2 THE DRAM MARKET

1996 FACTS		1997 FORECAST	
Market Size:	**$25,130 million**	**Market Size:**	**$21,485 million**
Shipments:	**2,762 million**	**Shipments:**	**3,064 million**
ASP:	**$9.10**	**ASP:**	**$7.01**

OVERVIEW

Dynamic random access memory or DRAM is the main memory component of most computers and many electronic systems. From 1993-1995, industry observers were stunned and amazed as the DRAM market displayed relentless growth. Helping the DRAM market grow at its accelerated pace was the lack of sufficient memory production capacity available to meet the needs of the vigorous PC market.

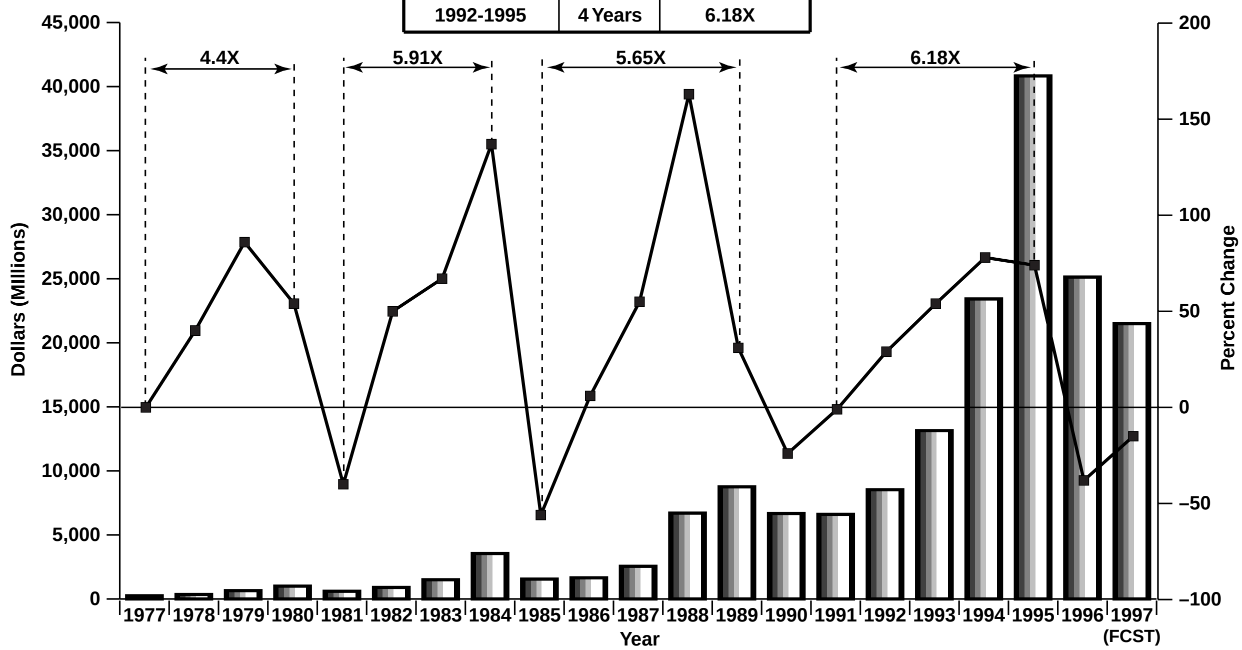
In 1996, a different scenario panned out for the DRAM market and its suppliers. In 1Q96, DRAM prices for 4Mbit devices plunged and continued to drop through the balance of the year. Furthermore, 16Mbit DRAM average selling prices (ASPs) also rapidly declined. Softer PC sales and a rather sudden glut of worldwide production capacity turned the DRAM market from one of the most lucrative to one of most difficult in which to participate.

For 1997, ICE anticipates another soft year for the DRAM market. Although unit demand will remain strong and bit volume will continue to grow nicely, excess capacity will further erode average selling prices. This will keep the market from growing at the rapid pace it experienced just a few years ago.

THE DRAM MARKET

The DRAM market has been through many up and down cycles as shown in Figure 2-1, but few suppliers recalled demand being so strong over such a long period of time as during the recent past few years. For the already huge DRAM market to grow by such large percentages over a several year period was quite remarkable.

Upward Growth Period	Average Length	Size of Market at End of Cycle
1978-1980	3 Years	4.4X
1982-1984	3 Years	5.91X
1986-1989	4 Years	5.65X
1992-1995	4 Years	6.18X



	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997 (FCST)
Total Market ($M)	250	350	650	1,000	600	900	1,500	3,550	1,550	1,650	2,550	6,700	8,750	6,675	6,605	8,525	13,140	23,420	40,835	25,130	21,485
Percent Change	—	40%	86%	54%	–40%	50%	67%	137%	–56%	6%	55%	163%	31%	–24%	–1%	29%	54%	78%	74%	–38%	–15%

Source: ICE, "Memory 1997" 20870D

Figure 2-1. DRAM Market History

However, as the graph shows, good times don't last forever. Excess capacity and plunging average selling prices resulted in a 38 percent decline in the 1996 DRAM market. Following that disastrous year, there is good news and bad news.

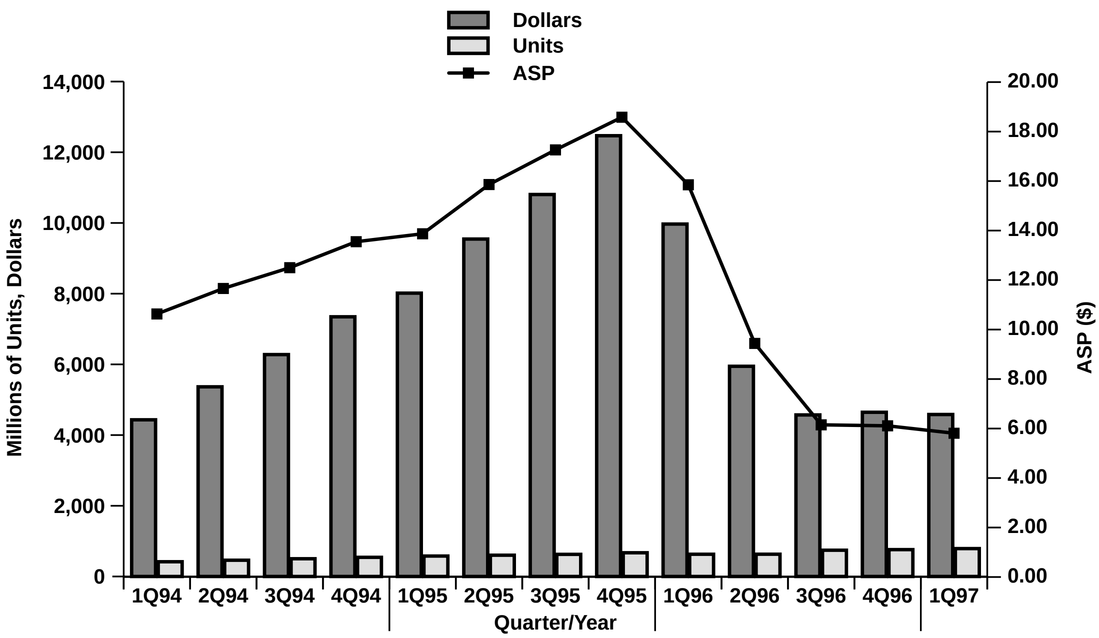
The bad news is that ICE forecasts another double-digit decline in for the 1997 DRAM market (–15 percent). Back to back double-digit declines would be a first for the DRAM market. The good news is that recent DRAM market history shows that negative growth has lasted one or, at the most, two years, while positive growth periods have been three or four-plus years in duration. At the end of these growth spurts, the DRAM industry has always greatly increased in size.

Shown in Figure 2-2 is ICE's complete DRAM market forecast for the 1992-2002 time period. Displayed are the market size, units shipments, ASPs, and price per megabit for several densities. The quarterly DRAM market shown in Figure 2-3 details the strong quarterly growth period in the DRAM market. DRAM manufacturers must look back fondly upon 1994 and 1995 when everything was up, up, up! There was no end in sight to the outstanding growth—until 1Q96. As noted in the chart, average selling prices fell steeply and fell quickly.

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
64Kbit Units (M)	30	4	—	—	—	—	—	—	—	—	—	—
ASP ($)	1.33	1.45	—	—	—	—	—	—	—	—	—	—
Price Per Mbit ($)	20.29	22.13	—	—	—	—	—	—	—	—	—	—
Market ($M)	40	6	—	—	—	—	—	—	—	—	—	—
256Kbit Units (M)	272	197	107	64	32	23	15	—	—	—	—	—
ASP ($)	1.80	1.70	1.80	2.15	2.00	1.95	2.00	—	—	—	—	—
Price Per Mbit ($)	6.87	6.48	6.87	8.22	7.63	7.44	7.63	—	—	—	—	—
Market ($M)	490	335	193	139	65	44	30	—	—	—	—	—
1Mbit Units (M)	827	822	596	500	463	260	187	145	100	45	25	10
ASP ($)	4.50	3.01	3.10	3.60	3.00	2.85	2.56	2.40	2.30	2.25	2.20	2.25
Price Per Mbit ($)	4.29	2.87	2.96	3.43	2.86	2.72	2.45	2.29	2.19	2.15	2.10	2.15
Market ($M)	3,720	2,470	1,848	1,800	1,388	741	479	348	230	101	55	23
4Mbit Units (M)	145	457	776	1,254	1,649	1,498	958	835	615	350	250	125
ASP ($)	16.05	11.72	11.91	12.00	12.85	5.31	2.39	2.00	1.80	1.65	1.55	1.50
Price Per Mbit ($)	3.83	2.79	2.84	2.86	3.06	1.27	0.57	0.48	0.43	0.39	0.37	0.36
Market ($M)	2,328	5,355	9,240	15,048	21,190	7,955	2,295	1,670	1,107	578	388	188
16Mbit Units (M)	0.1	2	20	103	333	974	1,800	2,100	1,750	1,700	1,480	1,200
ASP ($)	275.00	180.00	93.00	61.85	54.41	16.11	7.39	6.51	5.80	5.25	4.90	4.75
Price Per Mbit ($)	16.39	10.73	5.54	3.69	3.24	0.96	0.44	0.39	0.35	0.31	0.29	0.28
Market ($M)	28	360	1,860	6,371	18,135	15,691	13,310	13,671	10,150	8,925	7,252	5,700
64Mbit Units (M)	—	—	—	0.1	0.25	7	103	460	1,300	2,100	2,800	3,000
ASP ($)	—	—	—	575.00	225.00	100.35	51.94	2,600	16.00	10.00	7.25	6.75
Price Per Mbit ($)	—	—	—	8.57	3.35	1.50	0.77	0.39	0.24	0.15	0.11	0.10
Market ($M)	—	—	—	63	56	697	5,371	11,960	20,800	21,001	20,300	20,250
128Mbit Units (M)	—	—	—	—	—	—	—	0.1	4	45	125	100
ASP ($)	—	—	—	—	—	—	—	405.00	155.70	65.00	33.00	24.00
Price Per Mbit ($)	—	—	—	—	—	—	—	3.02	1.16	0.48	0.25	0.18
Market ($M)	—	—	—	—	—	—	—	41	623	2,925	4,125	2,400
256Mbit Units (M)	—	—	—	—	—	—	—	0.1	5	80	375	1,100
ASP ($)	—	—	—	—	—	—	—	600.00	325.00	140.00	73.00	40.00
Price Per Mbit ($)	—	—	—	—	—	—	—	2.24	1.21	0.52	0.27	0.15
Market ($M)	—	—	—	—	—	—	—	60	1,625	11,200	27,375	44,000
512Mbit Units (M)	—	—	—	—	—	—	—	—	0.1	5	15	65
ASP ($)	—	—	—	—	—	—	—	—	700.00	300.00	155.00	94.00
Price Per Mbit ($)	—	—	—	—	—	—	—	—	1.30	0.56	0.29	0.18
Market ($M)	—	—	—	—	—	—	—	—	70	1,350	2,325	6,110
1Gbit Units (M)	—	—	—	—	—	—	—	—	—	—	0.1	12
ASP ($)	—	—	—	—	—	—	—	—	—	—	700.00	350.00
Price Per Mbit ($)	—	—	—	—	—	—	—	—	—	—	0.65	0.33
Market ($M)	—	—	—	—	—	—	—	—	—	—	70	4,200
Total Market ($M)	6,605	8,525	13,140	23,420	40,833	25,130	21,485	27,750	34,605	46,080	61,890	82,870
Total Units (M)	1,274	1,482	1,499	1,921	2,477	2,762	3,064	3,540	3,774	4,325	5,070	5,612
ASP ($)	5.18	5.75	8.77	12.19	16.48	9.10	7.01	7.84	9.17	10.66	12.21	14.77

Source: ICE, "Memory 1997" 18838E

Figure 2-2. DRAM Market Forecast



	1Q94	2Q94	3Q94	4Q94	1Q95	2Q95	3Q95	4Q95	1Q96	2Q96	3Q96	4Q96	1Q97
Market ($M)	4,432	5,365	6,277	7,346	8,015	9,545	10,805	12,468	9,969	5,946	4,570	4,645	4,582
Units (M)	417	460	502	542	578	602	626	671	629	630	743	760	789
ASP ($)	10.63	11.66	12.50	13.55	13.87	15.86	17.26	18.58	15.85	9.44	6.15	6.11	5.81

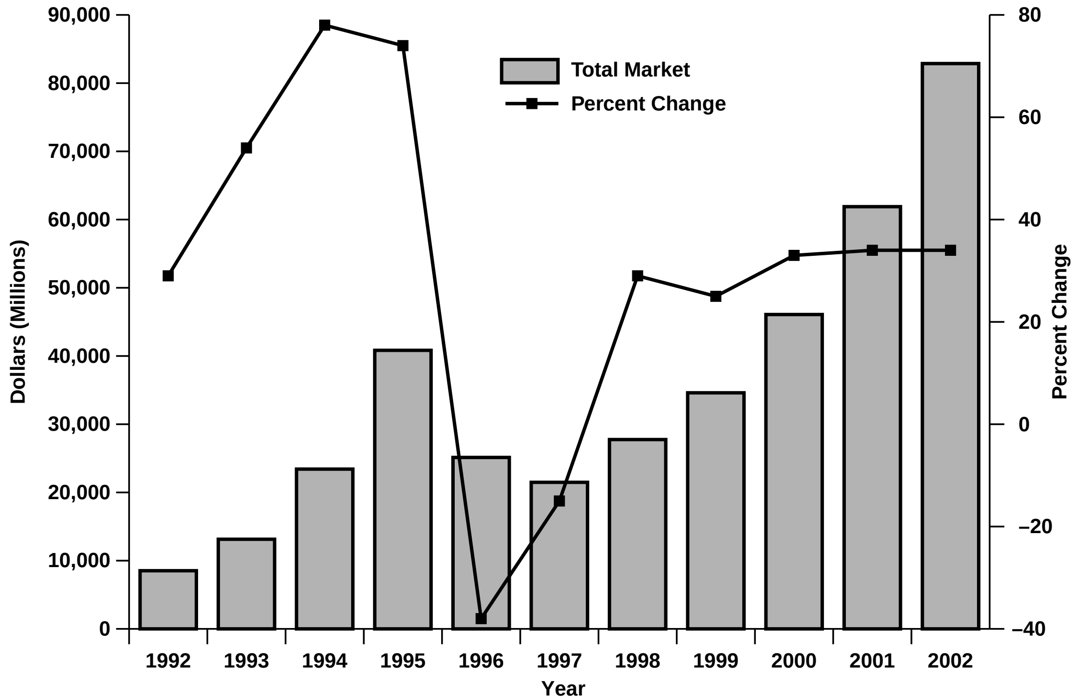
Source: ICE, "Memory 1997" 20881A

Figure 2-3. Quarterly DRAM Market

It appears the overall DRAM market stabilized in the latter half of 1996 and into 1Q97. While the market did stabilize, ICE forecasts further erosion of the market in 1997, but at a much more gradual pace.

The total DRAM market for the period 1992-2002 is shown in Figure 2-4. Following four years of outstanding growth, the long-anticipated "recovery" in the market hit in 1996. ICE forecasts that it will take the DRAM market a few more years (to the year 2000) to be at least the size it was in 1995. From 1997 to the year 2002, ICE forecasts the DRAM market to have a cumulative average annual growth rate of 31 percent.

Excess capacity will remain a fact of life for the DRAM suppliers in 1997. The potential for price wars will continue as companies seek to grow or maintain their share of the market. As the decade closes, however, ICE believes DRAM supply and demand will be better balanced. Early into the 2000's, ICE forecasts that demand will once again outstrip supply, causing the market to grow at an accelerated pace.



Total Market ($M)	8,525	13,140	23,420	40,833	25,130	21,485	27,750	34,605	46,080	61,890	82,870
Percent Change	29	54	74	74	–38	–15	29	25	33	34	34

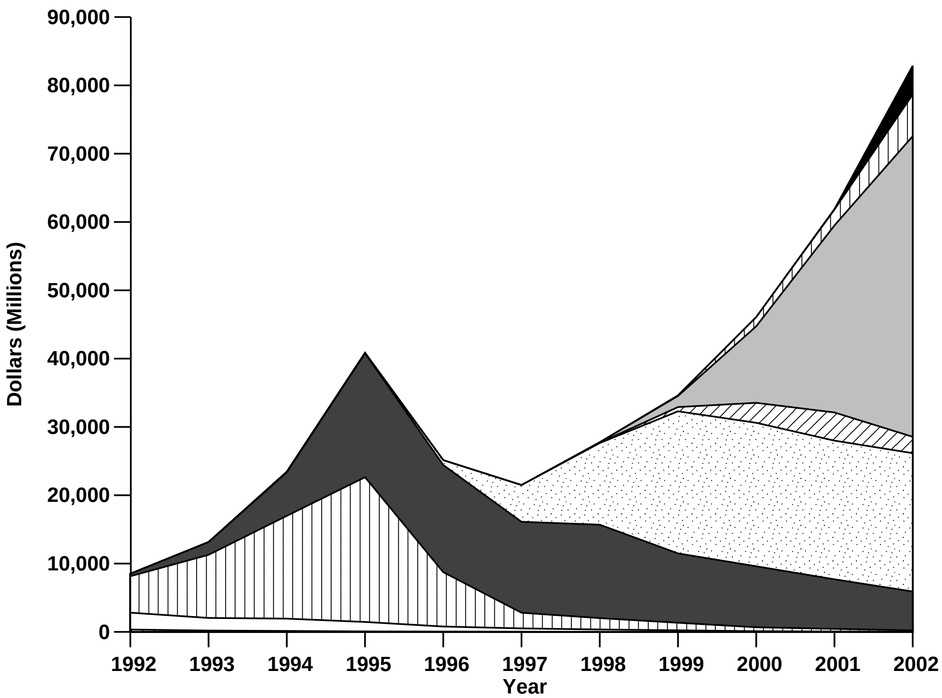
Source: ICE, "Memory 1997" 18857E

Figure 2-4. DRAM Market Growth

Displayed in Figure 2-5 is the DRAM market by density. In terms of dollar volume, the 16Mbit density was the largest in 1996 and is forecast to remain the biggest market in 1997 and 1998. However, ICE believes that market demand for the 64Mbit generation will develop in 1997 and grow rapidly to challenge the 16Mbit market beginning in 1998. Meanwhile, the 4Mbit density is forecast to quietly slip closer to the obsolete phase in the product lifecycle—a distant “memory” of a grand time in the DRAM market.

DRAM UNIT SHIPMENTS

Shown in Figure 2-6 are quarterly DRAM shipments beginning in 1994 and continuing through 1Q97. During the 13-quarter span, total DRAM shipments increased 89 percent. 4Mbit devices, which accounted for 61 percent of total shipments in 1Q94, represented 36 percent of shipments in 1Q97. Meanwhile, shipments of DRAMs with densities greater than 4Mbit grew rapidly in the last three quarters shown. In 1Q97, these devices accounted for 57 percent of total DRAM unit shipments.



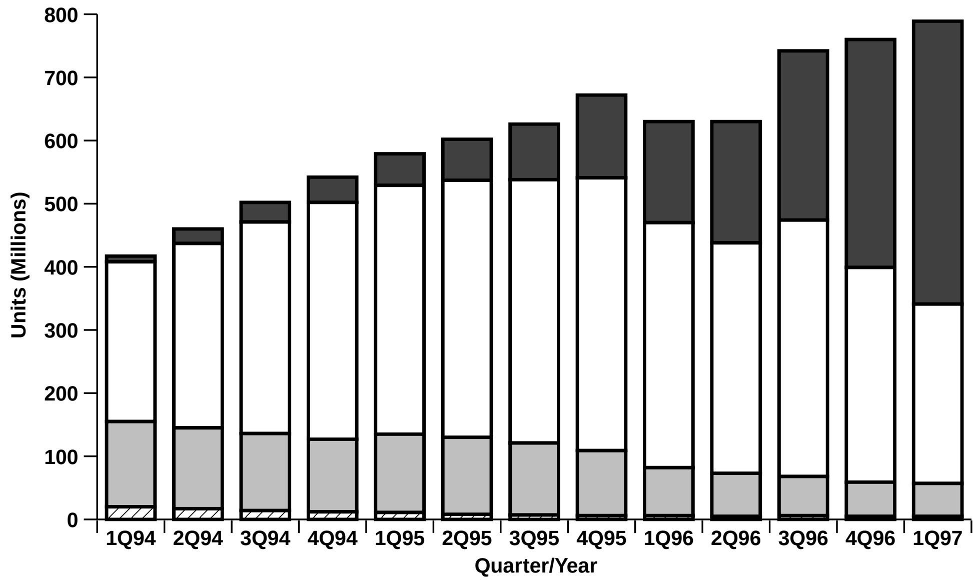
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
64Kbit	6	—	—	—	—	—	—	—	—	—	—
256Kbit	335	193	139	65	44	30	—	—	—	—	—
1Mbit	2,470	1,848	1,800	1,388	741	479	348	230	101	55	23
4Mbit	5,355	9,240	15,048	21,190	7,955	2,295	1,670	1,107	578	388	188
16Mbit	360	1,860	6,371	18,135	15,691	13,310	13,671	10,150	8,925	7,252	5,700
64Mbit	—	—	63	56	697	5,371	11,960	20,800	21,001	20,300	20,250
128Mbit	—	—	—	—	—	—	41	623	2,925	4,125	2,400
256Mbit	—	—	—	—	—	—	60	1,625	11,200	27,375	44,000
512Mbit	—	—	—	—	—	—	—	70	1,350	2,325	6,110
1Gbit	—	—	—	—	—	—	—	—	—	70	4,200
Total Market ($M)	8,525	13,140	23,420	40,834	25,128	21,485	27,750	34,605	46,080	61,890	82,870

Source: ICE, "Memory 1997" 20880B

Figure 2-5. Dollar Volume of Select DRAM Densities

Total DRAM unit shipments for the 1992-2002 time period are displayed in Figure 2-7. With the exception of 1993 when units increased a mere one percent, shipments of DRAMs grew well through the first part of the 1990's. From 1997-2002 units shipments are forecast to average annual growth of 13 percent.

DRAM shipments by density are graphed in Figure 2-8. Despite its dwindling market size, 4Mbit units continued to be a popular selection among system designers in 1996—and for good reason. Although they started 1996 priced around $11.50, 4Mbit DRAMs ended the year priced at $2.55!



	1Q94	2Q94	3Q94	4Q94	1Q95	2Q95	3Q95	4Q95	1Q96	2Q96	3Q96	4Q96	1Q97
≤256Kbit	20	17	14	12	11	8	7	6	6	5	6	5	5
1Mbit	135	128	122	115	124	122	114	103	76	68	62	54	52
4Mbit	253	292	335	375	393	407	417	432	388	365	406	340	284
≥4Mbit	9	23	31	40	50	65	88	130	160	192	268	361	448
Total Units (M)	417	460	502	542	578	602	626	671	629	630	743	760	789

Source: ICE, "Memory 1997" 20885A

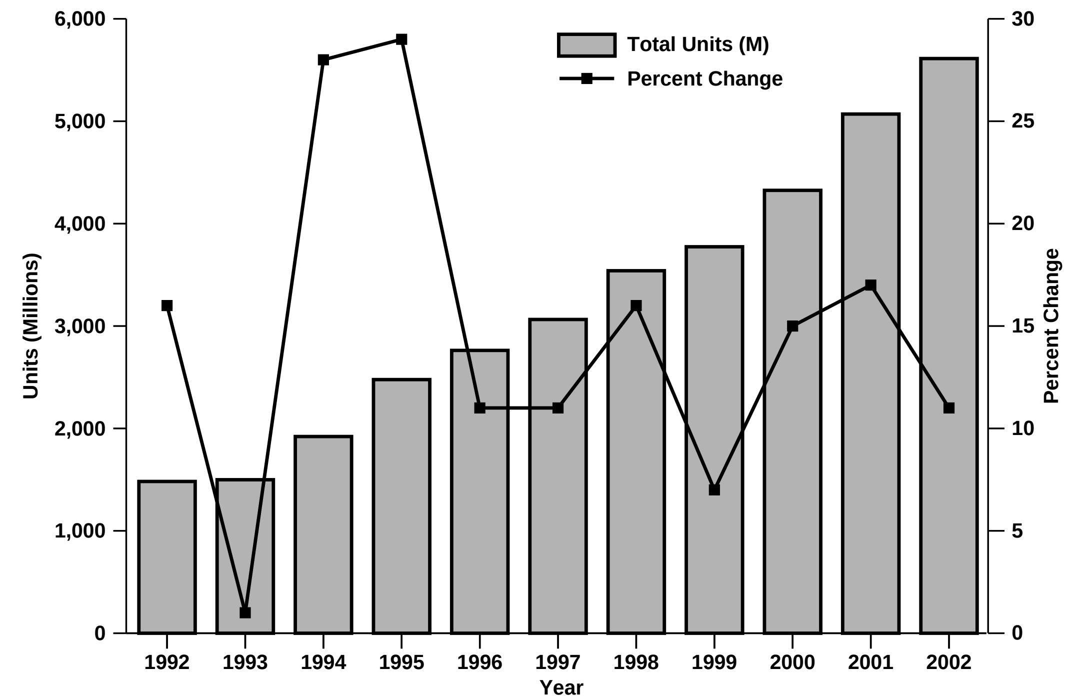
Figure 2-6. Quarterly DRAM Shipments by Density

With low pricing, designers employed these devices in great numbers in their systems. Consumers, who long awaited to upgrade the memory in their PCs also took advantage of the tremendously lower prices for 4Mbit DRAMs. As a result, unit shipments at this density remained well over one billion pieces during 1996.

A big jump in 16Mbit shipments is forecast for 1997. Nearly all the major Japanese and Korean vendors ramped their output of this density to supply the world’s needs.

Figure 2-9 provides a look at the typical lifecycle curve for DRAM unit shipments. The 1Mbit density took a long, slow decline on its way out of the market spotlight after peaking in 1991. 4Mbit shipments peaked in 1995, more than doubling the highest yearly 1Mbit output. Perhaps more than any other generation to date, 4Mbit DRAMs enjoyed more time in the “spotlight,” which is the mature/saturation phase of the product lifecyle.

16Mbit devices ramped up in 1996 and will be followed by the 64Mbit generation in 1997/1998. ICE forecasts that shipments of 16Mbit DRAMs will peak in 1998 and that 64Mbit devices will top out early in the next century. Whether by a few hundred million or several hundred million units, each successive DRAM generation ships more than its predecessor.



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total Units (M)	1,482	1,499	1,921	2,477	2,762	3,064	3,540	3,774	4,325	5,070	5,612
Percent Change	16	1	28	29	11	11	16	7	15	17	11

Source: ICE, "Memory 1997"

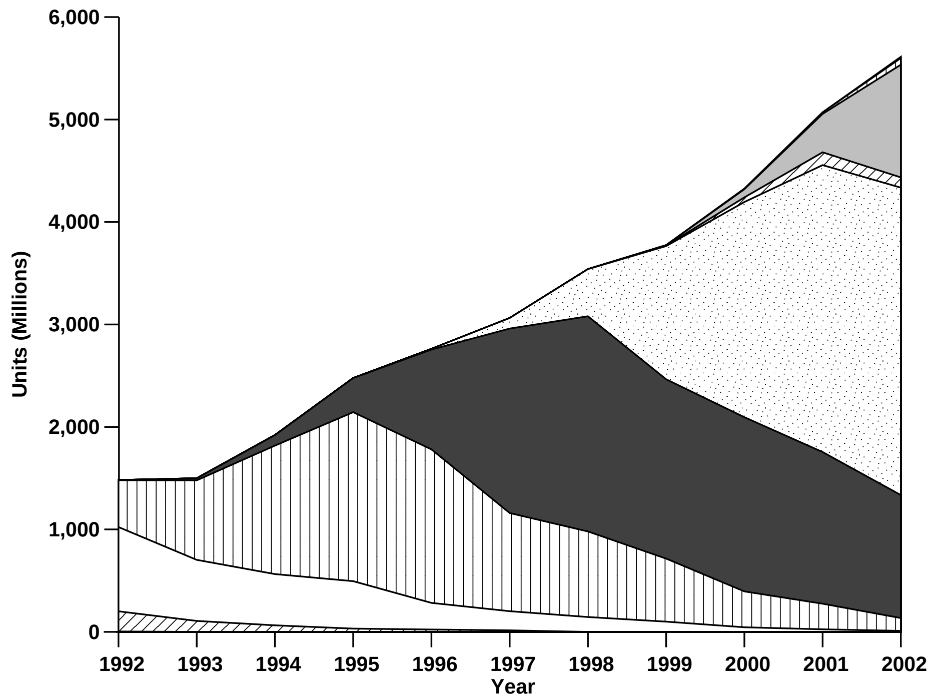
20006C

Figure 2-7. DRAM Unit Shipments

Unit Shipments by Architecture

Until recently, all DRAMs were made using the same fast-page mode (FPM) architecture. However, FPM devices can no longer keep pace with faster microprocessors, and, consequently, hamper overall system performance.

As a result of FPM DRAM's inability to keep pace with high-speed microprocessors, and since almost three-fourths of all DRAMs wind up in PC systems with high-speed microprocessors, DRAM architectures have changed. Though there are numerous revolutionary and evolutionary alternatives (reviewed in Section 7), three main architectures emerged that appear likely to contend for the largest share of 1997 and 1998 DRAM shipments. Figure 2-10 shows the three—extended data out (EDO) DRAM, synchronous DRAM (SDRAM), and Rambus DRAM—and how ICE believes the market will be divided among these different architectures in the coming years.



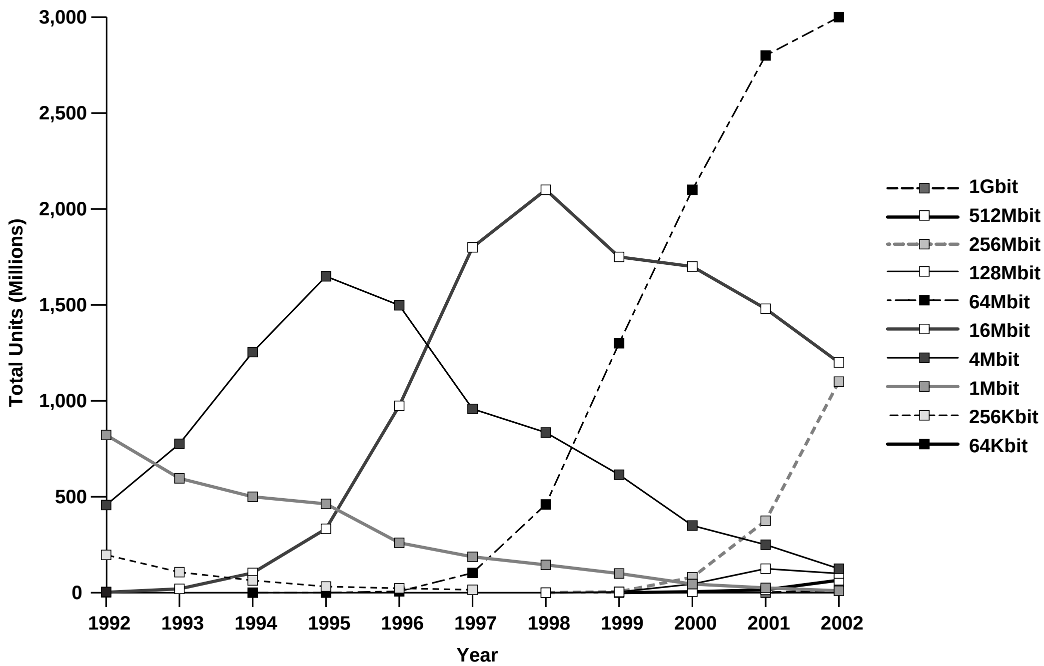
	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
64Kbit	4	—	—	—	—	—	—	—	—	—	—
256Kbit	197	107	64	32	23	15	—	—	—	—	—
1Mbit	822	596	500	463	260	187	145	100	45	25	10
4Mbit	457	776	1,254	1,649	1,498	958	835	615	350	250	125
16Mbit	2	20	103	333	974	1,800	2,100	1,750	1,700	1,480	1,200
64Mbit	—	—	0.1	0.3	7	103	460	1,300	2,100	2,800	3,000
128Mbit	—	—	—	—	—	—	0.1	4	45	125	100
256Mbit	—	—	—	—	—	—	0.1	5	80	375	1,100
512Mbit	—	—	—	—	—	—	—	0.1	5	15	65
1Gbit	—	—	—	—	—	—	—	—	—	0.1	12
Total Market (M)	1,482	2,981	1,921	2,477	2,762	3,063	3,540	3,774	4,325	5,070	5,612

Source: ICE, "Memory 1997" 20886B

Figure 2-8. Unit Volume of Select DRAM Densities

Most leading DRAM manufacturers curtailed production of their fast-page mode DRAMs in 1995 and 1996 and now manufacture DRAMs based on EDO and SDRAM technology. EDO is a reasonably cheap and easy upgrade from fast page mode DRAMs. They represented a marginal improvement over fast-page mode devices. While useful, the market for these devices was short-lived. Furthermore, the investment required to make further marginal performance gains in EDO memory has made it impractical to continue using it in new PC platforms. As a result, the industry witnessed the transition from EDO to synchronous DRAM in 1996.

Initially, SDRAMs were tagged with a 10-15 percent price premium compared to a similarly packaged and configured EDO DRAM. That price premium will be essentially non-existent by the second half of 1997.



Source: ICE, "Memory 1997"

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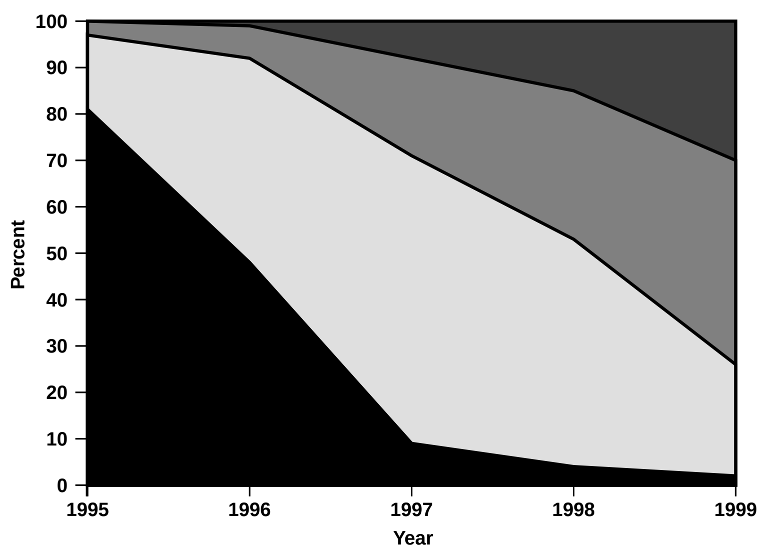
Figure 2-9. DRAM Unit Shipments by Density



Fast Page Mode	81	48	9	4	2
EDO	16	44	62	49	24
Synchronous	3	7	21	32	44
Rambus and Other	—	0.1	8	15	30

Source: ICE, "Memory 1997"

20888C

Figure 2-10. DRAM Shipments by Architecture (Percent)

The transition from EDO to SDRAMs may be a bumpy one for suppliers and buyers alike. For suppliers, the process of converting today's DRAM fabs to manufacture SDRAMs has been somewhat difficult, which may delay the supply of parts just as demand is heating up. Meanwhile, some memory IC buyers indicated that initial qualification of an SDRAM vendor was difficult, apparently since SDRAM specifications varied from vendor to vendor. These are problems that will undoubtedly be resolved with time, but which initially made for a less-than-ideal transition to SDRAMs.

Toshiba's schedule to increase SDRAM production is shown in Figure 2-11. The company, in 2Q97, introduced a 64Mbit synchronous DRAM family that featured three organizations and speeds to 125MHz. The Hitachi DRAM product roadmap is displayed in Figure 2-12. Hitachi will ship 50 percent of its DRAMs in the form of synchronous DRAMs by the end of 1997. Both Fujitsu and NEC expect that 70 percent of all their DRAMs will be synchronous by the close of the fiscal year (ending March 31, 1998).

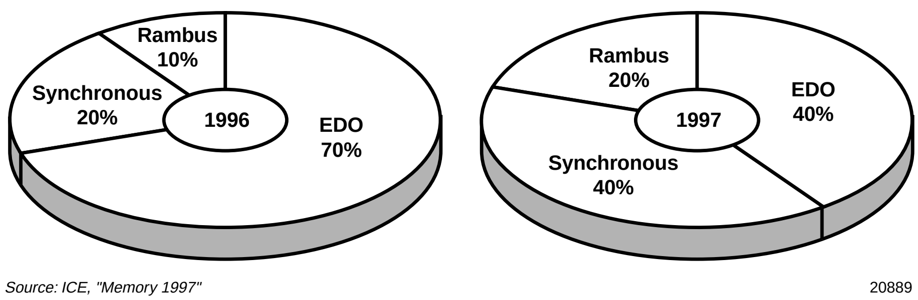


Figure 2-11. Toshiba's DRAM Shipments by Architecture

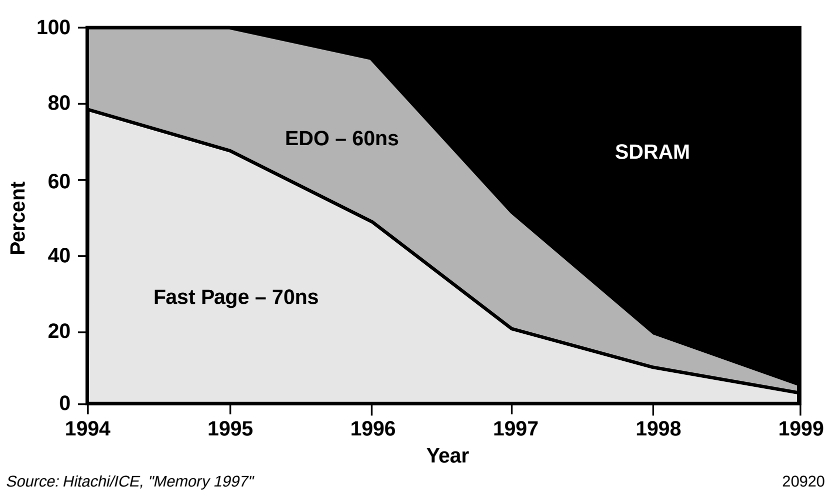


Figure 2-12. Hitachi's Main Memory Solutions Shift to SDRAM

Texas Instruments expanded its SDRAM family in 1996 and will continue to grow this segment of its memory business in 1997 to support more PC applications. TI's x32 solution (Figure 2-13) is targeted to support the demands of graphics in low-power applications.

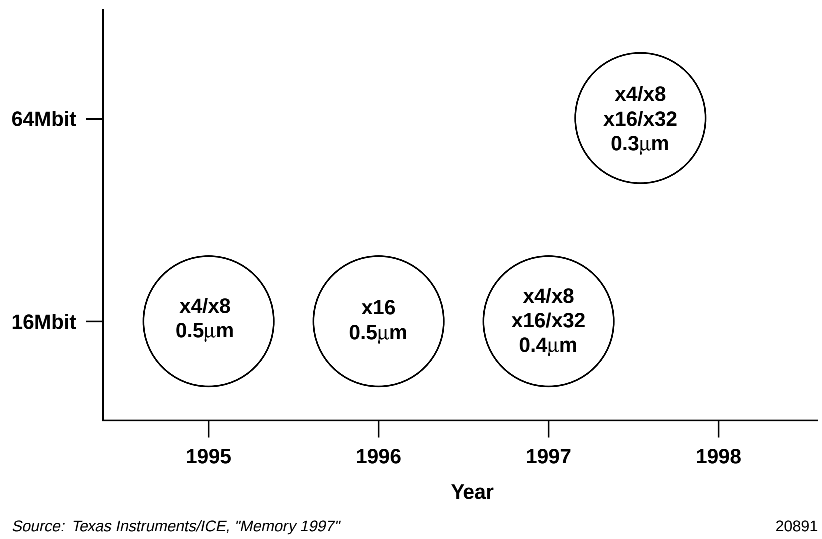


Figure 2-13. Texas Instruments' SDRAM Roadmap

Samsung, the world's leading memory IC supplier, is another company that has aggressively moved into SDRAM production. Its outlook of the PC memory technology transition is shown in Figure 2-14. Samsung noted that U.S. OEMs consumed an equal value of its 16Mbit and 64Mbit SDRAMs in 2Q97.

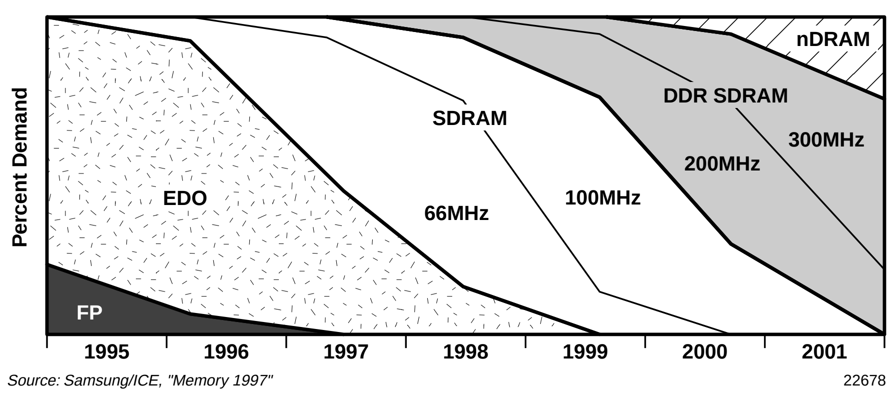


Figure 2-14. Samsung DRAM Technology Roadmap for Main Memory

Beyond SDRAMs, Samsung is promoting double data rate (DDR) SDRAM, which doubles the transfer rate of information compared to a standard SDRAM (which transfers almost twice as much data as an EDO DRAM device, Figure 2-15). Samsung believes the DDR SDRAM technology will extend the life of synchronous memory into the 300MHz range, thus directly competing with the Rambus DRAM and perhaps delaying the day when vendors have to embrace a new architecture.

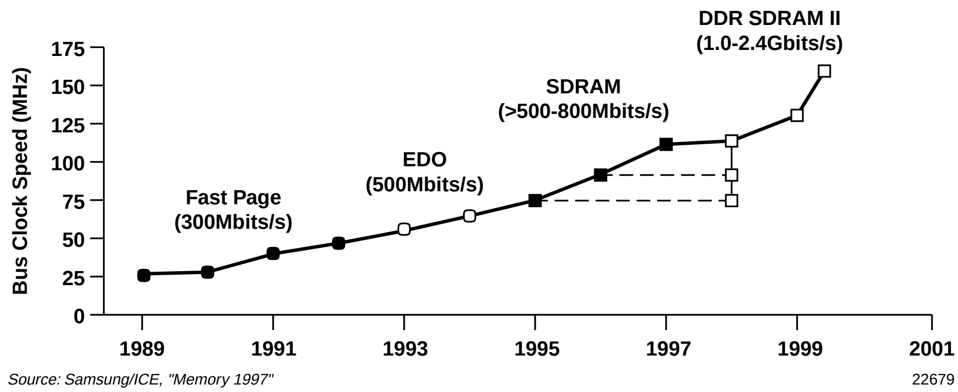


Figure 2-15. Samsung Promotes DDR SDRAM to Match Bus Clock

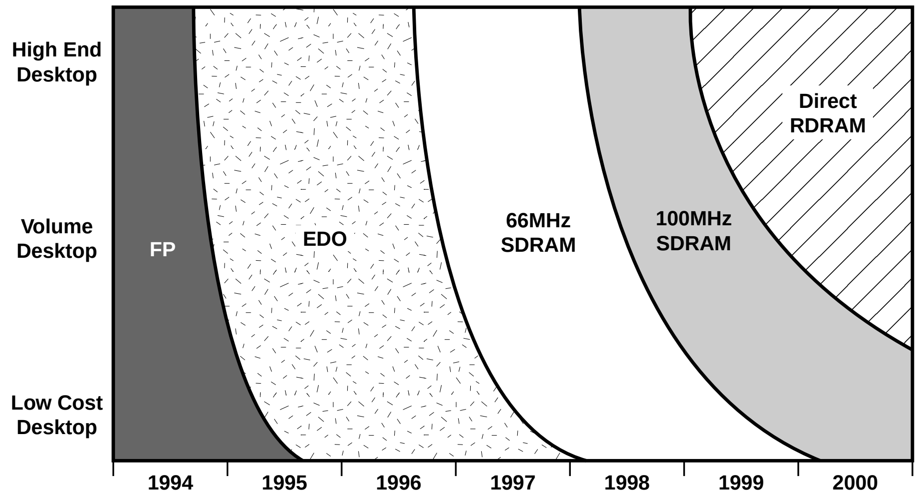
In 1996, it became obvious that standard SDRAMs would not be able to perform to the 1.5Gbit to 3.0Gbit/second system bandwidth necessary to provide realistic 3D graphics and DVD processing. The Rambus DRAM (RDRAM) provides that solution. This technology provides a wide path for fast data transfer between the memory and the processing segments of a system.

Rambus licensed the top five DRAM manufacturers (and several others) to use its technology. The company charges a flat "engineering fee" to customize its interface to a memory vendor's existing product. Vendors then pay royalties based upon the actual selling price of the Rambus DRAM.

Rambus scored a major win when it announced in 1Q97 that Intel would adopt the Rambus DRAM architecture as its next-generation main-memory technology for PCs. If all goes according to Intel's plan, Rambus DRAMs will begin to appear in high-end PCs in 1999 (Figure 2-16).

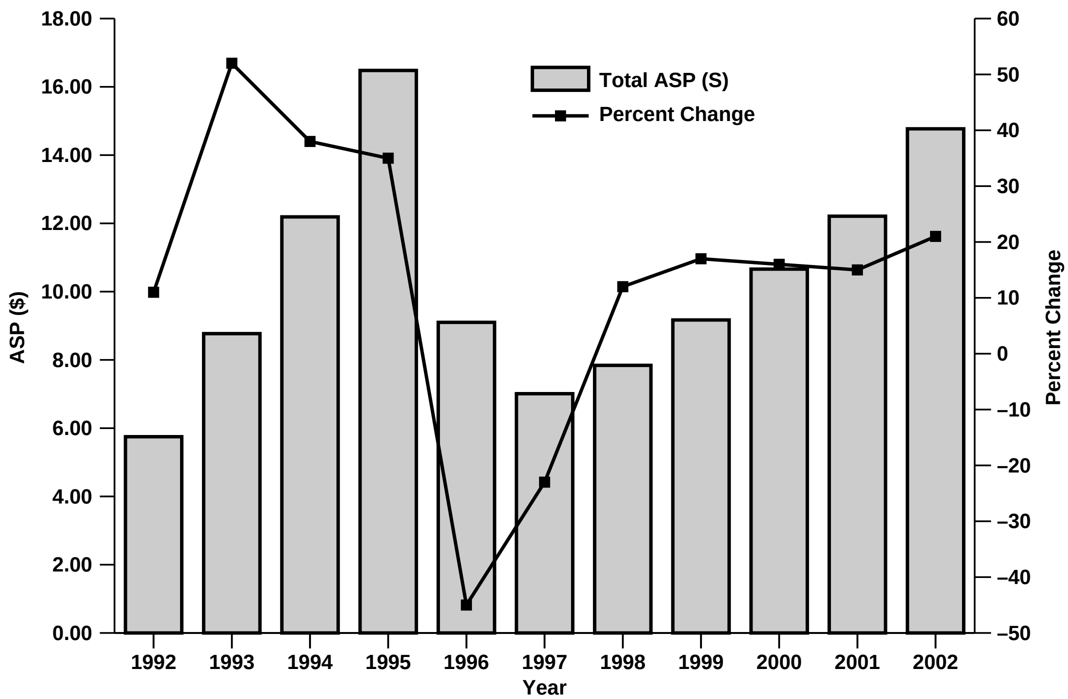
DRAM AVERAGE SELLING PRICES

The DRAM average selling price (ASP) from 1992 through 2002 is shown in Figure 2-17. Limited production capacity and strong demand kept ASPs rising quickly during the first part of the decade. To the contrary, added worldwide production capacity (i.e., greater supply) led to a crash in the DRAM ASP in 1996. ICE forecasts that an overcapacity condition will continue through 1997, which will lead to further erosion of average selling prices. Demand should begin to match supply in 1998 and then gradually out-grow supply through the year 2002. Accordingly, DRAM ASPs are forecast to climb during this time.



Source: Intel/Rambus/ICE, "Memory 1997" 22680

Figure 2-16. Intel's Outlook for PC Platform Memory

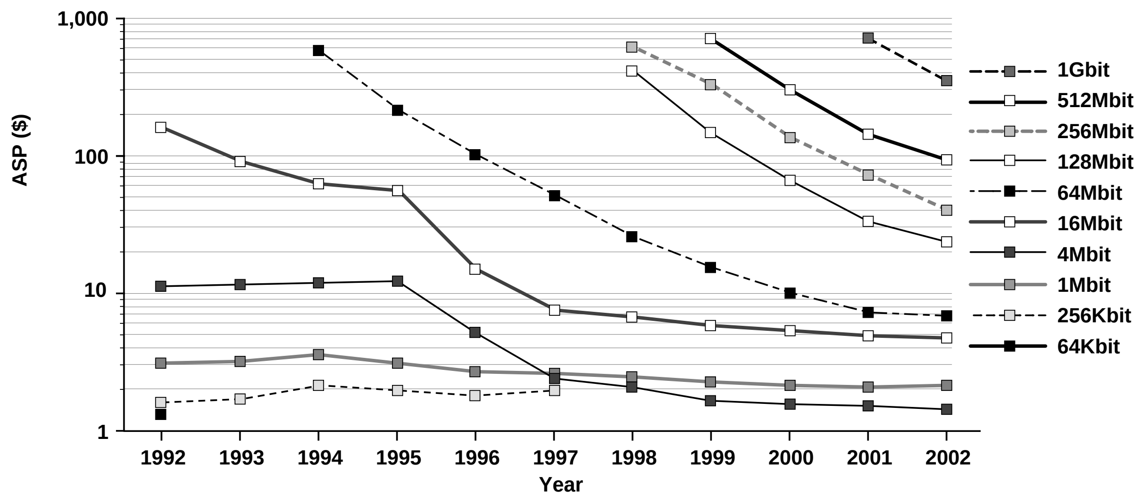


Total ASP ($)	5.75	8.77	12.19	16.48	9.10	7.01	7.84	9.17	10.66	12.21	14.77
Percent Change	11	52	39	35	–45	–23	12	17	16	15	21

Source: ICE, "Memory 1997" 20022D

Figure 2-17. DRAM Average Selling Price

ASP trends for several DRAM densities are plotted in Figure 2-18. It is interesting to note that demand at the 4Mbit level kept ASPs elevated and essentially flat for four years (1992-1995). As witnessed in the 1Mbit generation during 1989-1990 and in the 4Mbit generation during 1995-1996, when ASPs fall, they fall fast and they fall far. A bit unexpected, perhaps, was the way that prices for the 16Mbit generation (which stayed at approximately four times the 4Mbit DRAM ASP) followed right in step with the 4Mbit decline in 1996.



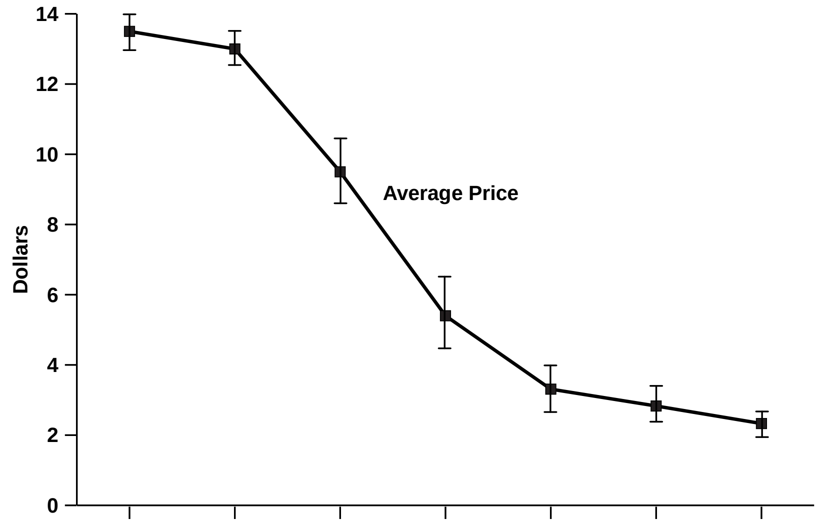
64Kbit	1.45	—	—	—	—	—	—	—	—	—	—
256Kbit	1.70	1.80	2.15	2.00	1.95	2.00	—	—	—	—	—
1Mbit	3.01	3.10	3.60	3.00	2.85	2.56	2.40	2.30	2.25	2.20	2.25
4Mbit	11.72	11.91	12.00	12.85	5.31	2.39	2.00	1.80	1.65	1.55	1.50
16Mbit	180.00	93.00	61.85	54.41	16.11	7.39	6.51	5.80	5.25	4.90	4.75
64Mbit	—	—	575.00	225.00	100.35	51.94	26.00	16.00	10.00	7.25	6.75
128Mbit	—	—	—	—	—	—	405.00	155.70	65.00	33.00	24.00
256Mbit	—	—	—	—	—	—	600.00	325.00	140.00	73.00	40.00
512Mbit	—	—	—	—	—	—	—	700.00	300.00	155.00	94.00
1Gbit	—	—	—	—	—	—	—	—	—	700.00	350.00

Source: ICE, "Memory 1997" 20892B

Figure 2-18. DRAM Average Selling Price by Density

As Figures 2-19 and 2-20 show, the decrease in 4Mbit and 16Mbit ASP during 1996 was anything but gradual. Each quarter brought about dramatically lower ASPs. ICE shows that the ASP for a 4Mbit DRAM decreased 78 percent during 1996 and 82 percent for 16Mbit DRAMs!

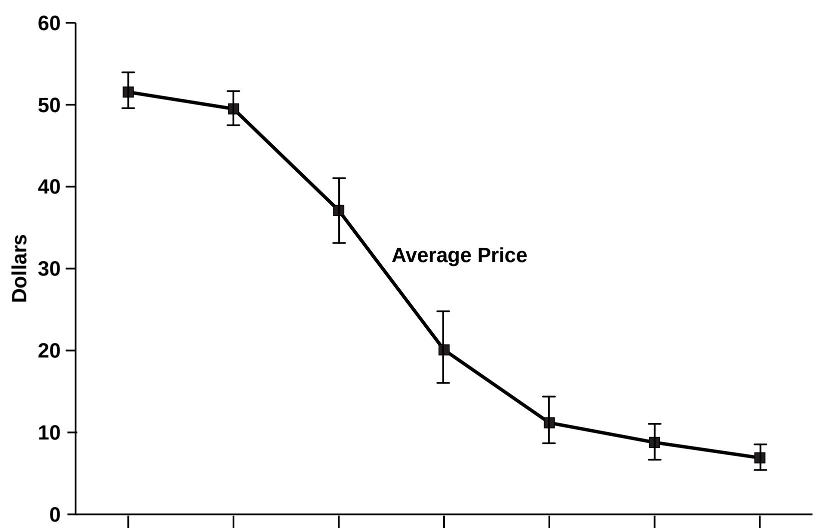
DRAM vendors are faced with the prospect of selling their 16Mbit parts for approximately $6.00 through the second half of 1997. This low average selling price will not bring in the kind of profits that many companies hoped to achieve. Faced with this situation, many Japanese, Korean, and Taiwanese DRAM vendors ramped production of 64Mbit DRAMs in the first half of 1997. In doing so, however, the companies defeated their goal of producing devices with higher profit margins.



	Nov '95	Dec '95	1Q96	2Q96	3Q96	4Q96	1Q97
High	13.75	13.24	11.55	6.80	3.65	3.10	2.30
Low	13.25	12.75	7.45	4.00	2.96	2.55	2.35
Average	13.50	13.00	9.50	5.40	3.31	2.83	2.33

Source: ICE, "Memory 1997" 20895A

Figure 2-19. 4Mbit DRAM Price Trends



	Nov '95	Dec '95	1Q96	2Q96	3Q96	4Q96	1Q97
High	54.15	52.00	43.45	25.00	13.06	9.50	7.15
Low	48.95	47.00	30.75	15.15	9.30	8.05	6.65
Average	51.55	49.50	37.10	20.08	11.18	8.78	6.90

Source: ICE, "Memory 1997" 20896A

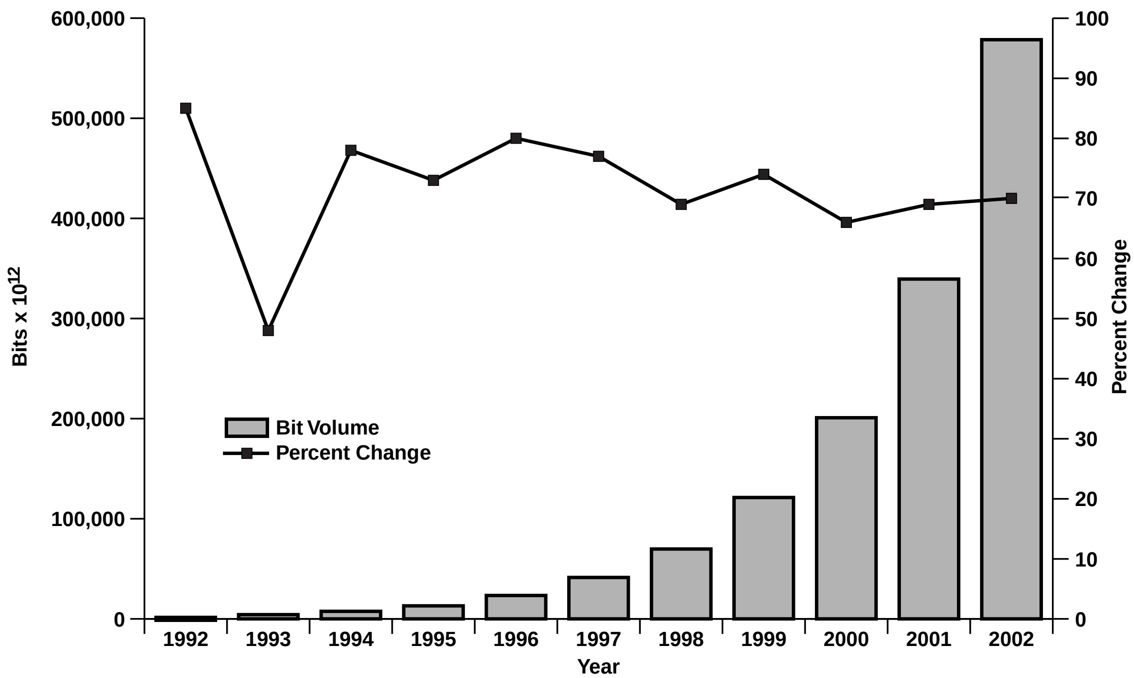
Figure 2-20. 16Mbit DRAM Price Trends

64Mbit DRAM ASPs followed the same path as 4Mbit and 16Mbit generations before them. At the beginning of 1996, 64Mbit DRAMs sold for $250. By the end of the year, they sold for $90. In 1Q97, the devices were offered for $60, and in 2Q97, the prices had dropped to less than $40. As of 2Q97, there was more 64Mbit product than the niche application of high-performance workstations could absorb.

ICE believes the DRAM buyers' market will continue throughout 1997. Plenty of fab capacity will keep prices flat or slightly down on all densities of DRAM during the upcoming year.

DRAM BIT VOLUME

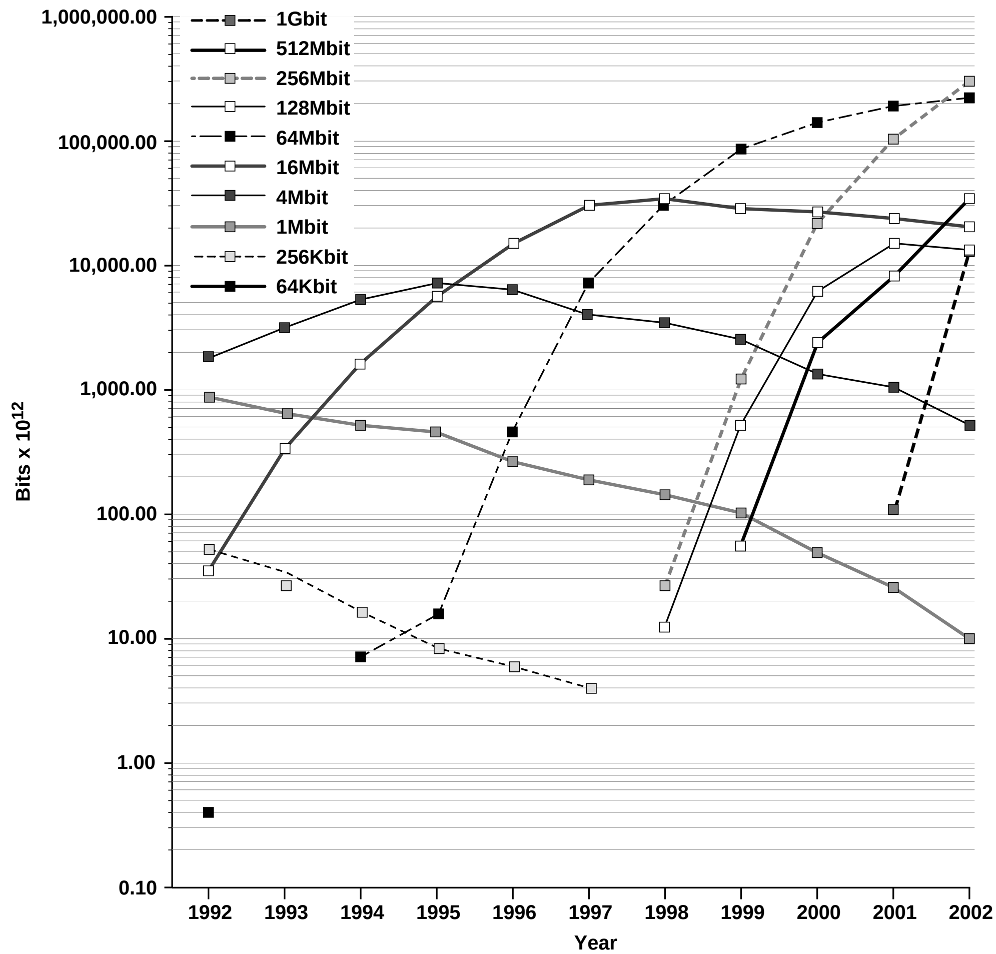
DRAM bit volume is provided in Figure 2-21. The DRAM bit volume forecast provides a clear indication that the DRAM market will remain vibrant through the year 2002. There will be demand for more bits. Annual bit volume growth from 1997 through the year 2002 is forecast to average 69 percent, with 64Mbit and 256Mbit devices serving as the backbone for that growth (Figure 2-22).



Total Bit Volume	2,864	4,243	7,536	13,019	23,370	41,363	69,797	121,219	200,896	339,411	578,476
Percent Change	85	48	78	73	80	77	69	74	66	69	70

Source: ICE, "Memory 1997" 20894C

Figure 2-21. DRAM Bit Volume



64Kbit	0.3	—	—	—	—	—	—	—	—	—	—
256Kbit	52	28	17	8	6	4	—	—	—	—	—
1Mbit	862	625	524	485	273	196	152	105	47	26	10
4Mbit	1,917	3,255	5,260	6,916	6,284	4,020	3,502	2,579	1,468	1,049	524
16Mbit	34	336	1,728	5,592	16,341	30,204	35,232	29,360	28,521	24,830	20,133
64Mbit	—	—	7	17	466	6,939	20,870	87,242	140,929	187,905	201,327
128Mbit	—	—	—	—	—	—	13	537	6,040	16,777	13,422
256Mbit	—	—	—	—	—	—	27	1,342	21,475	100,633	295,279
512Mbit	—	—	—	—	—	—	—	54	2,416	8,053	34,897
1Gbit	—	—	—	—	—	—	—	—	—	107	12,885

Source: ICE, "Memory 1997" 20882B

Figure 2-22. DRAM Bit Volume by Density

Much of the bit volume growth is due to the continued expansion of the PC industry. As noted in Figure 2-23, PC unit growth has been around 20 percent since about 1992. What is more interesting to note is the amount of DRAM used for main memory on the average new system. From a mere 4Mbytes in 1991 to 20Mbytes in 1996 to a forecast of 32Mbytes in 1997, the amount of PC main memory has increased eight-fold in six years. Price declines and new software capabilities (Netscape, Windows NT, etc.) contributed to the higher memory content.

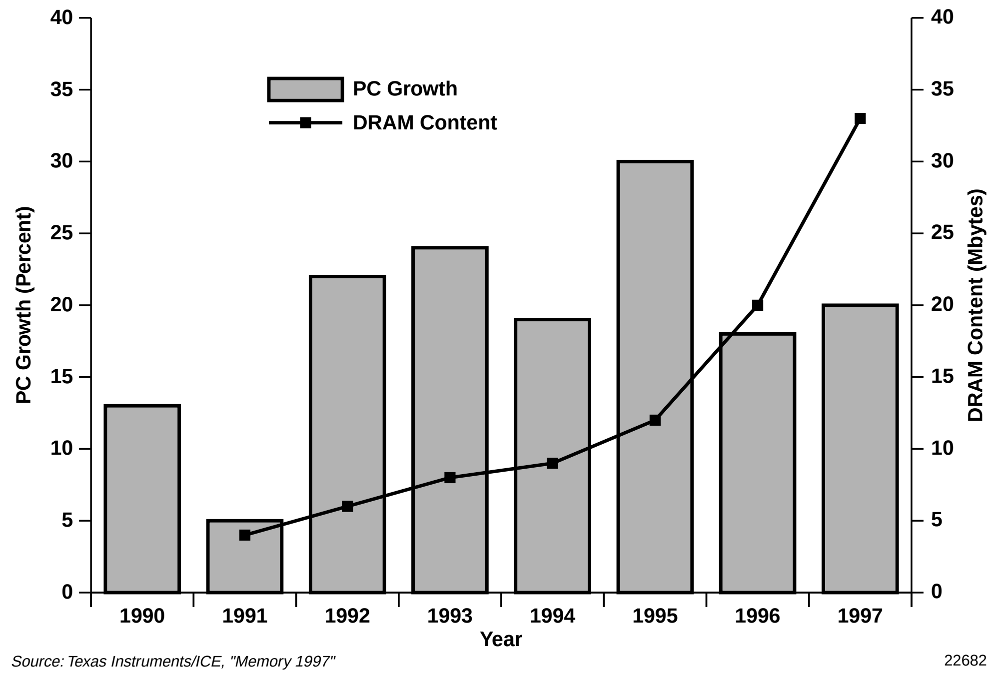


Figure 2-23. DRAM Content Growing Rapidly

A line representing total yearly bit volume for the DRAM market dating from 1973 is shown and plotted in Figure 2-24. With two exceptions (1975 and 1981) DRAM bit volume grew by triple-digit digit amounts from 1973 through 1984. Double-digit increases, averaging 67 percent per year, are shown as the norm from 1985 through the year 2002.

DRAM PRICE PER MEGABIT

DRAM price per megabit values for several densities are plotted in Figure 2-25 for the 1992-2002 time period. 1991 was the crossover year for the 4Mbit generation. It became the lowest-priced device and held that distinction through 1994. In a rare case, the 1Mbit density replaced 4Mbit devices as the low-price leader in 1995. In this case, demand, coupled with limited capacity, for 4Mbit devices kept the ASP (and price per megabit value) high, while that of 1Mbit devices continued to move downward.

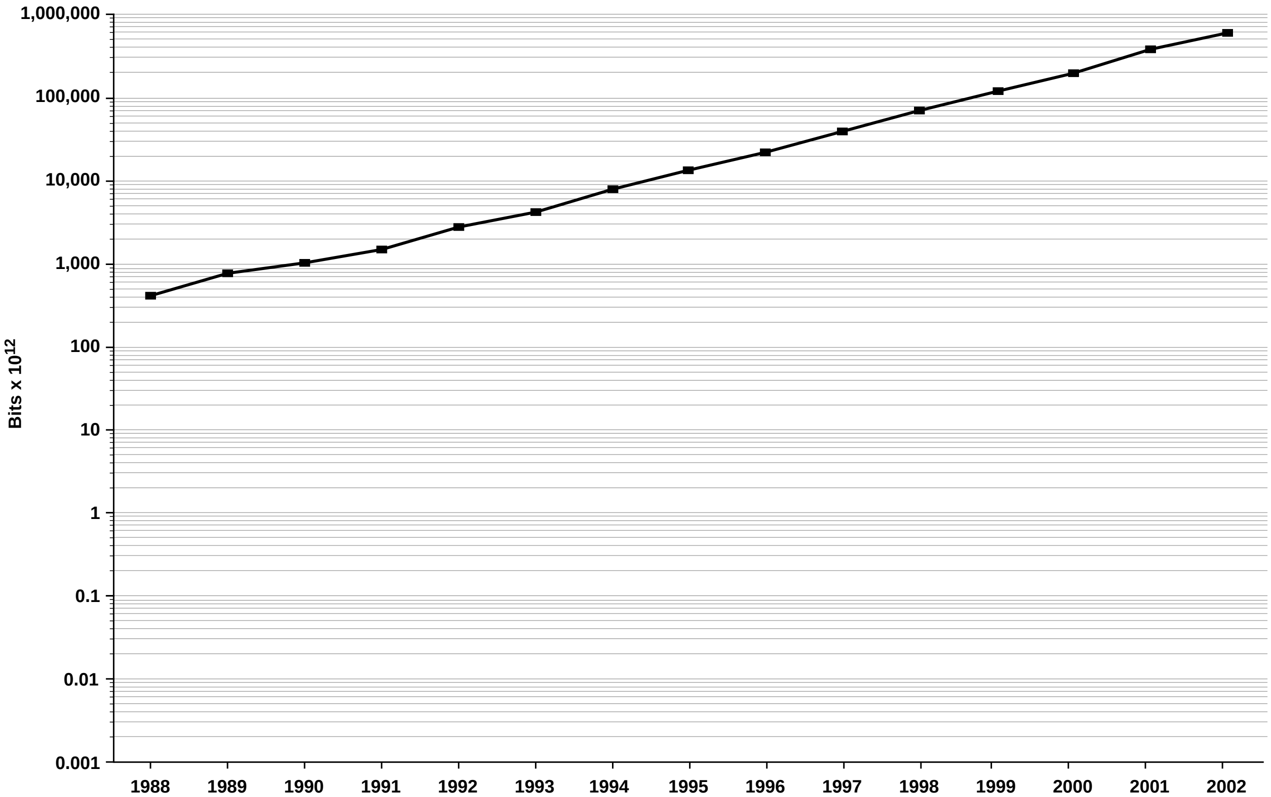
The price per megabit of 4Mbit and 16Mbit devices dropped significantly in 1996. In fact, the 16Mbit generation became the new cost-effective DRAM during the year. ICE expects the 16Mbit and 64Mbit DRAMs to have equal price per megabit values in 1998, with the 4X cross-over point occurring in mid-1998. Then, in 1999, the 64Mbit generation is forecast to take over as the price per megabit leader.

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Units															
1Kbit	8	21	19	13	10	5	1	1	1	—	—	—	—	—	—
4Kbit	—	—	3	24	50	67	70	31	15	10	5	—	—	—	—
16Kbit	—	—	—	—	2	17	71	184	230	240	220	120	35	10	—
64Kbit	—	—	—	—	—	—	—	1	11	100	330	820	500	380	150
256Kbit	—	—	—	—	—	—	—	—	—	—	2	40	240	520	680
1Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	4	45
4Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
64Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
128Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
256Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
512Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1Gbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total Units (M)	8	21	22	37	62	89	142	217	257	350	557	980	775	914	875
Percent Change	—	163%	5%	68%	68%	44%	60%	53%	18%	36%	59%	76%	-21%	18%	-4%
Bits															
1Kbit	0.0082	0.0215	0.0195	0.0133	0.0102	0.0051	0.0010	0.0010	0.0010	—	—	—	—	—	—
4Kbit	—	—	0.0123	0.0983	0.2048	0.2744	0.2867	0.1270	0.0614	0.0410	0.0205	—	—	—	—
16Kbit	—	—	—	—	0.0328	0.2785	1.1633	3.0147	3.7683	3.9322	3.6045	1.966	0.573	0.164	—
64Kbit	—	—	—	—	—	—	—	0.0655	0.7209	6.5536	21.6269	53.740	32.768	24.904	9.83
256Kbit	—	—	—	—	—	—	—	—	—	—	0.5243	10.486	62.915	136.315	178.26
1Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	4.194	47.19
4Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
64Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
128Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
256Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
512Mbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1Gbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total Bits (10^{12})	0.0082	0.0215	0.0317	0.112	0.248	0.558	1.5	3.2	4.6	10.5	25.8	66.2	96.3	165.6	235.3
Percent Change	—	163%	48%	252%	122%	125%	160%	121%	42%	131%	145%	157%	45%	72%	42%

Source: ICE, "Memory 1997"

20898A

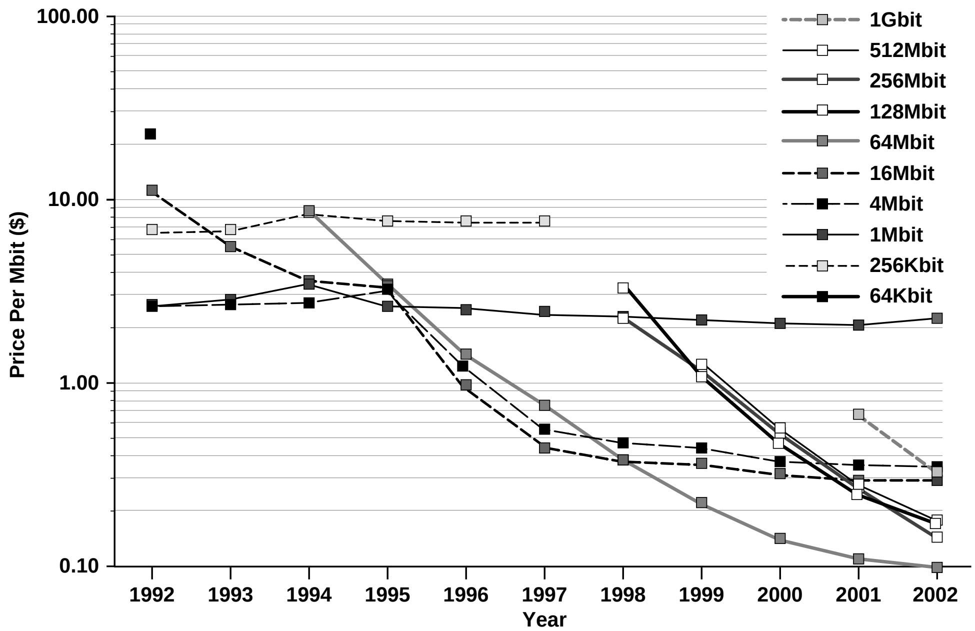
Figure 2-24. Annual DRAM Bit Volume Growth (1973-1987)



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Units															
1Kbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4Kbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16Kbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
64Kbit	150	110	60	30	4	—	—	—	—	—	—	—	—	—	—
256Kbit	875	775	600	272	197	107	64	32	23	15	—	—	—	—	—
1Mbit	180	470	670	827	822	596	500	463	260	187	145	100	45	25	10
4Mbit	—	1	35	145	457	776	1,254	1,649	1,498	958	835	615	350	250	125
16Mbit	—	—	—	0.1	2	20	103	333	974	1,800	2,100	1,750	1,700	1,480	1,200
64Mbit	—	—	—	—	—	—	0.1	0.25	7	103	460	1,300	2,100	2,700	2,600
128Mbit	—	—	—	—	—	—	—	—	—	—	0.1	4	45	100	370
256Mbit	—	—	—	—	—	—	—	—	—	—	0.1	5	75	285	730
512Mbit	—	—	—	—	—	—	—	—	—	—	—	0.1	5	70	225
1Gbit	—	—	—	—	—	—	—	—	—	—	—	—	—	0.1	10
Total Units (M)	1,205	1,356	1,365	1,274	1,482	1,499	1,921	2,477	2,762	3,064	3,540	3,774	4,320	4,910	5,270
Percent Change	38%	13%	1%	-7%	16%	1%	28%	29%	11%	11%	16%	7%	14%	14%	7
Bits															
1Kbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4Kbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16Kbit	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
64Kbit	9.83	7.21	3.9	2.0	0.3	—	—	—	—	—	—	—	—	—	—
256Kbit	229.38	203.16	157.3	71.3	51.6	28.0	16.9	8.5	6.0	3.9	—	—	—	—	—
1Mbit	188.74	492.83	702.5	867.2	861.9	625.0	524.3	485.1	272.7	196.1	152.0	104.9	47.2	26.2	10.5
4Mbit	—	4.19	146.8	608.2	1,916.8	3,254.8	5,259.7	6,916.4	6,283.9	4,019.8	3,502.2	2,578.5	1,469.0	1,048.6	524.3
16Mbit	—	—	—	1.7	33.6	335.5	1,728.1	5,591.8	16,341.0	30,204.0	35,232.2	29,360.1	28,521.3	24,830.3	20,132.7
64Mbit	—	—	—	—	—	—	7.4	16.8	466.4	6,939.1	30,870.1	87,241.5	140,928.6	187,904.8	201,326.6
128Mbit	—	—	—	—	—	—	—	—	—	—	13.4	536.9	6,039.8	16,777.2	13,421.8
256Mbit	—	—	—	—	—	—	—	—	—	—	26.8	1,342.2	21,474.8	100,663.3	295,279.0
512Mbit	—	—	—	—	—	—	—	—	—	—	—	53.7	2,415.9	8,053.1	34,896.6
1Gbit	—	—	—	—	—	—	—	—	—	—	—	—	—	107.4	12,884.9
Total Bits (10^{12})	428.0	707	1,011	1,550	2,864	4,243	7,536	13,019	23,370	41,363	69,797	121,219	200,896	339,411	578,476
Percent Change	82%	65%	43%	53%	85%	48%	78%	73%	80%	77%	69%	74%	66%	69%	70%

Source: ICE, "Memory 1997" 20899B

Figure 2-24. Annual DRAM Bit Volume Growth (continued, 1988-2002)



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
64Kbit	22.13	—	—	—	—	—	—	—	—	—	—
256Kbit	6.48	6.87	8.22	7.63	7.44	7.63	—	—	—	—	—
1Mbit	2.87	2.96	3.43	2.86	2.72	2.45	2.29	2.19	2.15	2.10	2.15
4Mbit	2.79	2.84	2.86	3.06	1.27	0.57	0.48	0.43	0.39	0.37	0.36
16Mbit	10.73	5.54	3.69	3.24	0.96	0.44	0.39	0.35	0.31	0.29	0.28
64Mbit	—	—	8.57	3.35	1.50	0.77	0.39	0.24	0.15	0.11	0.10
128Mbit	—	—	—	—	—	—	3.02	1.16	0.48	0.25	0.18
256Mbit	—	—	—	—	—	—	2.24	1.21	0.52	0.27	0.15
512Mbit	—	—	—	—	—	—	—	1.30	0.56	0.29	0.18
1Gbit	—	—	—	—	—	—	—	—	—	0.65	0.33

Source: ICE, "Memory 1997"

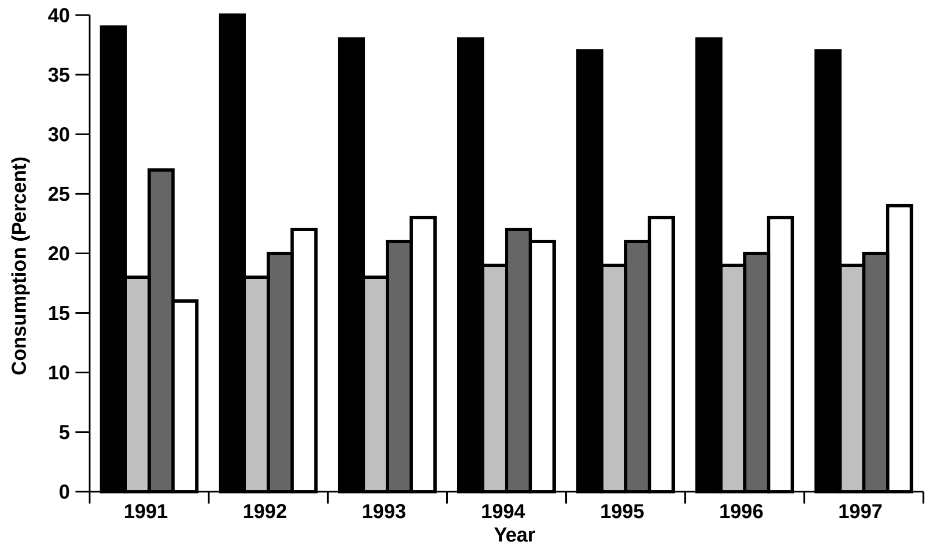
20883B

Figure 2-25. DRAM Price Per Mbit by Density

DRAM CONSUMPTION AND PRODUCTION

Throughout the 1990's, the North American region has been the DRAM consumption leader (Figure 2-26). In 1996, it had 38 percent of the DRAM market. Consumption of DRAMs in the ROW region (Asia-Pacific countries excluding Japan) first surpassed Japan's consumption in 1992. Strong consumer electronic consumption in the developing economies of the region along with PC-related work (assembly, packaging, test) will lead to greater consumption in this region.

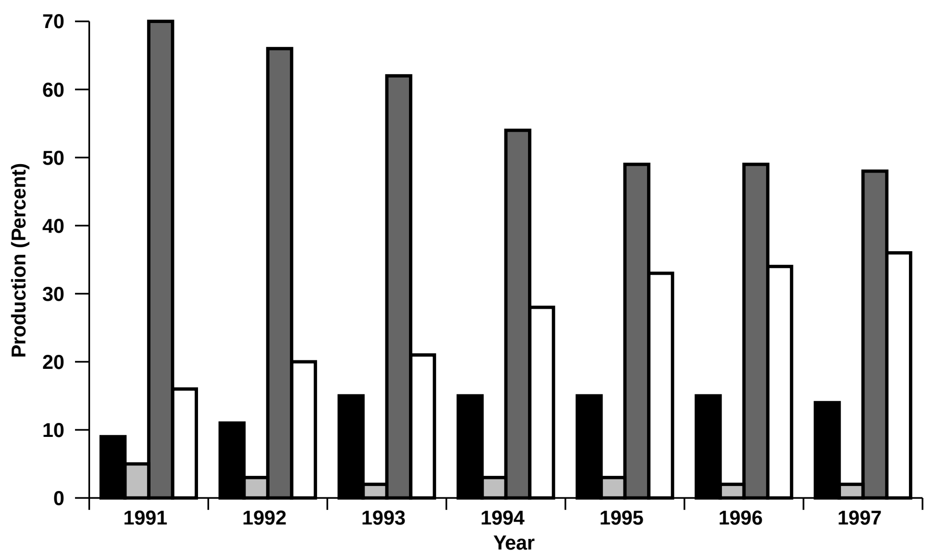
Although its marketshare dropped considerably since 1991, DRAM production has remained firmly in the hands of Japanese companies (Figure 2-27). The biggest threat to Japan's production lead comes from the ROW region (specifically, Korea), which continued to build more facilities at home and abroad to harvest additional marketshare.



	North America	39	40	38	38	37	38	37
	Europe	18	18	18	19	19	19	19
	Japan	27	20	21	22	21	20	20
	ROW	16	22	23	21	23	23	24

Source: ICE, "Memory 1997" 20026C

Figure 2-26. Regional DRAM Consumption

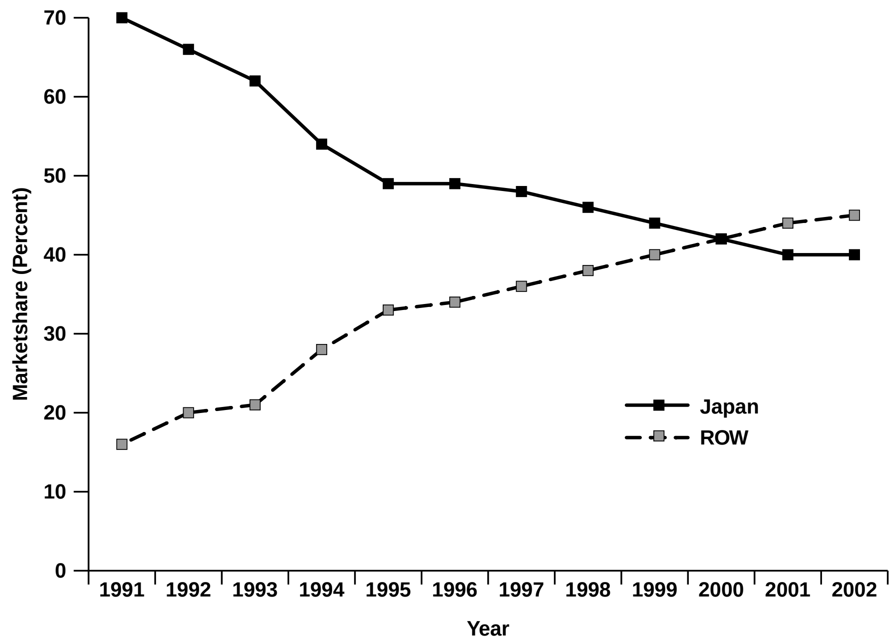


	North America	9	11	15	15	15	15	14
	Europe	5	3	2	3	3	2	2
	Japan	70	66	62	54	49	49	48
	ROW	16	20	21	28	33	34	36

Source: ICE, "Memory 1997" 20027A

Figure 2-27. Regional DRAM Production

Projecting out current trends in regional production through the year 2002, it appears that ROW-based manufacturers could very well be supplying a greater percentage of DRAMs to the world-wide market than their Japanese counterparts (Figure 2-28). World-class manufacturing prowess, generally lower labor costs, supportive governments, and a desire to quickly be a major player in the microelectronics industry are factors that will contribute to the growth in DRAM production in the ROW region.



Japan	70	66	62	54	49	49	48	46	44	42	40	40
ROW	16	20	21	28	33	34	36	38	40	42	44	45

Source: ICE, "Memory 1997" 20884A

Figure 2-28. ROW to Overtake Japan in DRAM Production

DRAM SALES LEADERS

Shown in Figure 2-29 are the leading DRAM suppliers for 1996. As noted in the chart, no vendor was spared from the huge decline in the DRAM market. Texas Instruments' DRAM sales were down 50 percent in 1996, while Samsung managed to control the bleeding with "only" a 26 percent decline in its DRAM sales for 1996. For most, the decline in DRAM revenue nearly matched that of the DRAM market itself (-38 percent).

Topping the list of DRAM suppliers was Samsung. Although its DRAM sales were down 26 percent in 1996, it easily remained the world's leading supplier of DRAMs and showed no sign of relinquishing that position.

Company	1995 Sales ($M)	1996 Sales ($M)	1996/1995 Percent Change
Samsung	6,462	4,805	–26
NEC	4,740	3,175	–33
Hitachi	4,439	2,805	–37
Hyundai	3,500	2,300	–34
Toshiba	3,725	2,235	–40
LG Semicon	3,005	2,005	–33
TI	3,200	1,600	–50
Micron	2,485	1,575	–37
Mitsubishi	2,215	1,400	–37
Fujitsu	2,065	1,350	–35
Others	4,999	1,880	–62
Total	40,835	25,130	–38

Source: ICE, "Memory 1997" 20875C

Figure 2-29. 1996 DRAM Sales Leaders

One reason why the top ten players accounted for the overwhelming majority of the DRAM market (93 percent in 1996) was that many marginal players fled the market or switched to producing other ICs once DRAM profit margins became extremely lean. And why not? Even though the loss was painful, large DRAM suppliers could afford to ship more DRAM units in 1996, yet come up with about $1-$2 billion less in revenue. For the small or marginal DRAM supplier, a proportionate reduction in revenue would likely have been much more devastating.

4Mbit DRAMs

Although the 4Mbit DRAM market declined 62 percent in 1996, 4Mbit units out-shipped all other DRAM densities. ICE estimates that 1.5 billion 4Mbit units were shipped in 1996, a decline of nine percent from 1995.

Though the luster faded from the 4Mbit market, PC OEMs and consumers wishing to upgrade their system memory took advantage of the long-overdue low prices and filled their computers with additional memory, which helped extend the demand for 4Mbit devices well into 1996 (Figure 2-30).

ICE's estimate of the top 4Mbit DRAM suppliers in 1996 is shown in Figure 2-31. Revenue generate by 4Mbit DRAM suppliers in 1996 dropped sharply. Watching ASPs fall and realizing revenue would be several hundred million (even more than one billion) dollars less than the previous year had to sting many of the 4Mbit DRAM suppliers in 1996.

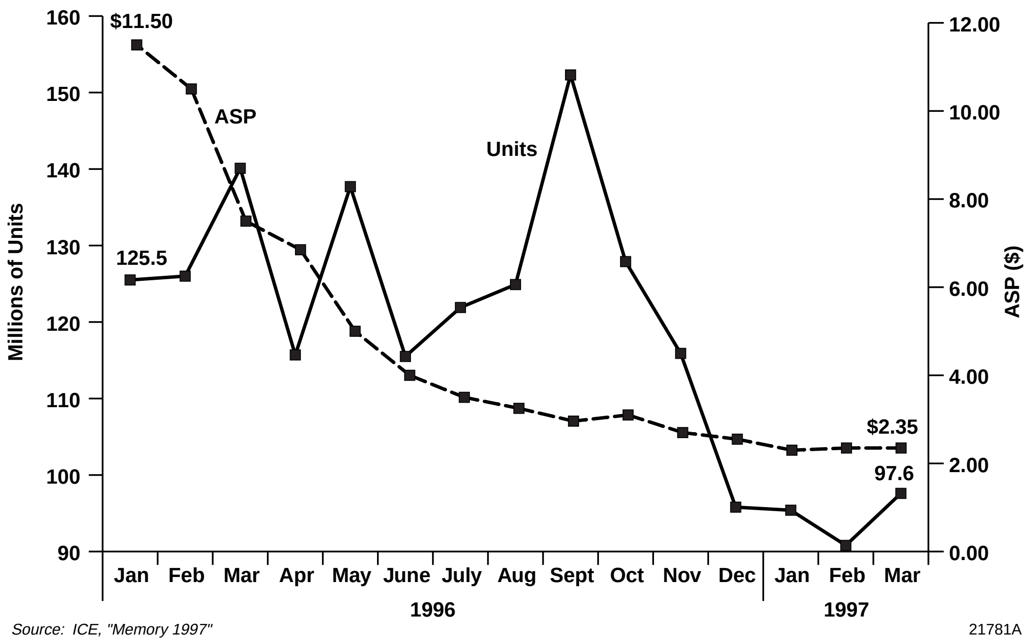


Figure 2-30. Lower Prices Extend 4Mbit DRAM Demand

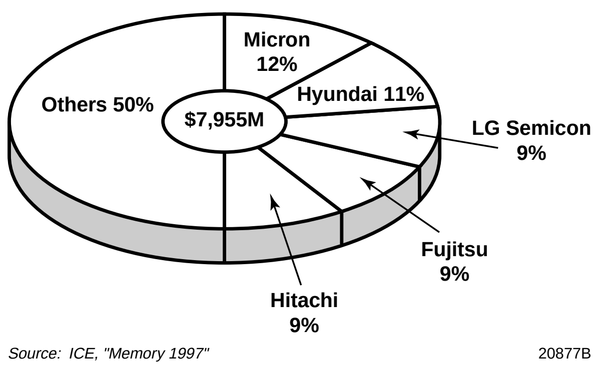


Figure 2-31. 1996 Leading 4Mbit DRAM Suppliers

The "big five" suppliers from Japan (NEC, Hitachi, Toshiba, Mitsubishi, and Fujitsu) reduced 4Mbit shipments beginning in 1Q96. By the end of the year, each had lowered 4Mbit output by at least one-third. Other Japanese manufacturers such as Oki slashed 4Mbit DRAM production 60 percent in 1996 compared to 1995. Though there was plenty of demand for 4Mbit DRAM devices, these and other suppliers quickly shifted to 16Mbit production.

16Mbit DRAMs

Figure 2-32 shows the leading 16Mbit DRAM suppliers for 1996. Samsung established an early lead in this segment and has managed to maintain its leadership as this market has matured. NEC, meanwhile, desired to match Samsung's aggressive 16Mbit DRAM schedule.

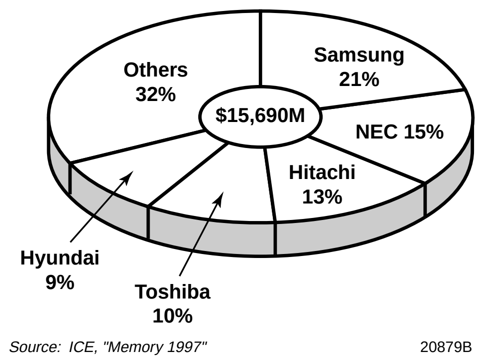


Figure 2-32. 1996 Leading 16Mbit DRAM Suppliers

16Mbit DRAM demand took a sharp upswing in 1996 as prices dropped for this density as well. Greater affordability and availability of the wide configurations helped to jump start this market. Figure 2-33 compares the rise in 16Mbit DRAM demand with the fall of ASPs during 1996 and 1Q97.

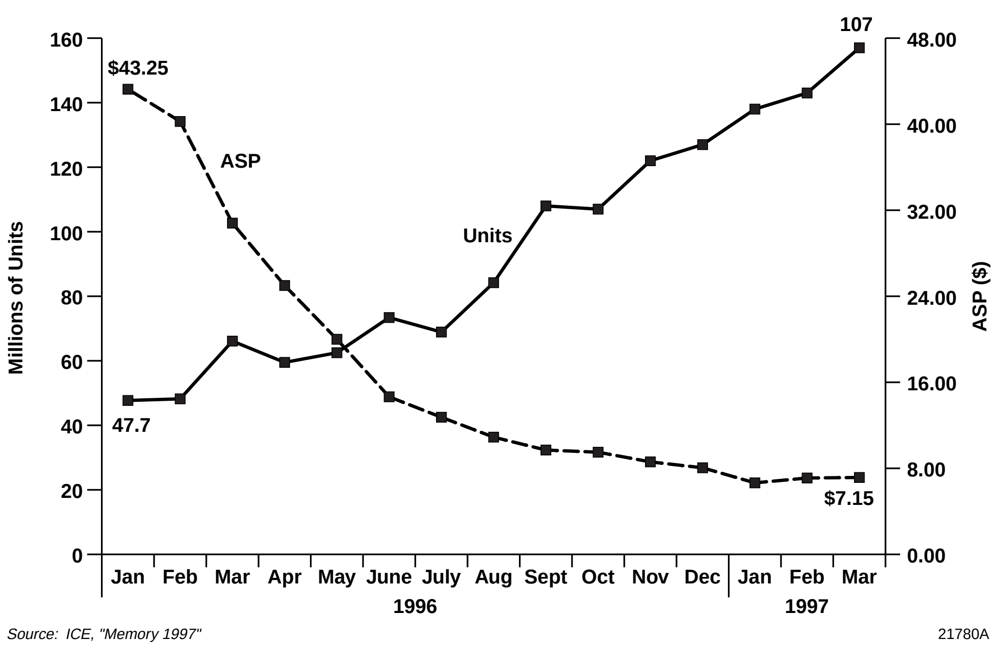


Figure 2-33. Lower Prices Increase 16Mbit Demand

With the rapid decline of 16Mbit ASPs, Korean DRAM vendors capped or reduced their output of 16Mbit devices in the first half of 1997 by as much as 30 percent. In 2Q97, Samsung reduced its monthly 16Mbit output from 18 million units to 16 million. A few Japanese suppliers (NEC, Toshiba, Oki, et al) took similar action. Prices fell so far that the business was no longer profitable and threatened their ability to invest in future products.

Despite the slim profit margins, talk of reduced output, and the move to the 64Mbit generation, production of 16Mbit DRAMs began in earnest in Taiwan during 4Q96. Nan Ya Technology started volume shipments of a 16Mbit (4Mbit x 4) EDO DRAM family from its new 200mm fab. The devices were manufactured using 0.4µm technology. The company plans additional configurations for 1997. Although it obtained its technology from Oki and will produce DRAMs for the Japanese company, Nan Ya will also sell its products on the merchant market using its own logo.

Taiwan's Powerchip Semiconductor also initiated 16Mbit EDO DRAM production in 1996. Powerchip, formed in late 1994, obtained its 16Mbit and 64Mbit DRAM technology from Mitsubishi. It will sell 50 percent of its output to the Japanese company, with the remainder dedicated to several Taiwanese-based firms.

Hyundai is bullish on the synchronous DRAM market and in 4Q96 released its 16Mbit SDRAM. Configured in x16, x8, or x4 versions, the device is expected to help improve Pentium Pro performance by as much as 20 percent compared to conventional EDO DRAM. Hyundai planned to expand its SDRAM product line in 1H97 with the introduction of a 64Mbit SDRAM.

To cut production costs, several Taiwan-based DRAM suppliers shifted their 16Mbit production lines to 0.35µm process technology in 2Q97. Among the companies moving to the finer process geometry were TI-Acer, Vanguard International, United Semiconductor, Mosel-Vitelic, and Powerchip Semiconductor.

In another cost-cutting move, Fujitsu accelerated its drive to shrink 16Mbit DRAM size in order to lower its production costs. The company currently manufactures 60mm-square chips using a 0.36µm process. It hopes to reduce that to a 40mm-square chip using a 0.28µm process by early 1998.

Some DRAM suppliers looked to more lucrative opportunities such as combining memory and logic on a single chip. Though there are several crucial technology and manufacturing hurdles to overcome, the idea of memory and logic on one chip is intriguing to OEMs and suppliers. Immediate benefits of incorporating both technologies on one chip include higher bandwidth (great for graphics applications) and the obvious board space savings. Section 7 (DRAM Technology) and Section 11 (Embedded Memory) further discuss the concept of DRAM and logic on the same chip.

Additional company and product highlights surrounding the 16Mbit DRAM market are listed below.

Fujitsu

Announced that it would rely on Taiwan Semiconductor Manufacturing Company (TSMC in Hsinchi, Taiwan) for as much as 40 percent of its 16Mbit DRAM production. Fujitsu said it will lower its own 16Mbit production by 15 percent and concentrate its own resources on 64Mbit production.

Hitachi

In response to the glut in the DRAM market, Hitachi underwent one of the most aggressive product restructurings of any Japanese chip maker. It shifted its production of 16Mbit DRAMs in Kofu, Japan, to flash memory devices. That move followed the news from 1Q97 to kill a joint-venture DRAM fab in Malaysia with LG Semicon and an announcement in December, 1996 to re-open a closed 16Mbit DRAM fab to make SH MPUs instead.

Of the 16Mbit DRAM devices Hitachi offers, approximately 40 percent are supplied by LG Semicon of Korea.

Intel

Intel announced in 1Q97 that it took an equity position in a $1.3 billion memory fab being built in Austin, Texas, by Samsung. In exchange for its equity position, Intel will be guaranteed an undisclosed number of wafers from the facility, which is expected to produce 16Mbit and 64Mbit DRAMs using sub-0.5µm technology.

Mitsubishi

Mitsubishi officials displayed a 16Mbit device built using silicon-on-insulator (SOI) wafers. The company claims that its new 16Mbit DRAM on SOI, slated for sampling in 1998, has the access speed of a 64Mbit device built on a standard silicon wafer. It should be noted that SOI starting wafers are three to five times more costly than standard silicon wafers.

NEC

Although unit demand is strong, NEC realizes that the market for 16Mbit devices will have a hard time recovering from its 1H97 levels. As a result, NEC announced it would trim 16Mbit DRAM output 20 percent by the end of fiscal 1997 (March 31, 1998).

Oki

Oki invested $700 million to build a 16Mbit/64Mbit DRAM production facility in the U.S. The 0.35µm 200mm wafer processing line will be located in Oregon.

Toshiba

Toshiba off-loaded a small portion of its 16Mbit DRAM production to Taiwan-based Winbond Corporation, which also expects to make 64Mbit DRAM for Toshiba. Additionally, the company lowered its own 16Mbit DRAM output by 15 percent in 1Q97.

64Mbit DRAMs

64Mbit DRAMs arrived on the market in volume in the first half of 1996—a time when overall DRAM prices were dropping quickly. With hopes of capturing some of the hefty profits that eluded the 16Mbit generation, several companies disclosed plans to ramp up 64Mbit DRAM production.

With many companies jumping into the lucrative 64Mbit DRAM market, an oversupply situation was created, which defeated DRAM manufacturers' goal of producing chips with higher profit margins. Once again, DRAM vendors deprived each other of the high margins they came to expect at the beginning of the DRAM product life cycle.

The rapid drop in average selling price is premature for this new-generation of devices. From a pricing standpoint, the 1997 market for 64Mbit devices is forecast to remain very fragile. Producers will try to maintain higher prices, but there could well be dissension among the ranks, which may result in even lower prices by the end of 1997.

Company	2Q97	1997 Year End Target
Fujitsu	100,000	1,500,000
Hitachi	500,000	1,500,000
Hyundai	300,000	1,000,000
LG Semicon	300,000	1,000,000
Mitsubishi	700,000	2,000,000
NEC	2,000,000	3,500,000
Oki	100,000	600,000
Samsung	2,000,000	4,000,000
Toshiba	100,000	1,000,000

Source: ICE, "Memory 1997" 22683

Figure 2-34. 64Mbit Monthly Output Targets

Through the first half of 1997, the highest-volume application for 64Mbit DRAMs remained servers and workstations. By the end of 1997, very high-end PCs will likely begin to use the devices. Despite this rather limited market, 64Mbit devices keep coming. Figure 2-34 shows a sampling of 64Mbit DRAM vendors and their 1997 year-end production targets.

Although most of the news regarding the 64Mbit DRAM market has come from the Japanese and Korean suppliers, Taiwanese companies also plan to play a significant role in this market as well. Figure 2-35 reviews a few of the plans by Taiwanese companies regarding 64Mbit DRAM production. Figure 2-36 shows how serious Taiwan is regarding the expansion of its DRAM and total IC industries.

Company	Design Development	First Shipments	Comments
Nan Ya Technology	Joint-development with Oki	1998	Will sell DRAMs under its own logo, but with technology licensed from Oki. Building its initial 200mm wafer fab near Taipei.
Powerchip Semiconductor	DRAM design/technology assistance from Mitsubishi	4Q96	Japan's Mitsubishi and Kanematsu have one-third ownership in Powerchip.
ProMos Technologies	Joint-development with Mosel-Vitelic and Siemens for 64M and later, 256Mbit DRAM devices.	4Q97/1Q98	Based in Hsinchu, ProMos is 38 percent owned by Siemens and 62 percent owned by Mosel-Vitelic. ProMos sampled 64Mbit devices in 2Q97, expects mass production to begin in 1Q98.
TI-Acer	Designs from TI, manufacturing from Acer	4Q97	TI sells the output under its own logo. Spending $1.2 billion to build a 64Mbit DRAM fab in Taipei. Operations are due to begin in the spring of 1997.
Vanguard International	—	4Q97	Formerly government sponsored Industrial Technology Research Institute. First Taiwan-based company to develop and show a fully functional 64Mbit DRAM. The part was made using a 0.4µm process.
Winbond	Design from Toshiba	2Q98	Licensing 64Mbit manufacturing technology from Toshiba. It will then supply the Japanese company with a portion of output.

Source: ICE, "Memory 1997" 20031E

Figure 2-35. Taiwan's Ambitious 64Mbit DRAM Plans

Additional highlights from the 64Mbit DRAM market are shown below.

Fujitsu

Fujitsu moved its 64Mbit DRAM ramp schedule forward. It decided to boost output to 1.5 million units per month by the end of 1997. It plans to cancel 16Mbit DRAM production at its Gresham, Oregon, plant and will instead launch 64Mbit fabrication there.

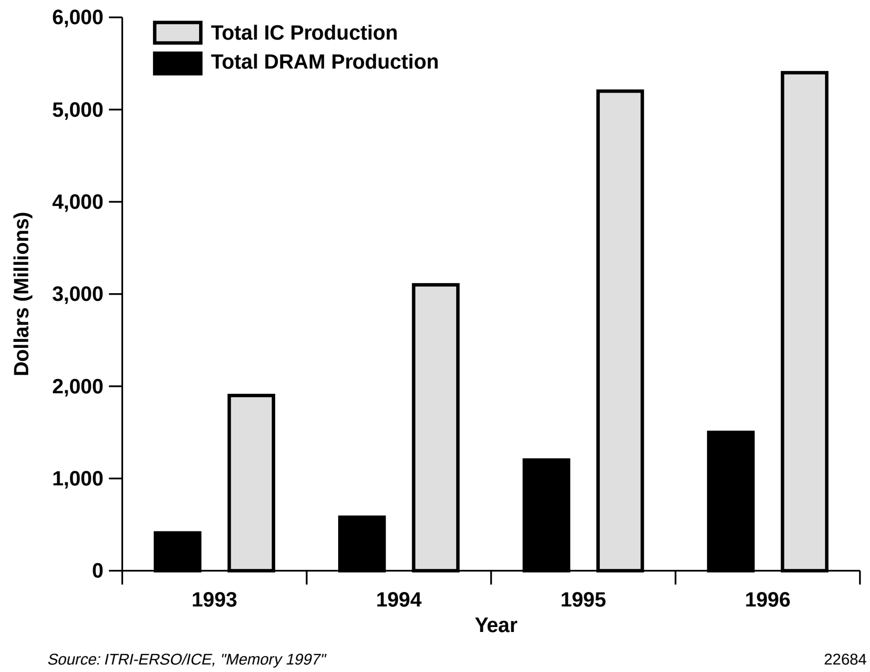


Figure 2-36. Taiwan's DRAM Sales Accelerate

Hitachi

Hitachi, Nippon Steel Semiconductor, and the Singapore government formed a joint venture that will invest nearly $1 billion to build a 64Mbit DRAM fab in Singapore. The facility will have the capacity to produce 20,000 200mm wafers per month using 0.35µm process technology. Production is slated to begin in the second half of 1998.

Mitsubishi

Mitsubishi developed its 64Mbit synchronous DRAM chip that operates at a clock speed of 125MHz. It will make the device available in 2H97. Designed using a 0.3µm process, the low-power chip reduces 3.3V supplied externally to 2.5V internally.

Samsung

Samsung began volume production of 64Mbit SDRAMs in 1Q97. The company, a leader in next-generation DRAM development and manufacture, said it had difficulty accelerating the market for 64Mbit DRAMs due to overcapacity (and very low prices) for 16Mbit parts. It hopes to achieve a crossover point with 16Mbits in late-1997, but realizes it will be difficult to achieve.

Toshiba

On the heels of Intel's equity investment announcement with Samsung, Toshiba also started negotiations with Samsung about acquiring a 20 percent stake in the Korean company's new Austin, Texas, DRAM fab. If the deal goes through, Toshiba would get 20 percent of the 64Mbit DRAMs produced at the Samsung fab.

Toshiba also announced, along with its joint-venture DRAM partner Motorola, that it would postpone by more than one year the construction of a 64Mbit DRAM production facility at its Tohoku Semiconductor operation. Although Toshiba has not ruled out giving up 64Mbit DRAM production at the joint venture, it and Motorola may not be able to launch volume production when demand for the devices peaks.

Additionally, Toshiba rolled out its first 64Mbit SDRAM parts in 2Q97. Three configurations vary in speed from 83MHz to 125MHz.

128Mbit DRAM

In 2Q97, at least five DRAM suppliers declared their intentions to manufacture 128Mbit DRAMs in order to delay the heavy costs associated with developing 256Mbit devices. Further, the group believes they can provide customers with a cost-effective means to meet growing system memory requirements.

Rather than jumping from the 64Mbit generation straight to 256Mbit devices, Samsung, NEC, Texas Instruments, Fujitsu, Hyundai, and a handful of other leading DRAM suppliers have planned a generational "half-step" with 128Mbit DRAM products. Driving the move to the 128Mbit density is industry concern over investment in 256Mbit DRAM technology after suffering through tremendous DRAM price declines during the past year. Also, computer manufacturers including IBM and Compaq called for a transitional density to satisfy memory granularity issues as PC main memory swells to 64Mbytes.

NEC expects to have samples of a 128Mbit SDRAM ready in the first half of 1998. Likewise, Fujitsu is working on a 128Mbit SDRAM and expects to have engineering samples available in 1Q98. Hyundai, also, plans to introduce its 128Mbit device in 1H98 when it shrinks its 75Mbit part to a 0.25µm process.

Texas Instruments plans to introduce its 128Mbit device in mid-1999. TI believes that the 256Mbit chip will be too expensive to bring to market until after the year 2000 and is therefore concentrating on the 128Mbit DRAM. TI will use the same 0.18µm process it expects to use for its 256Mbit chip. Samsung plans to stick with its 1999 volume production plans for 256Mbit devices and will build 128Mbit parts only to address a temporary need.

Toshiba gave the go-ahead to develop a 128Mbit SDRAM but actual development work had not started as of 2Q97. Hitachi's preliminary decision was to forego 128Mbit development because it felt its DRAM product portfolio was bloated. Other suppliers, including Micron and LG Semicon, have yet to decide whether to pursue the 128Mbit generation or move on directly to 256Mbit devices.

256Mbit DRAMs

256Mbit DRAMs have been developed by a few manufacturers. NEC shipped samples of its 256Mbit DRAM in 1996. The company initially forecasted that commercial production of the devices would begin in 1998. That date has since been pushed out to late 1999 or 2000.

Samsung sampled its 256Mbit part in 1996. Meanwhile, Fujitsu announced that it developed a 256Mbit SDRAM and plans to start sample shipments in 1998. Its chip was designed using a 0.28µm process.

Toshiba also plans to launch 256Mbit DRAM production in 1998. It plans to make its devices at its new facility in Oita, Japan, using 0.25µm process technology.

Gigabit DRAMs

It may be several years before the devices can be easily purchased, but for memory manufacturers, the era of the gigabit DRAM is at hand. In 4Q96, Samsung announced it fabricated a 1Gbit DRAM on "laboratory silicon," claiming to be the first company to do so. The company invested more than $250 million to develop the device, which was built using 0.18µm technology. Evaluation samples of its chip are expected to appear in 1997. The 500mm-square IC uses a special 32-bank synchronous technology to accelerate the chip's processing speed, estimated at 31ns, and to permit burst transfer rates as high as one gigabit per second. At the 1996 Cymer Seminar, Samsung provided a review of its DRAM roadmap through the 16Gbit generation (Figure 2-37).

	1Gbit	4Gbit	16Gbit
First Production	2001	2004	2007
First Working Die	1998	1999	2002
Design Rule (Microns)	0.18	0.13	0.10
Required Overlay (nm)	50	40	20
Die Size (sq. mm)	780	938	1,144
Stepper Field Size (mm)	26 x 30	26 x 36	26 x 44

Source: Samsung/1996 Crymer Seminar/ICE, "Memory 1997" 22685

Figure 2-37. Samsung's Gigabit DRAM Roadmap

At NEC, researchers rejected Samsung's 1Gbit leadership stance. The Japanese company stated it earlier developed a prototype and expected to ship evaluation devices to customers in 1997. Moreover, it claimed engineering samples would be ready for delivery by the year 2000.

Memory powerhouses Hitachi, Mitsubishi, and Texas Instruments announced in 1Q97 that they would cooperate in the development of 1Gbit DRAMs. The immediate purpose of the venture was to share technology, research and development of process and design capabilities, and the production of prototype chips.

The venture will compete with a joint-development team involving four of the world's leading IC manufacturers—IBM, Motorola, Siemens, and Toshiba. Together, the companies pooled their considerable resources in an effort to design, develop, and bring 1Gbit DRAMs to market (if only in sample form) by the year 2000.

It should be noted that Toshiba, in 2Q97, reviewed its role in the venture and recalled to Japan 70 engineers working on the project. The company claimed there was no rupture in the relationship but that it had to re-examine the 1Gbit effort before further committing to the venture.

At the next level, NEC reportedly prototyped a 4Gbit DRAM device that measured 986mm-square (compared to 100mm-square for a 1995/1996 16Mbit DRAM), or approximately one-and-a-quarter inches on a side. To achieve the die size, NEC adopted an advanced 0.15µm process CMOS process.

The 4Gbit DRAM can store 47 minutes of full-motion video, six hours of audio data, or the complete works of William Shakespeare 64 times over. NEC, which spent more than $160 million on development, plans to invest another $645 million of R&D before mass production is launched. Sample shipments are slated for 2000.

Hyundai also started on the long road to 4Gbit DRAM output. It signed a joint development agreement with Eaton Semiconductor Equipment Operations to develop the tools needed to make 4Gbit DRAM devices. The company stated that it did not expect 4Gbit DRAM devices to be available until 2010 when it would implement a 0.07µm process technology.