ESTIMATING THE IMPACT OF MIGRATION TO ASIAN FOUNDRY PRODUCTION ON ATTAINING THE WSC 2010 PFC REDUCTION GOAL

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Introduction

Recent reports describe two emerging and accelerating trends in semiconductor manufacturing: the increasing success of the foundry-fabless business model, accompanied by an emerging geographical shift in world manufacturing capacity to Southeast Asia—in particular the China, Malaysia and Singapore (CMS) region (FSA, 2003; SMA, 2002; Jelinek, 2003 and 2004). Both of these trends, in turn, influence geographical patterns of the usage and emissions of perfluorinated compound (PFC) gases such as C_2F_6, CF_4, SF_6 and NF_3, essential to manufacturing and characterized by high global warming potentials, thus contributing to the threat of global climate change (Burton and Lieberman, 2003 EPA report).

Since 1999, most PFC emissions from semiconductor manufacturing have been subject to a voluntary reduction goal established by members of the World Semiconductor Council (WSC).[1] That goal—to limit PFC emissions by 2010 to ten percent below a base-year (typically 1995) level of emissions—is incorporated into the semiconductor industry's International Technology Roadmap for Semiconductors (ITRS). The ITRS is developed through a "consensus building process" and "predicts the main trends in the semiconductor industry spanning 15 years into the future." (ITRS, 2003; WSC, 1999).

The WSC agreement sets forth obligations and expectations about 2010 emissions and is expected to shape the market for reduction technologies needed to achieve the goal. World PFC emissions from semiconductor manufacturing not included in the WSC reduction agreement (i.e., those originating outside of WSC member countries) appear to be increasing at an accelerating rate. While fabs operated by WSC members accounted for somewhat more than 90 percent of the world's semiconductor manufacturing capacity (measured in area of silicon processed) during 1995-1999 (the period when the agreement was being developed and adopted), recent reports and databases indicate that, by 2005, the share of world manufacturing capacity held by non-WSC members is expected to increase to almost 20 percent (WFW, 1996 – 2001; Burns, 2004; WFW, 2004). Approximately 60 percent of this nearly doubled capacity is projected to be located in the CMS region. Each month there are new reports about the rising manufacturing

[1] According to its website (www.semiconductorcouncil.org), "Membership …is open to associations representing semiconductor makers in nations or regions which support the objectives of the WSC and who have significant semiconductor industries or markets within their borders …[and who] either have zero tariffs on semiconductor [products] or a plan for expeditious tariff elimination." As of April 2003, members were: EECA-ESIA, JEITA, KSIA, SIA and TSIA.

dominance of the Asia/Pacific region and China's large and growing share (Electronic News, 2004).

Whether fabs in non-WSC member countries (most notably those in the CMS region) participate in international plans to reduce PFC emissions from semiconductor manufacture has global implications. If they do not embrace the WSC reduction goal, actual world industry emissions in 2010 will likely exceed the levels expected when the agreement was adopted even though current members may meet their goals.

This paper examines the impact of migration to Asian (specifically, CMS region) semiconductor production on attaining the 2010 WSC reduction goal. Pledged reductions in emissions vary by WSC-member country and region depending on base-year emissions and projected 2010 uncontrolled emissions, which are governed by projections of 2010 global demand for silicon. Several different scenarios are examined. This paper addresses three questions:

1. Compared to U.S. fab production levels in 2000, what portion of the U.S.'s reduction goal is met as production moves to other countries?
2. Considering the alternative scenarios in geographical shifts in capacity among production regions, what reductions in 2010 emissions might be required among WSC-member countries?
3. Considering estimates of emissions in 2000, 2005 and 2010 from current WSC member countries and those of key non-member countries, such as those in the CSM region, what might be realistic emission reduction goals for those countries should they join the WSC?

Approach—Considerations and Modeling Method

In its essence, our approach relies on 2010 projections of world and region-specific silicon consumption by technology node. With this and complexity (layer) information from the ITRS, we developed and applied a model derived from EPA's PFC Emissions Vintage Model (PEVM) to estimate region-specific *uncontrolled* PFC emissions (Burton and Bartos, 2002; Burton and Lieberman, 2003). We call this the foundry impact analysis model (FIAM). For a measure of impact, we use a region's obligation to reduce its emissions relative to its projected uncontrolled emissions in 2010. We consider 9 regions of interest: the current 5 member regions of the WSC, the three countries in the CMS region and the rest of the world.

Projections of World Silicon Consumption

VLSI Research, Inc. offers semi-annual updates of actual and projected world silicon demand in various forms. The projections extend 5-years beyond the year for which actual figures are available (e.g.., projections to 2008 were available for actual silicon demand for 2003). PEVM extends (via extrapolation) the VLSI Research world projections to 2010 and recasts them into the silicon consumption by technology node, excluding test-wafers not fully processed with PFCs. Applying estimates of annual region-specific shares of manufacturing capacity to these recasted estimates of world silicon consumption yields estimates of country and regional silicon consumption, under the assumption that fabs operate at approximately the utilization for each technology node.

Country-specific region-specific shares of world manufacturing capacity

To develop and examine alternative geographical patterns of fab manufacturing capacity from 1995 to 2010, we estimated region-specific shares of world capacity by technology node for two periods: 1995-2005 and 2006-2010. From 1995-2005, shares were estimated for each technology node from the World Fab Watch (WFW) database (WFW, 2003). From 2006-2010 (depending on technology node), one of two methods was used:

1. For silicon used to manufacture devices with linewdths ≥120 nm, the shares estimated from WFW for 2005 were assumed to remain constant through 2010.
2. For silicon consumed using linewidth technologies <120 nm, we estimated annual region-specific capacity shares from projections of annual capital spending.

The second method assumes that all capital spending goes to adding leading-edge capacity as presented in the ITRS (ITRS, 2003). PEVM projections of PFC emissions show that by 2010, approximately 60 percent of uncontrolled emissions would come from manufacturing devices with linewidths < 120 nm. Thus, each annual expenditure of capital, in effect, adds to the stock of existing capacity.[2]

Region-specific shares for 1995 – 2005—From WFW Databases

The WFW databases, updated semiannually since 1995, contain records of fab location (country), wafer size, design capacity (wafer starts per month), process geometry (µm), process technology (e.g., CMOS, BICMOS, etc.), product class (e.g., logic, memory, etc.) and first-year of production (or in the case of an announced or fab under construction, the expected first-year and quarter of production). Strategic Marketing Associates (SMA) maintains the WFW database through telephone surveys (SMA, 2003). Missing data rates vary between 2 – 10 percent depending on the field and edition of the database. For the editions and fields used for this paper, the average missing data rate was approximately 6 percent; no effort was made to fill in data gaps. Region-specific capacity shares (by technology node) were estimated using, for production years 1995, 2000 and 2005, the July 1996, 2001 and April 2003 Editions of WFW. The April 2003 Edition contained the needed information for fabs scheduled to start production in 2005. We confirmed the information for new fabs using independently published analyst reports on new capacity (location, wafer size, capacity, geometry and product) coming online (Deutche Bank, 2003).

[2] It should be noted here that the current analysis does not incorporate any delay, or "lag-time", between expenditure for capacity and the realization of that capacity. It is assumed, instead, that capacity increases occur during the same year that additional spending occurs. Importantly, incorporating such a lag would not change the essential findings of this study.

Region-specific shares for 2006-2010—From Historical Extrapolation of Capital Spending and WFW Databases

We assume annual capital spending is proportional to annual capacity additions. Among the defining characteristics of the dynamic semiconductor industry is an enduring practice of increasing capacity by increasing the amount of integrated circuitry that can be produced. By shrinking the size of the elements that comprise a circuit (i.e., by increasing the density of the elements on a unit of silicon), fab capacity is expanded even when wafer output capacity is not. The density of these electrical elements depends on the minimum feature size of the manufacturing process technology. Decreasing feature size then marks changes in process technology and increases in capacity. In industry parlance, changes in feature size are also called changes in linewidth or technology nodes.

Under this assumption, region-specific shares of annual capital spending are used to apportion the PEVM's annual projection of world silicon consumed during manufacture of devices at geometries <120 nm to the corresponding regions. As noted previously, for silicon consumed at geometries >120 nm, we obtained region-specific shares from WFW (April 2003 Edition), holding those shares constant from 2006 to 2010. Before describing how we estimated future trends in world and region-specific capital spending, we briefly describe the relationship between capital spending and capacity, capital spending and revenues, and revenues and silicon consumption (or demand).

Semiconductor manufacturing is a global, highly competitive, growth industry. To compete requires capital expenditures in increasing amounts—for new integrated circuit (IC) designs, new fabs and new process technologies for existing fabs. It is increasing revenues from IC sales to expanding markets that supports the requisite increase in capital, provided companies remain sufficiently profitable. Profitability comes from lower costs, increased manufacturing productivity, and maintaining a balance between spending and revenues. These revenues are a reflection of market prices as determined through the interaction between supply and demand, and result in fluctuations in the average selling price of manufactured products.

Figure 1 shows a relationship between capital spending and wafer capacity, expressed in 200 mm equivalency. The information for Figure 1 comes from the April 2003 edition of WFW database for fabs that were under construction or recently completed. These fabs process 200 mm and 300 mm wafers. The regression line, constrained to the origin, shows that every 1000 wafer starts per month of additional capacity (200 mm equivalent wafer size) requires, on average, expenditures of approximately $36 million. Information in WFW databases also shows that, on average, approximately 80 percent of capital expenditures go to the purchase of wafer processing equipment. Industry analysts report similar figures for the cost of incremental capacity and share of capital expenditures for equipment purchases (Deutsche Bank, 2003).

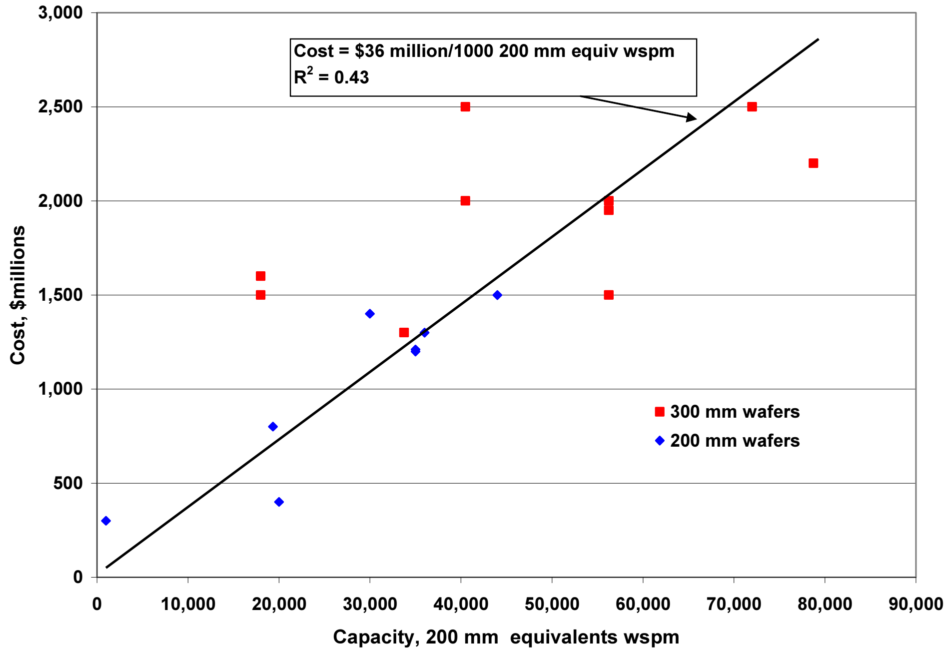

Figure 1. Reported capital cost (in 2003 $) for 200 and 300 mm wafer fabs recently completed or under construction worldwide (Source: WFW, April 2003 Edition)

As noted earlier, capital expenditures are financed by revenues from sales. Figure 2 shows, on a semi-logarithmic scale, the historical relationship between semiconductor revenues and capital spending. While revealing the often-lamented cyclical nature of industry revenues and capital spending, Fig. 2 also shows that, on average, annual capital spending represents approximately 25 percent of annual revenues, ranging from 22 to 33 percent. ICE reports approximately 28 percent as an average over the eight year period from 1992 to 1999 (ICE, 2000). The global revenues from IC sales and global silicon demand figures used in this paper track historical figures that range from $30 to $45 (depending on economic conditions) of revenue earned for each square inch of silicon consumed (ICE, 2000). We now return to how we estimated projected region-specific shares of capital spending that, it should be recalled, were used to apportion projections of world silicon consumption to specific regions for the purpose of estimating region-specific uncontrolled PFC emissions.

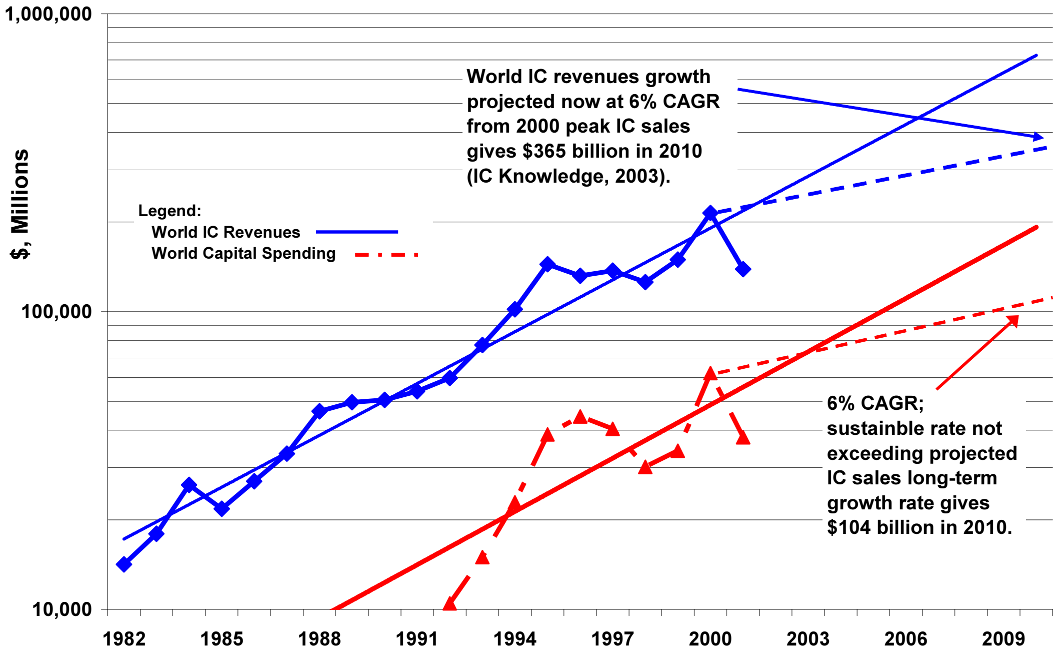

Figure 2. World IC revenues and capital spending: historical and projected (Source: IC Knowledge, 2003)

We used several publicly available sources for historical information about capital spending by country and region from which we estimated historical and future regional shares of world capital spending. For the historical period for the U. S., Japan, Taiwan, Europe and S. Korea we had two sets of information, each from a different source: (1) country total capital expenditures and (2) individual company totals by country (IC Knowledge, 2003; Deutche Bank, 2003). Country totals obtained by summing the company figures from the second set agreed with the totals from the first set within 90 percent across all five of these regions. For China, Singapore and Malaysia we had country totals but for different periods—1995-2003 for Singapore; 1996-2003 for China and 1998-2003 for Malaysia.

Table 1 provides the capital expenditures and corresponding shares of the world total for the countries and regions of interest for the historical years 1995 and 2000 as well as for future years 2005 and 2010. The figures in Table 1 for 2005 and 2010 (italicized), for five regions (U.S., Japan, Taiwan, Europe and South Korea), are simple extrapolations of capital expenditures using statistical relationships developed from the reported historical relationships between country or regional expenditures and the corresponding world total. Table 2 presents the best-fit parameters (and estimates of goodness-of-fit) for the logarithmic equation used to project capital expenditures for these five regions. The italicized figures for countries of the CMS region come from simple linear extrapolations of historical country shares of world totals. The logarithmic model for WSC members mathematically accounts for competition with the new CMS region and the slowing in WSC-member growth rates, while the linear model for CMS region provides a more conservative representation of the earlier years for the countries in the CMS region (and is therefore preferred for extrapolation). However, R^2 values for the historically-based linear equations varied between 0.80 (China) and 0.10 (Malaysia). Presumably, this wide variation occurs because of the variability in the relatively short-time series and small shares for these countries. When we used the CMS-share of world expenditures, which lengthened the record and increased the share amounts, we obtained an R^2 of 0.86.

Table 1. Actual and Projected (Base Case) Country Capital Spending and Share of World, by year ($MM)

	1995		2000		2005		2010	
Region/Country	**$, MM**	**%,World**	**$, MM**	**%,World**	**$, MM**	**%,World**	**$, MM**	**%,World**
WSC Members								
United States	12,615	33%	20,694	33%	*18,504*	*32%*	*25,150*	*25%*
Europe	2,810	7%	6,883	11%	*5,639*	*10%*	*8,339*	*8%*
Japan	13,158	34%	13,756	22%	*13,658*	*24%*	*20,229*	*20%*
Taiwan	2,285	6%	11,675	19%	*8,257*	*14%*	*11,885*	*12%*
S. Korea	4,616	12%	4,249	7%	*5,246*	*9%*	*6,604*	*7%*
Non- WSC								
China	0	0%	625	1%	*3,389*	*6%*	*9,573*	*9%*
Singapore	790	2%	1,600	3%	*1,741*	*3%*	*3,581*	*4%*
Malaysia	0	0%	1,050	2%	*1,068*	*2%*	*3,016*	*3%*
Other Total	2,426	6%	1,638	3%	*522*	*1%*	*12,500*	*12%*
WW Total	**38,700**		**62,170**		***58,023***		***100,878***	

Note: 1995 – 2000 values adapted from Deutsche Bank, Capital Spending by Company and Region, October 8, 2003. World share figures may not sum to 100% due to independent rounding. Italicized figures are from regression formulas and forecasted 2010 world capital spending of $100 billion (see Figure 2).

Table 2. Best-fit parameters (a and b) and goodness-of-fit (R^2) for estimating regional capital expenditures, y_r, from projected world capital expenditures using logarithmic equation, $y_r = a_r \ln w + b_r$, (r denotes region and w denotes world capital expenditures).

Region-country	a_r	$-b_r$	R^2
United States	12.65	31.95	0.71
Japan	11.56	34.27	0.81
Taiwan	8.83	26.00	0.87
Europe	6.22	18.85	0.75
S. Korea	3.80	10.09	0.53

When making these regional extrapolations of capital expenditures, we constrained *world* revenues from IC sales in 2010 to $365 billion, a figure consistent with world silicon demand in 2010, estimated by PEVM's extrapolation of VLSI Research's global demand projected for 2008 (see Figure 2). The result is that world capital expenditures for 2010 are projected at approximately $101 billion, 28 percent of the corresponding revenues (see Figure 2). World capital expenditures in 2005 are projected to be approximately $58 billion, up approximately 31 percent from recent forecasts of 2004 capital expenditures and consistent with IC revenues in 2005 of approximately $200-215 billion, near the record revenues of 2000 (see Figure 2) (Layne, 2004; Manners, 2004).

To translate capital spending into shares of world manufacturing capacity, we need a projected trajectory of annual capital spending over the period 2005-2010 for each region of interest. As noted previously, we use the annual capital spending share for each region to apportion the corresponding annual *change* in silicon consumption (for nodes <120 nm) to that region. In this way, each region's share of manufacturing capacity is, by the end of 2010 for nodes <120 nm, the accumulation of all increments from 2006-2010 divided by the corresponding accumulation of world silicon consumption. It follows then that a region's share of capital spending in 2010 will not equal its share of manufacturing capacity for nodes < 120 nm in 2010. Instead, a region's share of world manufacturing capacity for such nodes will equal its cumulative capital spending over the 2006-2010 period.

Foundry Impact Assessment Modeling

FIAM provides estimates of country/region shares of PFC world emissions.[3] It uses emissions factors and projected world silicon consumption to 2010—both from PEVM and both functions of technology—to estimate uncontrolled world emissions. Using the methods described in the previous sections, FIAM calculates region-specific shares of capacity, which it then uses to apportion uncontrolled world emissions into the corresponding region-specific shares of emissions.

FIAM is designed to handle alternative scenarios that describe alternative capital spending, silicon consumption or both, among the regions of interest and over time. In addition to the base case scenario described in the previous section, several alternatives were analyzed. Two examples are described in the next section.

Scenarios—A Base Case and Two Alternatives

We seek to capture this expansion in capacity (and its concomitant increase in uncontrolled emissions) by assuming that that expansion is concentrated, as described previously, in small linewidth process technology (i.e., technology nodes less than 120 nm). Therefore, a region's share of world manufacturing capacity in 2010 for the <120 nm technology node equals its cumulative capital spending over the 2006-2010 period (i.e., all 2010 investments will affect linewidths <120 nanometers).

Our approach for developing alternative scenarios does not try to model either the global or regional economic factors that influence the where-or-when of capacity additions. Instead, we use projections of silicon demand as well historical trends of capital expenditures and reports of industry trends for our regions of interest as "guides" of future spending among current WSC member and non-member regions. In this way, we define alternative (changes in) spending patterns (in both rate and location) that are consistent with those of our guides. We simply assert that these alternatives are potential alternative scenarios for purposes of our analysis.

Of the three scenarios presented here, the first is a base case. The capital expenditure figures presented earlier (in Table 1) reflect this base case, and result in the geographical distribution of manufacturing capacity (at the <120 nm technology node) in 2005 and 2010 as shown in Figure 3. Note Japan's two-fold increase in manufacturing capacity for these nodes from 2005 to 2010. While Taiwan and S. Korea show falling technology-specific manufacturing capacity, the corresponding world capacity shares for China,

[3] Countries/regions modeled in FIAM include the United States, Japan, Europe, Taiwan, South Korea, China, Singapore, Malaysia, and Rest-of-World.

Malaysia, and Singapore (the CMS group) can be expected to grow from insignificant proportions to approximately 15 percent of world capacity by 2010.

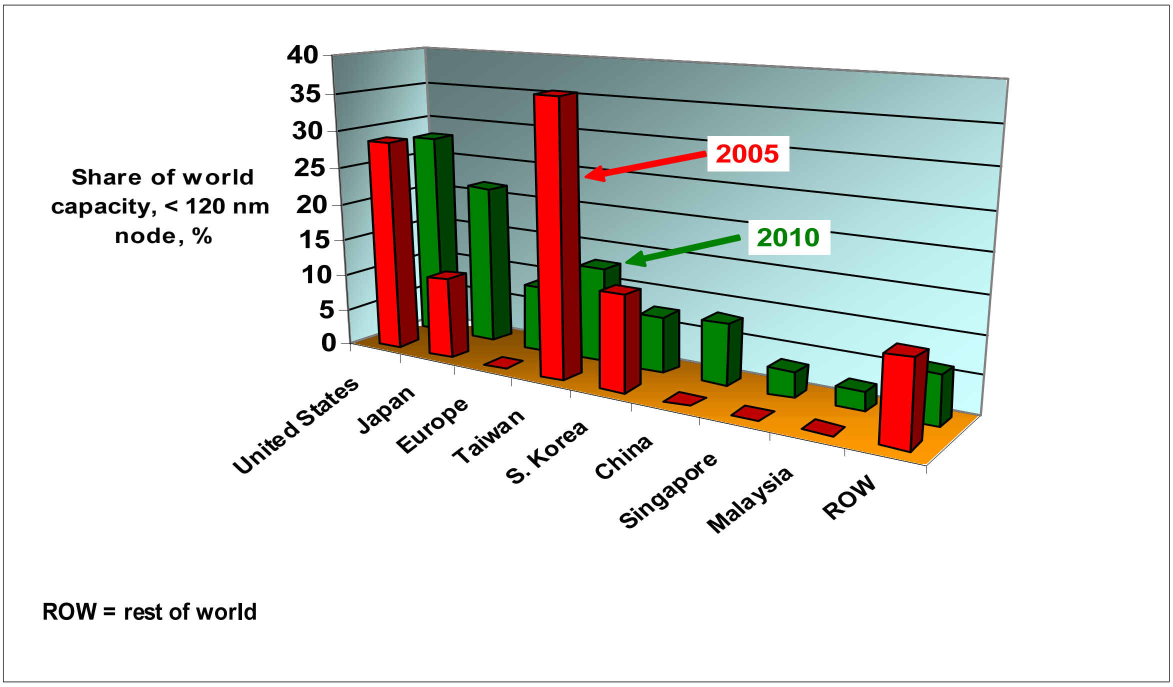

Figure 3. Projected country shares of world manufacturing capacity for technology nodes <120 nm in 2005 and 2010 using annual capital spending shares as a proxy for annual capacity additions (see Table 1 for capital spending shares).

The distribution of world capital expenditures in 2010 is presented for three scenarios in Table 3. For ease of discussion, the two alternative scenarios are summarized together with the base case (Scenario 1).

Table 3. 2010 Capital Spending by Scenario and Country and WSC Membership, $MM

Region	Scenario 1		Scenario 2		Scenario 3	
	Million $	Percent	Million $	Percent	Million $	Percent
WSC	72,207	72%	64,986	64%	72,207	62%
United States	25,150	25%	25,150	25%	14,441	12%
Japan	20,229	20%	18,063	18%	10,831	9%
Europe	8,339	8%	7,617	8%	3,610	3%
Taiwan	11,885	12%	8,996	9%	25,272	22%
Korea	6,604	7%	5,159	5%	18,052	16%
Non-WSC	28,671	28%	35,892	36%	43,671	38%
China	9,573	9%	21,355	21%	27,949	24%
Singapore	3,581	4%	4,576	5%	3,494	3%
Malaysia	3,016	3%	4,576	5%	3,494	3%
ROW[1]	12,500	12%	5,384	5%	8,734	8%
Total	100,878	100%	100,878	100%	115,878	100%

[1] Denotes Rest of World

For Scenario 2 (a redistribution scenario), world capital spending is held to the base case levels but the total is redistributed, shifting capital spending from certain WSC members to non-WSC members – specifically the CMS region – with China assumed to be the area of largest growth. Scenario 2 is intended to reflect continued incremental success of the fabless-foundry model as well as opportunities in China. Scenario 2 also fixes the U. S. and Europe shares of world capital spending to those in scenario 1 (base case) and allows the shares of world capital spending for Japan, Taiwan and S. Korea to drop as the share of world spending in CSM region is increased.

In Scenario 3, a high-growth case scenario, world capital spending in 2010 is increased by approximately 15 percent, to $116 billion (with all of the increase assigned to China). Accompanied with this increase are reductions in shares of capital spending for the U. S., Japan and Europe. Scenario 3 is intended to reflect an acceleration of the fabless-foundry mode and opportunities that China would experience as a major player in this increasingly successful business model.

It is informative to compare the levels of capital spending in 1995 for WSC members with the corresponding figures for our three scenarios in 2010. In 1995 capital spending across WSC member countries accounted for 92 percent of the global total (see Table 1, 33% + 7% + 34% + 6% + 12% = 92%). By 2010 that share is projected to drop to 72 percent under Scenario 1 and possibly as low as 62 percent in Scenario 3 (see Table 3). The effects of these shifts on associated emissions and reduction commitments are discussed in the following section.

Results and Findings

FIAM produces the impact on PFC emission levels of each of several alternative region- and country-specific industry growth scenarios. By this study's design, the projected and uncontrolled global emissions for 2010 are static across all scenarios and equal to 34.51 MMTCE (Burton, 2004a). Shares of global capital expenditures are used as a proxy in distributing these global emissions but are assumed by definition not to affect the level of emissions. FIAM's projected 34.51 MMTCE represents a 5-fold increase from the 1995 worldwide emissions level, 7.1 MMTCE, and does not include any emission reduction that may result from voluntary actions. We therefore call this baseline projection business-as-usual. Within this global baseline, regional shares differ according to the scenarios presented above, and the resulting emissions breakdowns are shown in Table 4 below.

Table 4. PFC Emissions by Region 1995 – 2010 and Future Reduction Requirements to Meet WSC Goal

	1995	2000	2005	2010 (Scenario 1)			2010 (Scenario 2)			2010 (Scenario 3)		
Region	MMTCE	MMTCE	MMTCE	MMTCE	World %	Goal	MMTCE	World %	Goal	MMTCE	World %	Goal
WSC	6.34	9.46	13.63	27.95	81%	80%	27.06	78%	79%	24.93	72%	77%
US	1.48	2.26	3.39	8.47	25%	84%	8.47	25%	84%	5.71	17%	77%
Japan	3.62	4.18	4.46	7.85	23%	59%	7.58	22%	57%	5.65	16%	42%
Europe	0.55	1.18	1.19	2.75	8%	82%	2.66	8%	82%	1.71	5%	71%
Taiwan	0.29	1.05	3.06	5.84	17%	95%	5.49	16%	95%	7.41	21%	96%
Korea	0.41	0.79	1.53	3.04	9%	88%	2.86	8%	87%	4.44	13%	92%
Non-WSC	0.78	1.25	3.08	6.56	19%	NA	7.44	22%	NA	9.58	28%	NA
China	0.10	0.20	0.99	2.32	7%	NA	3.56	10%	NA	5.13	15%	NA
Singapore	0.18	0.21	0.54	1.22	4%	NA	1.20	3%	NA	1.16	3%	NA
Malaysia	0.00	0.00	0.14	0.61	2%	NA	0.73	2%	NA	0.69	2%	NA
ROW	0.49	0.84	1.40	2.41	7%	NA	1.95	6%	NA	2.61	8%	NA
Total	7.12	10.71	16.71	34.51	100%	NA	34.51	100%	NA	34.51	100%	NA

In the 1995 base year, the WSC-member countries' share of aggregate PFC emissions is 89 percent; the remaining 11 percent of world emissions then results from manufacturing in non-WSC-member countries. However, under the base Scenario 1, reflecting the regression-determined pattern of regional spending of world capital with increasing shares of manufacturing and emissions going to foundries located in non-WSC countries, total emissions in non-WSC member countries account for 19 percent of world emissions in 2010. Thus Scenario 1—the most conservative of the three estimates shown—shows non-WSC countries almost doubling their share of world PFC emissions from 1995 to 2010. The third scenario, which further assumes increased investment in non-WSC countries and a substantial shift in global production to foundry fabs in the CMS region, especially China, shows their share climbing as high as 28 percent.

If U.S. fab activity were to remain constant at year 2000 levels (an assumption that we have not made in this analysis but do make here for comparative purposes), U. S. PFC emissions from semiconductor manufacture would reach 10.1 MMTCE by 2010 (Burton, 2004b). In the 2010 PFC Reduction Goal agreement as outlined in the ITRS, members of the WSC established a goal to reduce global PFC emissions from the semiconductor manufacturing industry to a level equal to 90% of 1995 year emissions (or 90% of 1.48 = 1.3 MMTCE) by 2010. Accounting for this voluntary commitment, a 10.1 MMTCE baseline implies an emission reduction obligation of 8.8 MMTCE (= 10.1 – 1.3 MMTCE) for the U.S. For this (10.1 MMTCE) obligation to be achieved requires the application of measures that, on average, reduce emissions by 87 percent. A similar estimate (88 percent) has been reported previously (Burton and Beizaie, 2001; Burton and Bartos, 2002).

When this hypothetical case is compared to the alternative scenarios developed for this analysis (cf. Table 4), taking into account increased capital spending by non-WSC countries and corresponding geographical shifts in production, a decrease in the percent reduction required to attain the WSC reduction goal is evident. For example, under the first scenario, Table 4 shows the United States' reduction goal is 84 percent, less than the 87 percent noted above. The emission reduction obligation becomes 7.2 MMTCE (= 8.5 – 1.3 MMTCE). In the high-growth alternative, Scenario (3), the reduction requirement for the United States drops to 77%. The corresponding obligation is 4.4 MMTCE (=5.7 – 1.3 MMTCE), 56 percent below the obligation expected in 2000.

The effect of moving production among and from WSC members is further illustrated in Figure 4. The figure shows the pattern of total PFC emissions (in MMTCE) by region for 1995, 2000, 2005 and 2010 (for each scenario). The top four, darker colored, regions denote non-WSC regions while the bright red, orange, yellow, green, and blue represent the WSC members; the horizontal dashed line denotes the aggregate 2010 emissions target for all fabs located in regions that currently are members of the WSC.

The influence on emissions of shifting production to non-WSC member regions is clear. Unless WSC-membership expands to include China, Singapore, Malaysia and most of the rest of the world, aggregate emissions from semiconductor manufacturing in 2010 would appear headed towards higher levels than what was probably envisaged when the WSC goal was formally established in 2000.

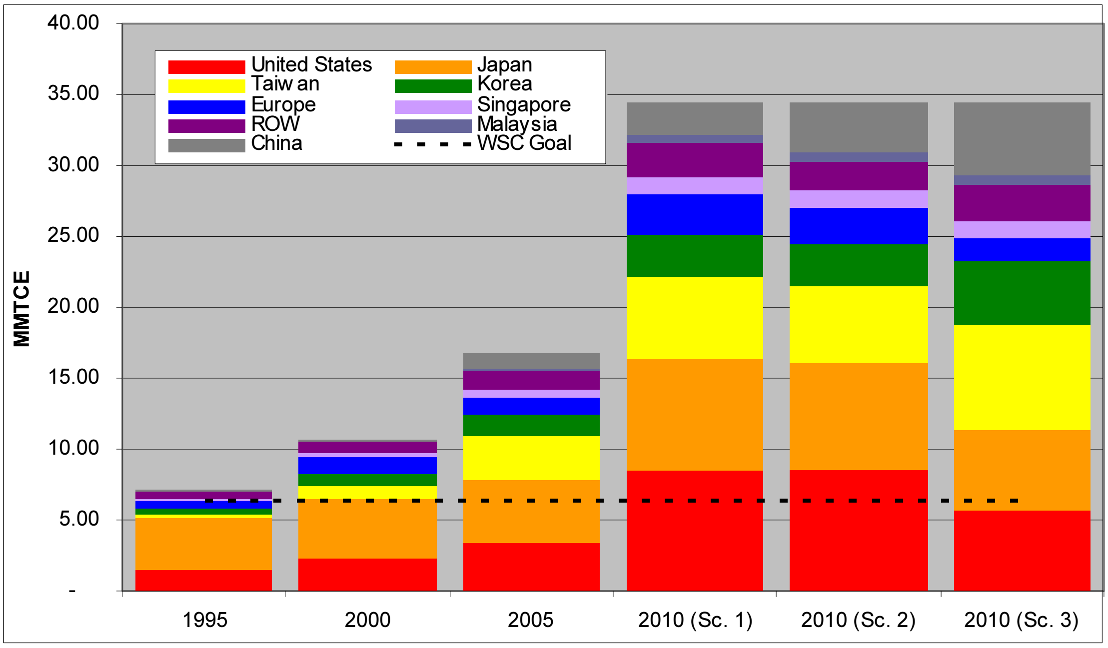

Figure 4. Regional emissions for WSC and non-WSC member regions for 1995, 2000, 2005 and 2010 for Scenarios 1 – 3. Dashed line denotes nominal 2010 WSC emission target.

Implications

The previous section begins to answer the first of our initial research questions. In all three of the 2010 scenarios presented in Table 4, a share of the burden for reducing emissions has been lifted from the United States (and from other WSC countries as well, second-most notably Japan). As a consequence, a portion of the U.S.'s reduction goal is satisfied through the production migration that industry analysts expect to continue. As more capital spending for new manufacturing capacity and technology shifts from WSC-member regions to non-WSC member regions, WSC member shares of emissions drop, as do the emission reductions required to achieve the WSC goal by 2010.

However, if the WSC goal is a commitment among members to reduce worldwide emissions to a particular level (as is the public perception), it cannot be assumed by parties to the agreement that the goal will be achieved as this analysis suggests. While the United States, for example, might expect to face – in 2010 – a challenge less daunting than that expected when the reduction goal was originally drafted (as described above), the end result of meeting that *country-specific* goal will not effectively address escalating total global emissions (i.e., it will only address the declining portion of emissions that *originates* in the United States).

It seems ill-advised for parties to the WSC goal to assume that, because production migrates to the CMS region (or elsewhere), emission reduction efforts to attain the goal will also take place there. Rather, at present, it would seem prudent to assume that mitigation efforts will not take place in non-WSC member countries. Because we choose not to entertain the scenario in which uncontrolled emissions continue to rise, this leaves open two alternatives for discussion: one in which the current WSC member countries claim responsibility for reducing global emissions, thus making larger commitments; and a second in which current non-member countries join the WSC and make emission reduction commitments. These are discussed below, and will answer the second and third of our initial questions.

Along with the reduced commitment requirements in the United States, however, comes a doubling of emissions in China, a non-WSC country, as well as increases throughout the non-WSC world. Whether global reductions will, in fact, take place is dependent in large part either upon action in those countries in which emissions rise because of an increased share of production or upon the unlikelihood of assumed responsibility for these "displaced" emissions by WSC member countries. The answer to this question, largely unknown, will determine the level of emissions in 2010; global emissions in 2010 will likely exceed the level contemplated when the WSC goal was established if a large – and growing – portion of the semiconductor manufacturing industry does not participate in the voluntary commitment. In fact, as illustrated below, WSC member countries will be entirely unable to sustain the 2010 PFC reduction goal without the participation of non-members.

If parties to the WSC emission reduction goal were to share the responsibility of limiting global emissions by 2010 to 10% below their 1995 levels (i.e., to 5.7 = 0.9 x 6.34 MMTCE, or 83 percent below the 2010 world baseline emissions figure of 34.5), it would require emission reductions in 2010 of greater than 100 percent of the baseline for all WSC member countries.

Table 5. Capacity-Weighted Shares of Global PFC Emission Reduction Goal among WSC Member Countries

	2010 (Scenario 1)			2010 (Scenario 2)			2010 (Scenario 3)		
	MMTCE	WSC %	Reduction	MMTCE	WSC %	Reduction	MMTCE	WSC %	Reduction
WSC	27.95	100%	28.8	27.06	100%	28.10	24.93	100%	28.10
US	8.47	30%	8.73	8.47	31%	8.80	5.71	23%	6.44
Japan	7.85	28%	8.09	7.58	28%	7.87	5.65	23%	6.37
Europe	2.75	10%	2.84	2.66	10%	2.77	1.71	7%	1.93
Taiwan	5.84	21%	6.02	5.49	20%	5.70	7.41	30%	8.35
Korea	3.04	11%	3.13	2.86	11%	2.97	4.44	18%	5.01
Non-WSC	6.56	NA	NA	7.44	NA	NA	9.58	NA	NA
Total	34.51	100%	83%	34.51	100%	83%	34.51	100%	83%

Because this illustrative situation assumes that – even while production and emissions increase in non-WSC member countries – members will assume the additional burden of achieving their 2010 global target without the participation of non-members, each of them takes on a disproportionate share of the global reductions required. Note that in all three scenarios shown in Table 5, the reduction column shows that each country's share of the worldwide emission reduction commitment exceeds that country's 2010 baseline emissions.

Having thus determined that, given current trends, the reductions required of member countries to achieve the 2010 goal are unattainable without the participation of current non-member countries, it becomes necessary to consider the substantial opportunities for emission reductions that exist in countries such as China, Malaysia, and Singapore.

Whereas the WSC member regions' share of world emissions was 89 percent in 1995, this figure is expected to drop substantially as production migration continues. In fact, as shown in the 2010 chart below, non-WSC members might be expected to emit as much as 28% of world emissions (under high-growth Scenario 3).

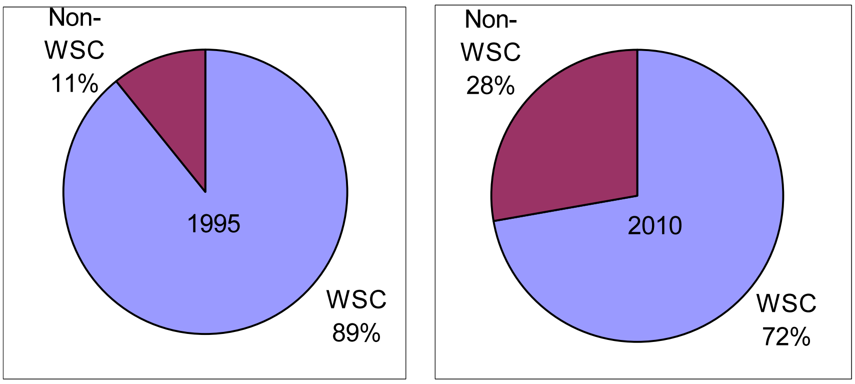

Figure 5. Non-WSC member countries increasingly contribute a significant share of global PFC Emissions from semiconductor manufacturing.

The results discussed thus far suggest that fabs in China, Singapore and Malaysia, representing the overwhelming majority of non-WSC production and emissions in all cases, should all become parties to the WSC emission reduction goal in order for the share of uncontrolled emissions to remain at the levels expected when the WSC goal was formally established in 2000. Because the Chinese industry has the capacity to emit five times more than the second-largest non-WSC producer (Singapore), it seems a priority to encourage Chinese participation in global emission reduction partnership efforts.

While Chinese participation is important, perhaps even necessary, in seeking to achieve the WSC goal, it cannot realistically be expected that China (or Malaysia, or Singapore) will ever achieve levels lower than their own 1995 emissions. To do so would place a disproportionate share of the global reduction burden on these countries. Bearing in mind that most non-WSC countries had little or no emissions from semiconductor manufacturing in 1995, this year is not a practical reference. A different base year is needed—one chosen, perhaps, with the aim that percentage emission reduction requirement by 2010 for new members approximates the corresponding reduction of charter members.

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