhile, imports for that region increased from $1,050 million to $3,950 million during the same time period.

Figure 11: International semiconductor trade

United States

Imports from/ Exports to	Imports ($ m) 1984	Imports ($ m) 1988	Exports ($ m) 1984	Exports ($ m) 1988
Japan	$1,585	$2,200	$700	$1,400
Western Europe	200	450	2,000*	3,200*
ROW	70	500	600	1,000
Total	$1,855	$3,150	3,300*	5,600*

Japan

Imports from/ Exports to	Imports ($ m) 1984	Imports ($ m) 1988	Exports ($ m) 1984	Exports ($ m) 1988

United States	$700	$1,400	$1,585	$2,200
Western Europe	n/m	200	465	1,350
ROW	n/m	100	350	2,650
Total	$700	$1,700	$2,400	$6,200

Western Europe

Imports from/ Exports to	Imports ($ m) 1984	1988	Exports ($ m) 1984	1988
United States	$2,000*	$3,200*	$200	$450
Japan	465	1,350	n/m	200
ROW	n/m	100	100	300
Total	$2,465*	$4,650*	$300	$950

ROW

Imports from/ Exports to	Imports ($ m) 1984	1988	Exports ($ m) 1984	1988
United States	$600	$1,000	$70	$500
Japan	350	2,650	n/m	100
Western Europe	100	300	n/m	100
Total	$1,050	$3,950	$70	$700

*Includes production of U.S.-owned plants in Western Europe

Source: Integrated Circuit Engineering, Scottsdale, Ariz.

Since 1980, the United States has had an IC trade deficit with Japan (see Figure 12). Thus far, the depreciated dollar has had little effect on reversing this trend. It is interesting to note that previous to 1980, the United States had exported more chips to Japan than it had imported.

Figure 12: Japan's IC trade surplus with the United States* (in $ millions)

1975	-$64
1976	-131
1977	-101
1978	-93
1979	-130
1980	11
1981	3
1982	133
1983	307
1984	834
1985	376
1986	250

1987	525
1988**	750

*A positive number indicates Japan had a trade surplus with the U.S. A negative number indicates the U.S. had a trade surplus with Japan

**estimate

Source: Japan Finance Ministry, Integrated Circuit Engineering Corp., Scottsdale, Ariz.

Figure 13 lists the United State's 1988 imports and exports of electronic components and devices. (The U.S. Department of Commerce lists semiconductors under the broad category "Electronic Components and Devices," which includes resistors, capacitors, connectors, switches, and other products.) It is interesting to note that Malaysia was the number one destination for U.S. exported electronic components and devices that year. And the country was number two, behind Japan, for exporting those products into the United States. The figures, however, are misleading. Much of the $1.2 billion U.S. exports into Malaysia were unfinished products that needed to be assembled and tested there. (Malaysia is one of the world's most active sites for semiconductor assembly and testing.) After the work was done, Malaysia shipped the finished products back into the United States which accounted for much of the $1.6 billion imports that year. The same can be said of Singapore which bought $670 million of U.S. electronic components and devices last year and exported $990 million back to the United States. In contrast, the electronic components and devices shipped to and from Japan and Western Europe are, generally speaking, finished products ready for use in electronics end-products.

Figure 13: The U.S.'s imports and exports of electronic components and devices (including semiconductors)

1988 Imports ($ m)		1988 Exports ($ m)	
From:		To:	
Japan	$3,200	Malaysia	$1,200
Malaysia	1,600	European Community	1,170
Singapore	990	Canada	760
European Community	760	Japan	680
Canada	730	Singapore	670
Other	3,680	Other	3,540
Total	$10,960	Total	$8,020

Source: U.S. Department of Commerce

Major companies in the global industry

It is interesting to note that the Top 10 largest companies in the north (which also happens to be the Top 10 largest companies in the world) accounted for $30.65 billion of sales in 1988, roughly 54% of total worldwide production (see Figure 14).

(Note: Figures for pretax profit and profit margins are difficult to come by because most of the major semiconductor companies are part of larger corporations which do not, in general, break out their profit numbers per each of their divisions. For example, Japan's Matsushita Electric Industrial Company Ltd. is an extremely diversified electronics manufacturer whose total sales last year exceeded $38 billion. In addition to semiconductors, the company makes, among other products, consumer electronics equipment such as televisions, VCRs and stereo equipment. In fact, of the company's total sales last year, semiconductors accounted for only $2 billion and the company does not release information on the profitability of that division.)

Figure 14: The largest semiconductor companies in the world (1988)

Company	Country	1988 Sales ($ m)	% change from 1987
1. NEC	Japan	$4,650	44%
2. Toshiba	Japan	4,545	52%
3. Hitachi	Japan	3,610	43%
4. Motorola	U.S.	2,900	22%
5. Texas Instrument	U.S.	2,750	28%
6. Intel	U.S.	2,330	57%
7. Matsushita	Japan	2,080	40%
8. Fujitsu	Japan	2,075	51%
9. Philips	Holland	2,010	25%
10. Mitsubishi	Japan	1,940	48%

Note: "Captive" producers, companies that manufacture semiconductors for internal consumption only, have been excluded. Thus, IBM which produced $3.7 billion of semiconductors last year, has been omitted because the company does not sell its semiconductors in the open market.

Source: Integrated Circuits Engineering Corp., Scottsdale, Ariz.

It is also interesting to note that U.S. companies are losing their dominance in semiconductors. Six years ago, Texas Instruments Inc. and Motorola Inc. were the two largest semiconductor companies in the world (see Figure 15). Last year, the three largest semiconductor companies were all Japanese; TI and Motorola fell to the number 5 and 4 spots, respectively. In fact, of the total worldwide $56.7 billion of semiconductor production in 1988, Japanese companies accounted for 45%, U.S. companies 42%, Western European companies 9%, and ROW companies 4%.

Figure 15: The largest semiconductor companies in the world (1983)

	Company	Country	1983 Sales ($ m)
1.	Texas Instruments	U.S.	$2,350
2.	Motorola	U.S.	2,255
3.	NEC	Japan	1,985
4.	Hitachi	Japan	1,690
5.	Toshiba	Japan	1,460
6.	National Semiconductor	U.S.	1,270
7.	Intel	U.S.	1,170
8.	Philips	Holland	1,150
9.	Advanced Micro Devices	U.S.	935
10.	Fujitsu	Japan	815

Note: "Captive" producers, companies that manufacture semiconductors for internal consumption only, have been excluded. Thus, IBM, which produced $3.7 billion of semiconductors last year, has been omitted because the company does not sell its semiconductors in the open market.

Source: Integrated Circuits Engineering Corp., Scottsdale, Ariz.

Figure 16 shows one market researcher's prediction of the largest semicondcutor companies in the world four years from now. Several points are worth noting about the prediction. U.S. companies, which held five of the Top 10 spots in 1983, will only hold three spots 10 years later. The Japanese, on the other hand, will increase their dominance from four spots to six, during the same time period. Europe will claim no company in the Top 10 in 1993 while South Korea's Samsung, the first company from the South, will make it onto the list in the number 10 spot.

Figure 16: The largest semiconductor companies in the world (1993)

	Company	Country	1993 Sales (forecast) ($ m)
1.	Toshiba	Japan	$7,400
2.	NEC	Japan	7,300
3.	Hitachi	Japan	5,700
4.	Texas Instruments	U.S.	4,100
5.	Motorola	U.S.	3,900
6.	Mitsubishi	Japan	3,700
7.	Fujitsu	Japan	3,600

8. Intel	U.S.	3,400
9. Matsushita	Japan	3,300
10. Samsung	South Korea	3,200

Note: "Captive" producers, companies that manufacture semiconductors for internal consumption only, have been excluded. Thus, IBM, which produced $3.7 billion of semiconductors last year, has been omitted because the company does not sell its semiconductors in the open market.

Source: Integrated Circuits Engineering Corp., Scottsdale, Ariz.

The South's largest semiconductor companies are all from South Korea (see Figure 17). Samsung, in particular, has made tremendous progress in a relatively short period of time. The company's sales this year should top $1 billion and many analysts believe that Samsung will one day emerge as one of the world's largest semiconductor companies. The South Korean company's success, however, has thus far been based on either older or commodity-like products such as DRAMs. It remains to be seen whether the South Koreans will be able to continue their success as they move upmarket to more state-of-the-art, value-added semiconductors such as microprocessors and ASICs (application-specific integrated circuits).

Nonetheless, the South Koreans show little signs of letting up. Goldstar recent began construction of a $2.22 billion semiconductor fabrication facility in Chongju, South Korea. Hyundai has announced that it will spend $1.[illegible]5 billion in electronics over the next five years.

Figure 17: The South's largest companies:

	Company	Country	1988 Sales ($ m)	Percent change	Products
1.	Samsung	South Korea	$955	19[illegible]	Discretes, CMOS Logic, EEPROMs, SRAMs, DRAMs, MPUs
2.	Hyundai	South Korea	200	400%	DRAMs, SRAMs, EPROMs
3.	Goldstar	South Korea	190	58%	Discretes, Linear ICs, TTL logic, Z80 MPUs, CMOS gate arrays, ROMs, SRAMs, DRAMs

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

There has recently been considerable consolidation among the major semiconductor companies in the world. During the past few years, several major mergers and acquisitions have occurred, particularly among the major semiconductor companies in the United States. National Semiconductor purchased

Fairchild Semiconductor after Fujitsu Ltd.'s unsuccessful attempt two years ago. Harris acquired the combined semiconductor operations of General Electric Co. and RCA Corp. last year. (This, after GE purchased RCA in 1986.) Advanced Micro Devices, which acquired Monolithic Memories Inc. recently, is itself currently a takeover candidate. Rumor has it that West Germany's Siemens A.G. is interested in the purchase.

Much of the consolidation is a reflection of the merger mania currently sweeping the United States. However, the consolidation is also an indication of something else. Less than three decades old, the semiconductor industry is maturing out of the infancy stage. And companies are now realizing that, to succeed in the future, they need a certain critical mass because R&D and capital expansion is becoming prohibitively expensive.

It is interesting to note there is a large handful of companies sales past the $1 billion mark and a host of companies with sales below the $200 million mark. However, there are very few companies in between those two sales volumes. Many analysts feel that because of the industry's maturation, very few small- and medium-sized companies will be able to join the major players. There seems to be some sort of barrier at the $1 billion market, which is why AMD said it had to purchase MMI two years ago. Industry analysts have speculated that without the acquisition, it would have taken AMD considerable time to grow from being a mid-sized company to a major player with sales past $1 billion.

Western Europe's chip makers also appear to be going through some sort of consolidation process. Earlier this year, Great Britain's General Electric Company and West Germany's Siemens A.G. (Europe's number 3 semiconductor company) were attempting to buy Great Britain's Plessey Semiconductor Ltd. (Europe's number 4 semiconductor company) for $3 billion. Plessey's plight is ironic in that the company acquired Ferranti Electronics Ltd., another major player in the European semiconductor industry, two years ago. And late last year, Great Britain's Inmos signed a preliminary agreement to be acquired by SGS-Thomson.

Figure 18 shows the consolidation that has taken place in Western Europe's semiconductor industry over the past five years. In 1983, the top integrated circuit (IC) companies in Western Europe were all pretty much in the same size class. However, last year's figures show that two companies -- Philips and SGS-Thomson -- have broken away from the pack, thanks to major acquisitions. Several years ago, Philips acquired the U.S.'s Signetics Corp. and Italy's SGS-ATES Componenti Elettronici SpA and France's Thomson Semiconductors merged. Some industry analysts believe that the only way in which Western Europe's chip makers will be able to compete with those from the United States, Japan, and the developing Asian nations is by combining forces. In fact, some pundits believe Western Europe's semiconductor industry will consolidate into just two or three companies within the next decade.

Figure 18: The consolidation of
Western Europe's semiconductor industry

Top European IC

Top European IC

companies in 1983 ($ m)

1.	Siemens	$200
2.	Philips	200
3.	SGS-ATES	170
4.	Thomson	100
5.	ITT	100
6.	Ferranti	75
7.	Inmos	57
8.	Plessey	50
9.	Telefunken	40
10.	Others	48
	Total	$1,040

companies in 1988 ($ m)

1.	Philips	$905
2.	SGS-Thomson	820
3.	Siemens	440
4.	Plessey-Ferranti	305
5.	ITT	200
6.	Inmos	125
7.	Telefunken	100
8.	Matra Harris	55
9.	Marconi	30
10.	Asea Hafo	30
11.	Others	190
	Total	$3,200

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

In addition to mergers and acquisitions, companies are also partnering more and more with their competitors, particularly as the cost of manufacturing and R&D for each new generation of semiconductors skyrockets. Dataquest Inc., a market research firm in San Jose, Calif., says that the number of cooperative ventures among semiconductor companies has soared, from a handful in 1980 to 93 in 1987.

Many of the alliances are East-West arrangements. For example, Motorola Inc. and Toshiba Corp. announced late in 1986 that they would establish a joint venture. Through the partnership, Toshiba is obtaining Motorola's coveted microprocessor technology. In return, Motorola is receiving Toshiba's memory chip know-how. Both companies are also jointly making semiconductors in Japan. Texas Instruments Inc. and Hitachi Ltd. recently announced that they would pool R&D resources. Industry analysts assert that this trend of East-West partnerships will continue in the future.

II. MANUFACTURING CAPACITY OF DEVELOPING COUNTRIES

Manufacturing in developing countries, with South Korea the notable exception, has generally been limited to the "back-end," or assembly, packaging and test steps. Wafer fabrication -- the complex "front-end" where electronic circuitry is etched onto silicon wafers -- is generally done in the United States, Japan and in Western Europe. Also, full manufacturing of semiconductors in developing countries has been limited to low-end semiconductors because the manufacturing processes in those countries are at the same levels as in Northern countries. For example, in India and China, wafer fabrication is done using 2-micron geometries, i.e., the smallest width of the etched electronic circuitry is 2-microns. Whereas in the United States, Western Europe and Japan, some fabs are being built with 1-micron and below capabilities.

As discussed earlier, South Korea is the dominant ROW producer of semiconductors. It is interesting to note that the country's production is geared towards overseas markets. Figure 19 shows how the major companies in South Korea have structured their production.

Figure 19: South Korea's major semiconductor producers (January 1989)

Company	Main products produced	Destination
Samsung	7 million DRAMs/month 400,000 SRAMs/month	65% of DRAMs exported 70% of SRAMs exported Of total exports: 40% shipped to U.S. 30% shipped to Western Europe 20% shipped to Southeast Asia 10% other (includes Argentina, Brazil, and Japan)
Goldstar	450,000 SRAMs/month	80% of SRAMs exported mainly to the U.S.
Hyundai	2.7 million SRAMs/month	85% of SRAMs exported to: 47% shipped to Asia 29% shipped to U.S. 24% shipped to Western Europe
	6.0 million DRAMs/month	90% shipped to U.S. 10% shipped to Asia and Western Europe

III. CAPACITY UTILIZATION AND EXPANSION PLANS, 1988

During 1983 - 1984, capacity utilization was extremely high as a result of the personal computer boom. PC manufacturers could not get enough chips to meet their demand. Semiconductor manufacturers around the world geared up for the market explosion. And then the PC market stalled which led to serious overcapacity in the semiconductor industry in 1985 - 1986 (see Figure 20). Demand caught up with supply in 1987 - 1988 and, in fact, there was a shortage of many types of chips -- most notably DRAM (dynamic random access memory) chips -- last year. However, some industry analysts believe that capacity utilization will drop this year and in 1990 due to a further slackening of demand for PCs and other electronics products that use semiconductors. Worldwide capacity utilization should then recover in 1991 - 1992, according to many analysts.

It is interesting to note that, from Figure 20, the ROW capacity utilization has increased from 2.1% of total worldwide capacity in 1982 to 5.8% this year. ROW capacity utilization should continue increasing to 7.3% in 1992, according to Dataquest Inc., a market research firm in San Jose, Calif. Meanwhile, capacity utilization as a percent of total worldwide capacity has decreased for the United States from 39.5% in 1982 to 25.3% this year.

Figure 20: Estimated capacity utilization
(as percent of total worldwide capacity)

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
United States	39.5%	43.3%	42.8%	20.3%	19.3%	24.9%	27.4%	25.3%	25.8%	27.4%	27.5%
Japan	21.9	32.7	40.0	30.0	30.5	38.7	42.1	39.0	36.1	37.0	36.6
Western Europe	8.5	8.6	9.7	7.6	8.2	9.9	10.7	10.4	10.2	10.6	11.0
ROW	2.1	2.7	3.1	2.2	3.0	4.6	5.6	5.8	5.4	6.6	7.3
Total WW capacity utilization	72.0%	86.2%	95.6%	60.1%	61.0%	78.1%	85.8%	80.5%	77.5%	81.6%	82.4%

Source: Dataquest Inc., San Jose, Calif.

Figure 21 gives a more detailed look at semiconductor fab capacity utilization in the United States and Japan. Figure 21 reveals that, in general, Japan's fabs operate at a higher capacity utilization rate than their counterparts in the United States. Indeed, during 1986, the tail end of the last semiconductor recession, Japan's fabs were running at 74% of capacity while the U.S.'s were running at only 59%.

Figure 21: Chip fab capacity utilization

	1984	1986	1988	1990
U.S.	94%	59%	88%	75%
Japan	90%	74%	90%	80%

Note: Based on 5-day working weeks, 2 shifts per day
Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

However, not all plants are created equal. In fact, how busy a plant was in 1988 depended very much on the type of technology that facility could handle see Figure 22). State-of-the-art fabs that could manufacture chips with circuitry less than 1-micron line widths, were running at 105% capacity last year. Meanwhile, older facilities that could handle no better than 3-micron line widths were running at only 60% capacity during the same time period.

Figure 22: Capacity utilization in 1988

Technology	Percent capacity utilization
less than 1.00 micron	105%
1.00 to 1.49 micron	95%
1.50 to 3.00 micron	90%
greater than 3.00 micron	60%

Note: Based on 5-day working weeks, 2 shifts per day
Source: Integrated Circuit Engieering Corp., Scottsdale, Ariz.

Although capacity utilization is expected to drop in the near future, semiconductor capital spending will rise 9.2% to $9.30 billion this year (see Figure 23), according to Dataquest Inc., a market research firm in San Jose, Calif. But Dataquest predicts that capital spending will increase by only 1.4% next year. In fact, Japan is expected to decrease its capital spending 3.1% to $3.92 billion in 1990. ROW spending, however, should remain strong. ROW countries are spending $545 million on capital expansion this year, up 16.4% from 1988. ROW spending should rise another 20.2% next year, according to Dataquest.

Figure 23: Estimated semiconductor capital spending
($ millions)

	1984	1985	1986	1987	1988	1989	1990	1991	1992
United States	$3,661	$2,629	$2,066	$2,474	$3,332	$3,654	$3,729	$4,640	$6,056
Japan	3,900	3,336	1,850	2,439	3,796	4,044	3,919	5,238	7,056
Western Europe	843	803	823	843	923	1,061	1,135	1,402	1,706
ROW	434	463	299	380	468	545	655	900	1,096
Total WW	8,838	7,231	5,039	6,136	8,518	9,304	9,438	12,179	15,914

Source: Dataquest Inc., San Jose, Calif.

In particular, the South Koreans have been very aggressively increasing their capital expenditures. Figure 24 shows the individual investments of the major semiconductor manufacturers in South Korea. As can be seen from Figure 24, Goldstar leads the South Korean semiconductor industry in terms of capital expenditures. Goldstar spent nearly $200 million on capital expansion last year, according to the Korea Economic Daily.

Figure 24: South Korean semiconductor capital
expenditures in 1988 ($ m)

Company	1988 Semiconductor

capital expenditures ($ m)

Goldstar	$194
Samsung	107
Hyundai	16
Daewoo	7

Source: Korea Economic Daily

IV. RESTRUCTURING AND REDEPLOYMENT

Cost of production

The cost of materials in the semiconductor industry is not, relatively speaking, that significant a portion of the total cost of production. Figure 25 shows that both R&D expenses and equipment costs outweigh the cost of materials. Labor costs are also significantly less than either R&D or equipment expenses. This is one reason why, to this day, the bulk of semiconductor production has remained in the United States, Japan and Western Europe.

For the forseeable future, analysts do not expect any major changes in the manufacturing cost structure. In fact, if anything, R&D and equipment costs will only increase in proportion to materials and labor costs. R&D costs are soaring due to the increasing complexity of chip designs. The latest microprocessor from Intel Corp. contains more than one million transistors and the company spent four years and $300 million to develop it. Not surprisingly, the equipment required to build such a semiconductor is extremely complex and expensive. The price tag for a state-of-the-art photolithography system, used to etch electrical circuitry onto silicon wafers, currently tops the $4 million mark.

Figure 25: Cost of production in the semiconductor industry

Item	% of total production cost
General & administrative	28.9%
Research and development (R&D)	19.8%
Equipment	14.7%
Wafer fab equipment (10.0%)	
Assembly equipment (1.5%)	
Automatic test equipment (3.2%)	
Materials	14.1%
General materials and chemicals (2.1%)	
Packaging materials (5.3%)	
Silicon wafers (3.8%)	
Masks and services (2.9%)	
Facility construction	5.6%
Labor	8.9%
Utilities	2.4%

Contractors for assembly work	2.1%
Misc.	3.5%
Total	100.0%

Note: Numbers are based on 1986 figures for the worldwide semiconductor industry

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

North-South labor wages

Although the cost of labor is only 8.9% of the total cost of production (Figure 25), large differences in labor rates still makes manufacturing in certain ROW countries attractive. Figure 26 clearly shows that the wages in the United States are markedly above those in the ROW countries. (Comparable figures could not be obtained for Japan and Western Europe. However, due to the highly appreciated yen, analysts estimate that the cost of production is now roughly equal between Japan and the United States.)

Labor rates notwithstanding, semiconductor manufacturers from the United States, Japan and Western Europe will generally only make their older products in ROW countries. Or, ROW countries are used for just the back-end manufacturing processes: the assembly, packaging and test work. The main reason for this is quality control. Manufacturing a state-of-the-art semiconductor is a very intense and complicated process. Electronic circuitry of 1-micron width -- roughly 1% of the diameter of a human hair -- has to be etched onto 6-inch round silicon wafers. The circuitry is so complex that it is equivalent to drawing a roadmap containing every side street of the entire United States, according to one semiconductor scientist. Because of the microscopic scale used, an extremely clean facility is required for the wafer fabrication process because even a tiny dust particle can mess up the electronic circuitry. In the most advanced wafer fabrication facilities today, one cubic foot of air contains at most one 0.2-micron particle and nothing larger. (At this manufacturing level, even a flu virus can cause defects.)

Figure 26: Hourly wages for equipment operators (1987)

United States	$10.70
Singapore	3.00
South Korea	2.50
Hong Kong	2.50
Taiwan	2.00
Thailand	1.15
Malaysia	0.80
Philippines	0.60
India	0.60

Source: U.S. Bureau of Labor Statistics; Integrated Circuit Engineering Corp., Scottsdale, Ariz.

Adjustments to overcapacity (or undercapacity)

Detailed employment figures for the worldwide semiconductor industry are difficult to obtain. Individual countries, in general, do not track employment specifically for the semiconductor industry, and neither do industry trade organizations like the Semiconductor Industry Association of Cupertino, Calif.

The United States, however, is one country that does keep detailed employment figures. Figure 27 shows that U.S. employment in the semiconductor industry increased from 223,400 workers in 1980 to 279,100 in 1985. However, employment fell to 247,300 in 1987, the last year in which statistics are available. The decrease was mainly due to the severe recession in 1985 - 1986, which forced most U.S. semiconductor companies to pare their staffs. Massive layoffs during that time period were extremely common in Silicon Valley.

Figure 27: U.S. semiconductor industry employment

1980	223,400
1981	223,700
1982	225,700
1983	235,000
1984	237,800
1985	279,100
1986	261,200
1987	247,300

Source: U.S. Bureau of Labor Statistics

Detailed figures for the Japanese semiconductor industry are not easy to obtain. However, Figure 28 shows the total employment of the country's electronics industry, which includes the semiconductor segment.

Figure 28: Total employment of Japan's electronics industry

1982	947,780
1983	1,044,729
1984	1,189,363
1985	1,201,342
1986	1,211,767

Source: Ministry of International Trade and Industry, Japan

Sourcing of materials and equipment

Semiconductor materials are not, relatively speaking, that costly a component of the semiconductor manufacturing process (see Figure 25). The major material involved is silicon wafers, which, because of the difficulty in manufacturing them, are made predominantly by Japanese and Western European companies.

There has recently been much concern in the United States because of the U.S.'s lack of local silicon wafer suppliers. With the sale of the U.S.'s Monsanto Co.'s silicon wafer business to Heuls AG, a West German company, there now exists no remaining major merchant domestic supplier of silicon wafers in the United States. In fact, the Top 7 silicon wafer suppliers -- SEH, Osaka Titanium, Wacker, Japan Silicon (owned by Mitsubishi), Komatsu Electronic Metals, Monsanto (now owned by Heuls AG) and Toshiba Ceramics -- are all based in Japan or Western Europe. Together these seven controlled about 90% of the $2 billion market last year.

As stated earlier, capital equipment is a larger cost component than materials is for the semiconductor manufacturing process. In fact, the price tag of a new wafer fabrication facility stocked with state-of-the-art equipment now runs about $200 million. Within a decade, the cost is expected to reach the $1 billion mark as each succeeding generation of semiconductor products becomes increasingly difficult to manufacture. Today, just one piece of photolithography equipment can top $4 million.

Virtually all semiconductor production equipment comes from the North. Of the Top 10 semiconductor production equipment companies in 1987, six were U.S.-based and the remaining four were Japanese (see Figure 29).

The presence of local equipment companies is a major advantage for U.S. and Japanese semiconductor makers. Particularly in Japan, the chip makers and equipment companies work closely together to develop the next-generation equipment needed to manufacture the next-generation semiconductors. By doing so, manufacturing problems can be ironed out at an earlier and less expensive stage. Also, when a U.S. or Japanese chip maker runs into any manufacturing problems, the equipment companies are always nearby to help.

On the other hand, South Korea's lack of a semiconductor infrastructure places the country at a significant disadvantage. South Korea often does not get the latest production equipment and because the local market there is not that significant yet, many Japanese and U.S. equipment companies do not have subdiaries that can adequately service the equipment in South Korea. The country is currently trying to build up its infrastructure by encouraging indigenous companies to make silicon wafers and production equipment. Nonetheless, it will be some time before South Korea has a sufficient infrastructure in place.

Figure 29: Top semiconductor equipment companies in 1988 (estimates)

	Company	Country	Fiscal 1987 sales ($ m)	Fiscal year ending
1.	Nikon	Japan	$242	March, 1988
2.	Perkin-Elmer	U.S.	212	July, 1987
3.	General Signal	U.S.	208	December, 1987
4.	Advantest	Japan	205	March, 1988
5.	Applied Materials	U.S.	174	October, 1987
6.	Tokyo Electron	Japan	173	September, 1987
7.	Canon	Japan	151	March, 1988
8.	Teradyne	U.S.	130	December, 1987
9.	Varian	U.S.	125	September 1987
10.	LTX	U.S.	120	July, 1987

Source: VLSI Research Inc., San Jose, Calif.

During the past few years, the high cost of building a fab and stocking it with the necessary state-of-the-art equipment has given rise to a new phenomenom in the United States: the "fab-less" semiconductor company. Because manufacturing has become prohibitively expensive for many small U.S. companies, they have chosen an alternative strategy: subcontracting their manufacturing out to Asian foundries. Innovative Silicon Valley companies like Altera Corp., Chips and Technologies Inc. and Xilinx Inc. decided to concentrate on chip design, leaving their manufacturing for others to do, hence the term "fab-less," or, without a wafer fabrication facility. For various reasons, larger U.S. companies like Texas Instruments and Intel Corp. have also begun to subcontract out their manufacturing. In fact, one U.S. market analyst estimates that the worldwide foundry business topped $1 billion last year.

So far, Japanese and South Korean companies have benefited from the windfall. Indeed, South Korea's Hyundai got its start in the semiconductor business by making chips for U.S. semiconductor companies. By doing foundry work for others, Hyundai was able to fine-tune its manufacturing processes and the company is now trying to sell on its own the chips that it makes. Several years ago, 80% of Hyundai's production was foundry work but the figure has since fallen to below 50% and, as Hyundai reaps greater success in selling semiconductors directly to customers, company officials are aiming to drive the foundry percentage down further, to below 30%.

R&D expenditures

R&D expenditures on a per country basis are difficult to obtain. For the United States, however, rather detailed figures are available. Figure 30 shows R&D expenditures for the U.S. semiconductor industry. Although the overall industry average of R&D expenditures as a percent of sales is 9.5%, many U.S. companies are spending considerably more than that. For example, Advanced Micro Devices routinely spends in excess of 20%. However, the company, as well as other big spenders in R&D, has lately been under pressure from Wall Street and stock investors to cut back. In fact, many U.S. corporations are paring their R&D budgets, in part, as a defense against hostile takeover attempts, which have reached near epidemic proportions in the United States. Consequently, the relative level of R&D spending in the U.S. semiconductor industry decreased in

1987, even though the absolute level increased by 12.7% over 1986. That is, R&D as a percent of sales fell from 10.6% in 1986 to 9.5% in 1987.

Figure 30: U.S. semiconductor industry R&D expenditures

1986 ($ m)	1987 ($ m)	% increase	1986 R&D as % of sales	1987 R&D as % of sales
$1,820	$2,052	12.7%	10.6%	9.5%

Source: Electronic Business

On the other hand, the South Koreans are dramatically increasing their R&D budgets. The South Koreans realize that their country is quickly losing its low-cost labor advantage because Korea's currency, the won, is rapidly appreciating. Thus the South Koreans are trying to move upmarket with higher value-added products.

However, U.S. and Japanese semiconductor companies have recently become more proprietary with their technology. For example, Intel has steadfastly refused to license the technology for its 32-bit microprocessor, the 80386. In the past, such second-sourcing agreements were commonplace. And, when companies do license their technology, they are now asking for more money. Texas Instruments recently took nine Far Eastern chip makers to court in order to collect five to ten times more in royalties for the DRAM technology the company had licensed. TI won the legal battle and, as a result, the company could collect more than $250 million through 1990.

Thus, the South Koreans realize that they will probably have to develop their own technology in order to remain competitive. Hyundai spent 25% of its sales on R&D last year and the company is planning to increase R&D expenditures dramatically in 1989. Hyundai has plans to enlarge its R&D staff from 250 last year to 400 workers this year.

In addition, the South Koreans have instituted a rash of research cooperatives, many of which have been sponsored by the government. Figure 31 summarizes the 18 joint-development projects which have been established since 1986. These projects were supported by the South Korean government at a total investment of $226 million. The projects cover a wide range of technologies and they involve the country's major electronics manufacturers. The projects span a short time period, at most three years, which reflects the country's strong desire to catch up with semiconductor technologies in Japan and the United States. The projects all have short-term commercial orientations and, consequently, should have an impact on the global semiconductor industry sometime in the early 1990s, according to Dataquest Inc., a market research firm headquartered in San Jose, Calif.

Figure 31: South Korean joint-development semiconductor projects

Project Name	Time period	Participants*	Investment** ($ m)
Sub-Micron Technology	10/86 - 3/89	ETRI, SST, GSS, HEI	$109.8
ETS Standard Cell ICs	1/87 - 12/89	DTI, GS	4.2
300V Power MOS FET	1/87 - 12/88	KEC, DTI	4.1
CDP IC	1/87 - 12/88	GS, DTI	4.9
GaAS Semi, Materials	1/87 - 6/89	GSC, SCC	6.9
High Lead-Type Leadframe	1/87 - 12/89	Pungsan, Anam	47.0
VLSI Level EMC	10/86 - 12/88	Dongyan Chemical, Anam	1.8
Automotive ICs	7/87 - 6/89	DEP, KEC, DTI	4.9
GaAs Photo Cell	10/86 - 9/89	KEC, GS	3.8
Thin Film Transistor	7/87 - 6/89	GS, DEP	4.9
Digital Video IC	10/87 - 9/89	GS, DTI	5.0
High-Power Transistors	1/88 - 12/90	KEC, HEI, SST	2.0
32-bit PC ICs	1/88 - 12/90	DTI, HEI, KEC, SST	5.0
CCD Camera Manufacturing	1/88 - 6/90	SED, SST	4.5
CCD Image Sensor	1/88 - 12/90	SED, SST	5.0
DAT IC	1/88 - 12/89	SEC, SST	5.6
Power Transistor Pkg.	1/88 - 12/88	Samsung Aerospace, SST	3.9
GaAs epi Wafer	1/88 - 12/89	GSC, GS	3.0
		Total	$226.3

*Key:
- ETRI = Electronics Technology Research Institute
- SST = Samsung Semiconductor and Telecommunications
- SEC = Samsung Electronics
- GS = Goldstar Company
- GST = Goldstar Telecommunications
- DTI = Daewoo Telecommunications
- HEI = Hyundai Electronics Industry
- SED = Samsung Electron Device
- SSC = Samsung Corning Company
- GSS = Goldstar Semiconductor
- GSC = Goldstar Cable
- DEP = Daewoo Electronic Parts
- KEC = Korea Electronics Company

**Converted at a constant rate of $1 = 800 won.

Source: Dataquest Inc., San Jose, Calif.

One of the reasons for forming consortiums is that semiconductor R&D is becoming increasingly expensive to conduct. As stated earlier, Intel Corp. has reported that the R&D cost of developing its most recent microprocessor reached $300 million -- more than a quarter of a billion dollars just to develop one semiconductor. Consequently, many companies have found that it has become too expensive to conduct certain R&D programs alone.

For example, the U.S.'s Texas Instruments, which heretofore had shunned partnering with its Japanese competitors, recently announced an intriguing alliance with arch-rival Hitachi Ltd. The partnership concerns 16-megabit DRAMs -- future memory chips that will be able to store 16 times the amount of memory as the latest commercial DRAMs. TI and Hitachi are separately gambling on different technologies in developing the 16-megabit DRAM and neither company is sure whether it has chosen the right approach. So, both companies have agreed to pool their results, thereby lessening the potential risks, estimated in the hundreds of millions of dollars. In today's world of staggering R&D costs, such partnerships will most likely continue.

The Western Europeans have also initiated various consortiums. For years now, the Western European semiconductor industry has been in serious decline. Many analysts believe that the recent flurry of Western European R&D consortiums is the region's last stand to re-emerge as a major player in the global semiconductor market. In order to get back into the memory chip market, the Netherlands' Phillips N.V. and West Germany's Siemens AG established the "Megaproject" in 1984. Phillips will invest a total of $1 billion; Siemens will invest $600 million; and the two company's respective governments have agreed to invest a total of $270 million. So far, Phillips has developed a 1-megabit SRAM (static random access memory) chip and Siemens has succeeded in developing a 4-megabit DRAM (dynamic random access memory) chip. Both companies are hoping to catch up with the Japanese.

Other Western European consortiums include ESPRIT, a $750 million R&D cooperative for microelectronics, software technology and advanced information processing; and JESSI (Joint European Silicon Submicron Initiative), a $3.3 billion project involving Siemens, SGS-Thomson, Plessey, and Phillips. JESSI's goal is to develop 0.3-micron chip technology by the mid-1990s.

And the United States, which previously shunned such consortiums, has recently joined the bandwagon. Various U.S. chip makers banded together in 1987 to form Sematech, a consortium whose charter is to develop advanced semicondcutor manufacturing processes. Sematech's annual budget is roughly $200 million, of which about half will come from the U.S. government. So far, 14 U.S. chip makers -- including major manufacturers like Advanced Micro Devices, Intel, Motorola, National Semiconductor and Texas Instruments -- have signed up. Sematech's minimum lifetime has been set at 5 years.

Shift in production

One way to measure the shift in production from bulk commodity products to more higher value-added ones is to separate semiconductor production into discrete semiconductors versus the more advanced integrated circuits (ICs), which are commonly called chips. Discrete semiconductors such as rectifiers and thyrisistors are, in comparison to ICs, relatively primitive in that they are only able to perform one function. ICs, on the other hand, are much more complex. For example, a microprocessor chip today contains all the brainpower of yesterday's large computers. Comparing discrete semiconductor production versus IC production gives a general, although admittedly crude, measure of a country's semiconductor manufacturing prowess. Figure 32 shows that for ROW countries, IC production, as a percentage of overall semiconductor production, grew from 53.5% in 1983 to 77.6% last year. Clearly, ROW countries are shifting their production to higher value-added products at a rapid pace.

Figure 32: The worldwide shift in production from traditional bulk products to higher value-added products

	Traditional bulk products: discretes in $m (% of production) 1983	1988	Specialty products: ICs in $ m (% of production) 1983	1988
North America	$2,145 (15.7%)	$2,530 (10.7%)	$11,475 (84.2%)	$21,025 (89.2%)
Western Europe	935 (47.3%)	1,880 (37.0%)	1,040 (52.6%)	3,200 (63.0%)
Japan	1,790 (28.8%)	5,500 (21.3%)	4,420 (71.2%)	20,300 (78.7%)
ROW*	200 (46.5%)	510 (22.4%)	230 (53.5%)	1,765 (77.6%)
Total WW	5,070 (22.8%)	10,420 (18.4%)	17,165 (77.2%)	46,290 (81.6%)

*Excludes the Soviet Bloc, but includes the People's Republic of China

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

The IC category can further be broken down into commodity products and high valued-added ones. At the high-end of the spectrum, application-specific integrated circuits (ASICs), which are ICs customized to meet a customer's specific requirements, are among the most sophisticated and complicated of semiconductors. Figure 33 shows that U.S. companies control the worldwide ASIC market. ROW countries have yet to penetrate this market segment.

Figure 33: 1988 worldwide ASIC sales
Total = $4.945 billion

U.S. companies	54%
Japanese companies	38%
Western European companies	8%
ROW companies	negligible

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

In contrast to ASICs, MOS (metal-oxide semiconductor) memory ICs are more commodity-like in that they can, in general, be used by a wide range of customers. Figure 34 gives a breakdown of the major MOS memory suppliers in the world. The market is clearly dominated by the Japanese, who commanded a 71% share last year. U.S. firms were a distant second with 19%.

It is interesting to note that, more than a decade ago, U.S. companies were the dominant suppliers of MOS memory chips. However, many of these firms were forced out of the market in the 1980s by severe Japanese price cutting. In particular, Intel Corp., which founded the DRAM (dynamic random access memory) market, was driven out years later. In a somewhat humiliating turn of events, Intel now re-sells DRAMs which it buys from South Korea's Samsung. There are currently only two U.S. manufacturers of DRAMs left -- Micron Technology and Texas Instruments.

The DRAM episode reflects a fundamental weakness of the U.S. semiconductor industry. U.S. chip companies are quick to develop innovative products, however, the companies often are not able to reap the full benefits of their inventiveness once the products become commodity-like. Industry analysts cite a lack of competitive manufacturing as the culprit.

Figure 34: 1988 worldwide MOS memory market
Total = $11.0 billion

U.S. companies	19%
Japanese companies	71%
Western European companies	3%
ROW companies	7%

Source: Integrated Circuit Engineering Corp., Scottsdale, Ariz.

Foreign direct investments

U.S. companies are continuing to expand their manufacturing in Asia. Motorola, for example, recently announced that it would spend $300 million on a semiconductor and telecommunications factory in China. The company also stated that it would build a $47 million wafer fab in Malaysia by 1991.

Because of the high-valued yen, the Japanese, too, are doing more manufacturing offshore (see Figure 35). Sony is building its first overseas wafer fab, which is scheduled for startup in Thailand later this year.

Figure 35: Number of overseas electronic component and device* production facilities of Japanese corporations (as of 1986)

North America	33

U.S.	31
Canada	2
Western Europe	21
West Germany	7
United Kingdom	6
Spain	2
Ireland	2
Belgium	2
France	1
Italy	1
ROW	183
Taiwan	62
South Korea	42
Singapore	30
Malaysia	14
Brazil	13
Hong Kong	7
Mexico	7
China	3
Thailand	2
Phillipines	2
Indonesia	1

*includes semiconductor facilities

Source: Electronic Industries Association of Japan

The role of government

Various governments are playing a major role in affecting industrial restructuring. As mentioned earlier, a growing mood of protectionism -- in the United States and Western Europe (via Europe 1992) -- is already affecting the investment decisions of many semiconductor companies.

In addition, most Northern and many Southern governments have decreed semiconductors a national priority. Thus, financial subsidies, often in the form of federally-assisted consortiums, are common. As discussed earlier, the governments of the United States, Japan, Western Europe and South Korea have all helped fund various R&D projects. And, in Japan the Ministry of International Trade and Industry takes an active role in planning the semiconductor industry's future. For example, during the latest memory chip glut, MITI strongly suggested to the various semiconductor companies in Japan that they cut down their production of such chips by a specified amount.

For Southeast Asian countries, government help comes in the form of certain incentives for foreigners to do manufacturing there. For example, as discussed earlier, the Malaysian government gives tax breaks to foreign companies in order to entice them to do local semiconductor manufacturing in Malaysia.

Major bottlenecks

For Northern countries, the pace of expansion is usually held back by limited capital. As was discussed earlier, building a wafer fabrication facility currently costs more than $200 million. Very few companies can afford that kind of expenditure without some kind of financial hardship.

Of course, the problem of limited capital pertains to Southern countries as well. However, Southern countries have other limiting factors. South Korea's predicament is a case in point. Several years ago, the country's chaebol, or industrial conglomerates, targeted electronics as a lucrative and important market. Money was no object. To date, Hyundai -- a shipbuilder, automaker and construction engineering powerhouse -- has spent more than $600 million to get into the electronics market. Samsung, Lucky Goldstar and Daewoo have similarly spent hundreds of millions of dollars. However, progress has been slower than expected due to a lack of technical know-how and experienced engineers in the country. In fact, Hyundai executives have admitted that South Korea's lack of technical talent is currently one of Hyundai Electronics' most crucial problems.

V. TECHNOLOGICAL TRENDS, NEW PRODUCTS DEVELOPMENT AND NEW PROCESSES

Future technologies

Technology, of course, is important in any industry. However, technology is crucially important in the semiconductor industry because of the short lifespans of products. Time-to-market is a critical concept. Getting to market six months earlier than your competitor can mean the difference of millions of dollars of sales. A new memory chip, when first introudced in the marketplace, can command a price in excess of $100. Three or fours years later, that same memory chip might sell for under $5, particularly if the next-generation memory chips have already arrived in the marketplace.

The technology having the most impact on shortening the time-to-market of semiconductor products is CAE/CAD/CAM (computer-aided engineering/design/manufacturing): the use of a computer to design and manufacture a chip. In fact, many complex chips today are too complicated for engineers to design manually; computer tools are absolutely necessary to design and lay out the hundreds of thousands of transistors that need to be placed on a thumb-nail sized area. The widespread use of computer-aided tools has given rise to a $5 billion industry in the United States, according to Daratech Inc., a CAE/CAD/CAM market researcher in Cambridge, Mass.

In terms of new products, different materials are always being studied as possible replacements for the ubiquitous silicon. One material that has been investigated for years is gallium arsenide, which conducts electricity roughly five times faster than silicon. Thus, gallium arsenide chips, and the computers made from them, will be able to process information that many times faster. However, gallium arsenide is a costly and difficult material to work with. Still, a host of U.S. start-ups are pioneering the market, which reached around $130 million last year. In addition, various Japanese conglomerates like

Fujitsu Ltd., Hitachi Ltd. and NEC Corp. are also conducting research on the material.

In the process technology area, the BiCMOS process -- a hybrid of the bipolar and CMOS (complementary metal-oxide semiconductor) processes hold much promise. BiCMOS combines the speed advantage of the bipolar process with the low-power and density -- the ability to pack more circuitry into a given area -- advantages of CMOS. Integrated Circuit Engineering Corp. of Scottsdale, Ariz., predicts that the market for BiCMOS chips will soar from $50 million last year to $1.5 billion in 1993.

Another important technology is in semiconductor production equipment. Etching electronic circuitry less than 1.0 microns wide on a wafer of silicon is, to say the least, a demanding process that taxes the field of photolithography. Up to now, optical lithography has been used with great success. However, optical lithography becomes unwieldy below 0.5 microns because, at that scale, the wavelength of light is too large to etch the circuitry. Consequently, production equipment companies are investigating equipment that uses either x-rays or electron beams. The Japanese, in particular, are concentrating on x-ray lithography research.

R&D in the South

Not surprisingly, the United States, Japan and Western Europe lead the world in semiconductor R&D. However, one ROW country -- South Korea -- is making rapid progress. The International Solid State Circuits Conference, held annually in the United States, gives a good indication of where the latest semiconductor technologies are being developed. At the ISSCC in New York last February, 39 of the technical papers presented were from the United States, 35 from Japan, 14 from Western Europe, and one -- on a gallium arsenide semiconductor -- from South Korea. It is interesting to note that, less than two decades ago, the bulk of the ISSCC papers presented were from the United States and Western Europe; Japan was a minor participant then.

North versus South.

As stated earlier, labor and material costs are not that large a percentage of overall production costs. For this reason, it is unclear whether the North will ever use the South for much more than back-end manufacturing and the manufacturing of low-end products. It appears that for any of the ROW countries to become major players in the global semiconductor industry, they will have to develop their own indigenous industry, much like what South Korea is currently trying to do by supporting local companies like Hyundai, Samsung, Lucky Goldstar and Daewoo.

VI. SHORT- AND MEDIUM-TERMED INDUSTRY OUTLOOK

Most industry analysts expect the ROW countries to play an increasingly large role in the global semiconductor industry. Integrated Circuit Engineering Corp. of Scottsdale, Ariz., predicts that the ROW semiconductor market will grow from 13% of the total worldwide market last year to 20% in 1993. These figures are based on the fact that production of electronic equipment -- end-products like personal computers, VCRs and telecommunications gear that use semicondcutors -- is rapidly moving to Asian countries such as Hong Kong, Korea, Taiwan and Singapore.

As a result of the market shift, a shift in semiconductor production is expected to follow. Already production is increasing dramatically in certain countries. The increase, though, has been due more from a concentrated domestic effort, such as in the case of South Korea, rather than from a concerted effort by foreign manufacturers from the United States, Japan and Western Europe. Still, companies from these Northern countries currently do a significant portion of their manufacturing in the ROW and they will continue to do so in the near-term future.

So far, though, manufacturing by Northern countries in the ROW has mainly been limited to low-end products or, if high-end products are involved, only the back-end of manufacturing -- steps like assembly and packaging -- is usually done. This situation will probably not change in the near future because of several reasons. First, to manufacture state-of-the-art semiconductors, a high degree of manufacturing expertise is needed, expertise that ROW countries, in general, lack. (In fact, many U.S. companies have great difficulties making such chips in the United States, even with trained personnel and advanced production equipment.) Second, labor and material costs are not, relatively speaking, that major a percentage of overall production costs. Third, many ROW countries lack the necessary infrastructure: reliable power and water supplies, adequate telecommunications capability and local production equipment support, among other items.

NOTES:

1. The currency exchange rates used are as follows:

	Per dollar 1985	1986	1987	1988
WESTERN EUROPE				
British pound	0.78	0.68	0.61	0.57
Dutch guilder	3.32	2.45	2.03	1.88
French franc	9.08	6.83	6.16	5.89
Italian lira	1909	1491	1297	1240
West German mark	2.96	2.19	1.81	1.77
JAPAN				
Japanese yen	240	170	145	130
ROW COUNTRIES				
Hong Kong dollar	7.79	7.80	7.80	7.81
Malaysian ringgit	2.48	2.58	2.52	2.57
Singapore dollar	2.20	2.18	2.10	2.02
South Korean won	862	884	826	755
Taiwan dollar	39.9	37.9	31.9	28.5

2. Figures which were forecasted for 1989 and beyond were done so at current currency values.