TECHNOLOGY TRANSFER AND CLIMATE CHANGE: INTERNATIONAL FLOWS, BARRIERS AND FRAMEWORKS

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(DRAFT 1)

ABSTRACT:

The purpose of the paper is to advance understanding of the issues associated with international technology transfers for addressing climate change, and to clarify and expand the international negotiating agendas at the intersections of climate change issues with trade and investment issues. Compared with the currently dominant paradigm that emphasizes North-South technology transfers and financial flows, the paper presents an alternative paradigm that includes developing countries as sources as well as recipients of international technology transfers. The new paradigm thus incorporates a more expansive global representation of the geography of technology flows. The paradigm also includes a focus on different international institutional frameworks for facilitating the flows and reducing the barriers to them, especially institutions and barriers involving trade and foreign direct investment. Further, the paradigm takes into account the important role of multinational firms as both facilitators and inhibitors of technology transfers. Empirically, the paper examines the flows and barriers that can inhibit them. The paper suggests an expanded international negotiating agenda, including the joint agenda of the post 2012 climate regime and the trade-investment regime.

[1] This paper reports the results of an on-going project concerning international technology transfers for climate change mitigation or adaptation. Much of that work has been and continues to be conducted in cooperation with the Centre for European Policy Studies (CEPS) in Brussels, where Christian Egenhofer is Director of the Energy and Climate Change Programme.

I - Themes and Structure of the Paper

Discourse concerning international technology transfers to address climate change issues is typically based on a paradigm that is focused on North-South technology flows and financial flows, especially in the context of official development assistance programs or offset projects under the Clean Development Mechanism of the Kyoto Protocol. This paradigm is useful for many analytic and negotiating agendas. However, it reflects an overly narrow conceptualization of the nature, sources and methods of international technology transfers. It thus neglects important issues that need to be addressed in order to utilize more fully the potential of international technology transfers for climate change mitigation and/or adaptation.

This paper proposals an alternative paradigm that emphasizes the importance of trade and foreign direct investment as the principal mechanisms by which technology is transferred internationally. The paradigm reflects diversity in the geography of technology flows, a different focus on the types of international economic flows that facilitate technology transfers, a different set of barriers to international technology flows, and different institutional frameworks that can facilitate or impede technology flows.[2] The paper is therefore responsive to the conference themes that emphasize issues at the intersection of climate change issues and international trade and investment issues.

Section 2 of the paper presents the paradigms in a more detailed and comparative discussion. Section 3 considers evidence about the geography of international technology flows, with an explicit recognition of developing countries as sources of such flows. Section 4 analyzes evidence about the barriers to international technology flows. Section 5 breiefly describes the international institutional frameworks affecting the flows. Section 6 discusses the implications for international negotiations.[3]

II - Paradigms of International Technology Transfer

Notions of Technology

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[2] Barton (2007) has also noted a shift in paradigms of technology transfer more generally - from a paradigm focused on licensing and intellectual property rights to a paradigm focused on foreign direct investment.
[3] Further empirical work on the geographic patterns of flows and the barriers to them is on-going as a project with the Centre for European Policy Studies (CEPS) in Brussels.

The two paradigms are based on a similar notion of "technology," as follows: The term "technology" continues to be used in common parlance to refer mostly to tangible goods, for instance computer hardware, but it is typically used in the academic literature to include more intangible elements of organizations' activities as applied knowledge or know-how. Further, the term is used to include managerial know-how, not only in the engineering of production processes, but also more generally in management processes.

Over time, the literature on international technology transfers has progressed from a relatively narrow definition of technology as "scientific and engineering knowledge …, which … are principally the outcome of R&D. The transfer of this codified knowledge … constituted technology transfer" in the earlier narrow notion of technology (Cantwell, 2001; 434). Current notions of technology, however, include a second notion as well – technology as tacit knowledge that is embedded in firms' procedures and personnel. While the first conceptualization leads to an analytic focus on explicit knowledge concerning specific products and their associated production processes, the second conceptualization leads to a focus on the capabilities and processes of firms, especially the tacit knowledge that is embedded in them. This encompassing notion of technology that includes both its "soft" and "hard" manifestations is now widespread in government policymaking and business strategy circles as well academic circles.

Relevant Technologies for Climate Change Mitigation or Adaptation

There are numerous lists of industries and products (both goods and services) related to climate change.[4] A well-known list was developed by Pacala and Socolow (2005) on the basis of the 15 "wedges" they identified as having the potential to contribute 1 gtCO2e reduction per year by 2054 (see Table 1). The UNFCCC (2006) has presented a lengthy list, as presented in Table 2.

There are yet other lists. An EU-US list of manufactured goods concerning trade issues related to climate change was the basis for a proposal to eliminate tariffs on them

[4] When identifying technologies in terms of standardized product or industry classification schemes, such as the Harmonized System (HS) of the World Customs Union, or the International Standard Industrial Classification system or the UN Product Code, there are a variety of technical issues, which can be important in negotiations. These and related issues have been raised recently, especially in regard to international technology transfer and thus trade issues (see Howse, 2006; OECD, 2006; Sugathan, 2006; World Bank, 2007). Furthermore, at the WTO, classification issues are different for goods and services because the agreement on goods (GATT) and the agreement on services (GATS) use different product classification schemes (Brewer, 2007).

through negotiations at the WTO (see World Bank, 2008: Appendix 6).[5] Stern (2007: 259) provides a list of nine types of technologies that could reduce carbon emissions in the energy sector: efficiency, carbon capture and storage, nuclear, biofuel, combined heat and power, solar, wind, and hydro. An Environmental Technologies Action Plan developed by an advisory group of the European Commission (2003) includes 51 categories organized in a matrix based on two dimensions. One dimension is industry sector, for instance energy supply, while the other consists of a combination of: energy efficiency and renewables, carbon sequestration, hydrogen&fuel cells. The U.S. Climate Change Technology Program (2006) itemizes hundreds of technologies, which are listed in "current portfolios" and "future research directions." They are organized according to: end-use/infrastructure (e.g. transportation), energy supply (e.g. hydrogen), carbon capture-storage (e.g. geologic storage), non-CO2 GHGs (e.g. methane from landfills), measuring & monitoring capabilities (e.g. oceanic CO2 sequestration). A US International Trade Commission (US ITC, 2005) list of renewable energy goods was more narrowly focused. A list of technologies developed by Lehman Brothers (2007) includes: renewables (hydropower, geothermal power, wind, solar, ocean, and biomass), carbon capture and storage, integrated gasification combined cycle, and nuclear power. The World Bank (2006a: Box 4, page 10) has developed a list of technologies for energy production, supply and end use that includes many of the same technologies as the other lists.

The Technology Needs Assessments (TNAs) conducted in developing countries for the UNFCCC secretariat provide both much commonality and much variation in the kinds of technologies that are viewed as important. A summary of the reports for over 20 countries found that the following were among the "key technologies": "renewable energy for small-scale applications, such as biomass stoves; combined heat and power; and energy efficient appliances and building technologies such as compact fluorescent light bulbs. For transport, traffic management and cleaner vehicles for public transport were most important" (Stern, 2007: 564-565; based on UNFCCC, 2004). Additional technologies and variations among countries are evident in individual country reports. The top priorities for Ghana, for instance, included (Stern, 2007: 565; based on UNFCCC, 2004): industrial energy

[5] The U.S. is a net importer of the items on the list. In 2006, U.S. imports of them amounted to $18 billion, while exports were $15 billion (Schwab, 2007).

improvements (including boiler efficiency enhancement), methane gas capture from landfill sites, biofuels (from jatropha), and energy efficient lighting (compact fluorescent bulbs).

Some countries have developed extensive, industry-specific needs, which of course also vary across countries. Vietnam, for instance, lists ten quite specific GHG-reducing technologies that are needed in its cement industry - among them, "large vertical roller mill for raw material crushing,…vertical roller mill for coal crushing,…high-efficiency separator in the finishing process,… burning used tires as substitute for cement kiln…." As of April 2008, there were 39 country reports in various stages of completion, some of them extremely detailed; Indonesia's for instance was 299 pages long. Individually and collectively, they offer developing country perspectives that are in some respects quite different from those of the developed countries. Yet, at the same time, there are many similarities. See for instance, a summary table of "the promise of technology" in a UNFCCC report (2004: 63).

Although such lists tend to identify "new" or otherwise "alternative" technologies, it should not go unnoticed that "old" technologies are also relevant. For instance, turboprop aircraft engines are much more fuel efficient than jet engines. As a result, orders for medium-range turboprop planes are increasing substantially, particularly by airlines in Europe which have used such technology extensively for many years but had been replacing them gradually with jet planes. In the martime shipping industry, there is interest in a step "backward" to re-adapt the use of wind power on large merchant vessels by the use of large sails; a vessel thus equipped as a pilot project has recently made a long-distance ocean voyage.

Climate change *adaptation* technologies have not yet been so systematically or explicitly identified, nor have they been the subject of such extensive interest, compared with mitigation technologies. However, the UNFCCC (2006) has identified a diverse variety of technologies for adaptation, including for coastal zones, water supplies, agriculture and health (see Table 3).

The lists of mitigation technologies differ in their level of detail and hence technological specificity, and they also differ in whether they include or exclude nuclear power in particular. At an aggregate level, however, these lists share many of the same technologies, especially those concerning energy efficiency and renewable energy sources, which are the focus of this paper.

Beyond common notions of technology and an openess about the relevant technologies for mitigation and/or adapation, the two paradigms are quite different in their principal features.

PARADIGM I: NORTH-SOUTH TECHNOLOGY AND FINANCIAL FLOWS

The currently dominant paradigm is reflected in numerous documents produced over time in the implementation and negotiating processes of the UN Framework Convention on Climate Change (see Figure 1). Although there has been some increased institutional interest in South-South transfers (see e.g. South Africa, 2006), the predominant focus remains on North-South technology transfers and North-South financial transfers, particularly through bilateral and multilateral official development assistance (ODA) channels.

PARADIGM II: GLOBAL TECHNOLOGY, TRADE AND INVESTMENT FLOWS

As depicted in Figure 2, Paradigm II exhibits three key differences from Paradigm I: First, it reflects the fact that there are significant technology transfers among many groups of countries, including from developing countries to developed countries as well as to other developing countries, and of course among developed countries. Second, the technology flows occur as a result of trade and foreign direct investment flows.

Figure 3 provides a side by side verbal summary comparison of the two paradigms. Of course, the conceptualizations of Paradigm II are useful only in so far as they reflect empirically valid representations of reality and/or offer relevant policy prescriptions. Thus, the remaining sections of the paper turn to evidence concerning the flows, barriers to them, institutional frameworks, and then the policy implications.

III - PATTERNS OF INTERNATIONAL FLOWS

The data of Tables 4, 5 and 6 provide aggregate perspectives on key features of international investment flows. First, the relative magnitudes of official development assistance (ODA) flows remain quite small (which of course is a basis of the Paradigm I policy prescription for more ODA). Bilateral ODA and multilateral ODA in 2000 were respectively only 0.7 percent and 0.4 percent of total gross fixed capital formation in non-Annex I countries. Second, international direct investment and international debt are both on the order of hundreds of billions of dollars per year, compared with total ODA flows on the order of hundreds of millions.[6] Third, international investments are overwhelmingly flowing into Annex I countries, with non-Annex I countries receiving only about 9 percent of the total in 2000. Fourth, international flows are about one-third of total world gross fixed capital formation, compared with the two-thirds from domestic sources.[7]

The sectoral distributions are also evident in Tables 4, 5 and 6. For non-Annex I countries, in particular, the relative importance of FDI flows in mining; manufacturing; electricity, gas, and water; and transport, storage and communications is evident. Whereas FDI flows are between 9 percent and 18 percent in each of those sectors, is only 4 percent at most, and less than 2 percent in four of the five sectoral categories.

As for sustainable energy sectors, the data in Table 7 indicate that three industries have received most of the investment - wind (27 percent), biofuels (18 percent) and solar (11 percent). Other renewables and energy efficiency have received less than 5 percent each. Table 8 indicates the relative large proportions of world investment in sustainable energy that are being made in Europe and the US - which together accounted for about US$ 50 billion or two-thirds of the world total in 2006. China accounted for about US$ 6 billion and India about US$ 4 billion. Of course, future projections the geographic and sectoral patterns and trends are of special interest for the future of climate change mitigation and adaptation. These can be found in reports of the IEA/OECD (2006), UNFCCC (2007), the World Bank (2006b; 2007), and Cambridge Energy Research Associates (2008).

Developing Countries as Technology Sources, and South-South Transfers

Table 9 reveals that several developing countries are world leaders in a variety of key climate friendly technologies. They include not only China in numerous technologies (coal-gasification, compact fluorescent light bulbs, solar voltaic cells, and wind power), but also

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[6] There are numerous conceptual and empirical issues about the precision of data about FDI and other investment flows - issues which are beyond the scope of this paper. For present purposes, these data are useful as indicators of approximate relative magnitudes. Readers who are interested in detailed discussions of these data quality issues should consult the annual reviews of international direct investment by UNCTAD and world debt by the World Bank.

[7] Because some foreign direct investments are partially financed from local host country sources, the distinction between international and domestic sources, as revealed in balance of payments statistics, is not entirely accurate.

South Africa in coal-to-synfuels technologies, and Mexico in solar hot water heaters. As for biofuels, although recent studies have put into doubt the net GHG-reducing effects of ethanol, especially when made with US-produced corn, there is continuing interest in Brazil's world leadership in the production of ethanol using sugar cane, particularly if/when it does not involve destruction of rain forests to create the sugar plantations.

India is well known already for its wind power industry, as noted in more detail below. Its leadership in the use of jatropha tree berries as a second-generation feedstock for biodiesel production is less well known and still in its infancy; as Table 10 indicates, however, India has already been involved in numerous projects for transferring jatropha-based biodiesel technology to other developing countries, including Ghana, Indonesia, Mozambique, and the Phillipines.

Table 11 briefly describes several other examples of South-South transfers of climate change mitigating technologies based on case studies that are diverse in terms of countries as well as technologies (biogas digesters, bamboo fibre reinforced cement board, and ceramic cookstoves).

FOREIGN DIRECT INVESTMENT AND MULTINATIONAL FIRMS

Paradigm II not only includes technology flows emanating from non-Annex I developing countries - whether to other developing countries or to Annex I countries - it also posits that technology flows are typically embedded in the trade and foreign direct investment flows of firms, particularly large multinational firms. Some of these multinational firms - indeed an increasing number - are themselves based in developing countries.

Two such firms based in India are notable examples. One is Suzlon, which is a world leader in wind turbine and gearing technologies and has foreign subsidiaries and other affiliates in the US and several European countries, as well as China (see Box 1). The other Indian firm is Tata, the well-know diversified conglomerate with extensive business interests in energy, transportation and other climate relevant industry sectors. It has wholly-owned subsidiaries, joint ventures and other forms of international business relationships for R&D and manufacturing in more than two dozen countries (see Box 2).

Of course, there are many other large multinational firms with significant roles in the development and international dissemination of leading-edge technologies in the wind power industries and more generally in the energy sector, and they are mostly headquartered in Annex I countries. GE and Siemens are two well-known examples (see Boxes 3, 4 and 5).

What is especially noteworthy about them in the present context is that they both have extensive climate change related energy R&D activities in China and India.

More generally, all of these firms - Suzlon, Tata, GE and Siemens - illustrate a basic fact about international technology transfer: it takes place to a great extent within multinational firms' internationalized R&D and manufacturing processes, sometimes with collaborators from local host countries. In fact, the research-development-diffusion process for any one given technology often involves many firms in many countries.

Although these examples are large multinationals, it should not be assumed that large firms are the only important sources of technology innovation or international diffusion. Indeed, small and medium-sized firms are often the originators of new technologies and even the principal internationalizers of them. For instance, small and medium-size firms have been instrumental in the development of biodiesel technology in many countries. A current example is the development of hybrid biodiesel-electric pick-up trucks by firms in India and the US.

IV - Barriers to International Flows

One of the key features of multinational firms is that they sometimes engage in foreign direct investment as a strategic alternative to trade in order to circumvent tariffs and non-tariff barriers to imports in foreign markets.[8] Barriers to FDI are thus one important category of barriers to international technology transfers, in addition to tariff and non-tariff barriers to trade. Finally, multinational firms are themselves sometimes barriers to international technology transfers, as they try to protect their propriety technology by keeping it internalized within the firm. The tendency for multinational firms to resist international licensing agreements for fear their licensee will become a competitor is, of course, one of the rationales for governments to require a joint venture arrangement with a local firm as a condition of access to the local market through direct investment.

The nature, availability and quality of the evidence about these types of barriers to international technology transfer is highly variable. Tariff data on trade in goods are the most readily available and the most easily comparable across countries and over time because of the widely used Harmonized System developed by the World Customs Organization and

[8] A common definition of a multinational firm is that is a firm that has foreign direct investments in wholly-owned subsidiaries or other foreign affiliates in a certain number of countries. There are many other strategic objectives involved in FDI, including gaining access to technology.

used in World Trade Organization negotiations. Non-tariff barriers to trade in goods are more problematic to identify and measure, but they can be estimated in terms of their tariff-equivalents, as illustrated further below. Measuring the impact of barriers to international *service* transactions is yet more challenging because there is less consistency in the usage and categories of such transactions, though the WTO and UN both have classification systems. Finally, barriers to FDI are also difficult to identify and measure, though they are subject to annual reviews by UNCTAD in its *World Investment Report*.

Of these many forms of barriers to international technology transfer for climate change mitigation or adaptation, this paper considers tariffs - and to a lesser extent non-tariff barriers - as they pertain to trade in goods. Further research is under way to address questions concerning trade and investment in services.

Table 12 contains evidence about the tariff levels affecting the energy efficiency of buildings. It is clear that the tariff levels of the three non-Annex I countries (Brazil, India and Mexico) are generally higher than those of the Annex I countries (Canada, EU, Japan and US). Except for Canadian tariffs of 15.1 percent on walled insulating units of glass, in every instance the non-Annex I countries' tariffs are higher. Of course, these are not only obstacles to North-South technology transfers, they are also obstacles to South-South transfers.

Impediments to trade in climate friendly products among developing countries are more explicit in Table 13. The technologies and developing country sources of them are identified in the top two rows, and the levels of the tariff and non-tariff barriers to imports of them in five developing countries are indicated in the lower rows of the table. With few exceptions, the tariffs are in the two-digit range, and the non-tariff barriers expressed as tariff equivalents, are in the two to three digit range. Thus, there are substantial barriers to South-South technology transfer through trade in these climate friendly goods.

EU tariffs of as much as 57 percent on compact fluorescent light bulbs imported from China are an especially noteworthy and timely example of barriers to South-North trade in a climate friendly technology. Although justified on anti-dumping grounds and slated for recission in the fall of 2008, the tariffs have led to a precipitous decline in Chinese CFL exports to Europe and the concomitant collapse of numerous Chinese manufacturers.

US limits on tax credits for purchasers of hybrid fuel autos is an example of a barrier to North-North transfer of a climate friendly technology. The United States has imposed de facto, firm-specific quotas on the number of hybrid fuel automobiles produced by any one manufacturer that can receive a tax credit – quotas that happen to affect only Japanese-based manufacturers, since their hybrids are the best-selling models in the US.

Table 14 indicates for the wind energy industry that barriers to trade in services and to foreign direct investment, along with tariffs on trade in goods, can be significant obstacles to international technology transfers. Further, the types of products (whether goods or services) interact with the types of barriers (whether specially targeted, for defined products or generic across products).

V - International Institutional Arrangements

There is already a wide range of both climate change and trade-investment international institutional arrangements that affect technology transfers, and they exist at the bilateral, regional and plurilateral levels as well as the multilateral level (see Table 15). This analysis focuses on the multilateral institutions.

To date, the multilateral institutional arrangements for the climate regime manifest the emphases of Paradigm I on technology flows and financial flows from North to South. This is evident in particular of the work of the UNFCCC Expert Group on Technology Transfer (EGTT). The mandate of the EGTT is to facilitate the implementation of Article 4, paragraph 5 of the Convention: "The developed country Parties and other developed Parties included in Annex II shall take all practicable steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies and know-how to other Parties, particularly developing country Parties, to enable them to implement the provisions of the Convention. In this process, the developed country Parties shall support the development and enhancement of endogenous capacities and technologies of developing country Parties. Other Parties and organizations in a position to do so may also assist in facilitating the transfer of such technologies."[9] Similar emphases are evident in the Bali Action Plan (see Box 6).

There is, however, increasing interest in the nature and extent of technology transfers associated with CDM and JI projects (de Coninck, Haake, van der Linden, 2007),

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[9] The work of the EGTT is discussed in detail in UNFCCC (2006); its first work programme is summarized in UNFCCC (2002) and its most recent work programme is summarized in UNFCCC (2007). Its clearing house for technology transfer information is accessible at www.ttclear.unfccc.int.

and the effects of host country investment and regulatory policies on the features of such projects (Anger, Bohringer, Moslener, 2007).

The Global Environment Facility (GEF), the various carbon programs at the World Bank and the proposed new clean energy fund to be administered by the World Bank are also all important elements of the current multilateral system for funding technology transfers to developing countries. As they are all likely to become much larger in the next few years, they will become increasingly significant, and they can be used to leverage other funding sources. Yet, the amounts of funds are likely to remain small in relationship to the technology flows associated with trade and investment through private channels.

An implication of Paradigm II, of course, is that the international institutional arrangements for trade and investment are also relevant to international technology transfers for climate change mitigation and adaptation. A detailed analysis of the complexities of those arrangements would be far beyond the scope of this paper. However, it can be briefly noted that the coverage is highly uneven across products (goods or services), method of technology transfer (trade or FDI) and the geographic scope of the agreement (multilateral, plurilateral, regional, bilateral). At the WTO, in particular, the coverage of methods of technology transfer varies significantly between the GATT for goods and in the GATS for services (see Table 16). Further, because of the limited coverage of FDI in the WTO, the FDI provisions of regional and bilateral agreements are particularly important, and there are several hundred of them (WTO, 2008).

VI - Implications

Paradigm II implies the need for more attention to South-North and South-South and even North-North technology flows, as well as the traditional focus on North-South Flows. This increased attention should occur in government policymaking and international negotiations as well as in analytic exercises. In that context, the role in international technology transfers of multinational firms based in developing countries - and barriers to them - need to be examined more thoroughly.

The negotiating agendas in both the international climate change and trade-investment arenas also need to take into account the broad array of barriers to international technology transfers for climate change mitigation or adaptation. Multilateral and bilateral official development assistance levels need to be increased significantly. But that is not enough. For most technology transfers occur through private international trade and foreign direct investment transactions, and they encounter diverse barriers. Further, the barriers are in Annex I countries as well as non-Annex I countries.

This suggests at least one obvious basis for a division of labor in the emerging international institutional architecture for the joint climate-trade agenda: The UNFCCC, World Bank, and other international development institutions should continue to focus their efforts on North-South financial flows and capacity building in developing countries to enhance technology transfers. At the same time, the WTO and other trade-investment institutions should substantially increase their efforts to reduce barriers to trade and foreign direct investment in climate related technologies. These efforts should include barriers in Annex I countries as well as non-Annex I countries. Further, the efforts should be undertaken with a recognition that barriers in non-Annex I countries are barriers to the exports and foreign direct investments from other non-Annex I countries as well as Annex I countries.

At the multilateral level, these efforts can be conducted largely on parallel tracks - one involving the international climate change and international development institutions, the other involving the international trade-investment institutions. However, there should be a more formalized liaison established between the two sets of institutions. This could be done through many institutional arrangements, for instance a climate-trade liaison committee that includes the UNFCCC, UNEP, WTO and World Bank.

There is, however, a much more complex and challenging problem in the current array of bilateral, regional and plurilateral, as well as multilateral, institutional arrangements. The newly-formed international institutional arrangements for climate change in addition to the already existing ones for trade and investment have created a "system" that is doubly fragmented as far as the joint climate-trade agenda is concerned. Some of the bilateral, regional and plurilateral arrangements might be justified on administrative and economic grounds as well as domestic and international political grounds. However, there are daunting analytic and policymaking challenges in trying to integrate them into the new international institutional architecture that will likely continue to have a wide array of multilateral climate, trade-investment and financial institutions at their center.

In any case, one hopes that such institution-building efforts will take into account the realities and policy implications represented by both Paradigm I and Paradigm II.

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Table 1. Summary of List of Technologies for Climate Change Mitigation Developed by Pacala and Socolow*

End-user efficiency and conservation
- (1) Increase fuel economy of automobiles
- (2) Reduce automobile use by telecommuting, mass transit, urban design
- (3) Reduce electricity use in homes, offices and stores

Power generation
- (4) Increase efficiency of coal-fired power plants
- (5) Increase gas baseload power (reduce coal baseload power)

Carbon capture and storage (CCS)
- (6) Install CCS at large, baseload coal-fired power plants
- (7) Install CCS at coal-fired plants to produce hydrogen for vehicles
- (8) Install CCS at coal-to-synfuels power plant

Alternative energy sources
- (9) Increase nuclear power (reduce coal)
- (10) Increase wind power (reduce coal)
- (11) Increase photovoltaic power (reduce coal)
- (12) Use wind to produce hydrogen for fuel cell cars
- (13) Substitute biofuels for fossil fuel

Agriculture and Forestry
- (14) Reduce deforestation, increase reforestation & afforestation, add plantations
- (15) Increase tillage conservation in cropland

* The estimated quantities of each technology required for a "wedge" have been omitted in this summary in order to focus attention in the context of this paper on the *types of technologies* rather the amounts of them needed to meet a specific goal.
Source: Socolow and Pacala (2006: 52) and Pacala and Socolow (2004: Table 1, page 4).

Table 2. Types of GHG Emission Reducing Technologies

Reducing emissions from energy supply and infrastructure

Low emission, fossil-based power and fuels

- Zero-emission power, hydrogen, and other value-added products
- High-efficiency coal/solid feedstock
- High-efficiency gas fuel cell/hybrid power systems

Hydrogen

- Hydrogen production from nuclear fission and fusion
- Integrated hydrogen energy systems
- Hydrogen production
- Hydrogen storage and distribution
- Hydrogen use
- Hydrogen infrastructure safety

Renewable Energy Fuels

- Wind Energy
- Solar photovoltaic power
- Solar buildings
- Concentrating solar power
- Biochemical conversion of biomass
- Thermochemical conversion of biomass
- Biomass residues
- Energy crops
- Photoconversion
- Advanced hydropower
- Geothermal energy

Nuclear

- Existing plant research and development
- Next-generation fission energy systems
- Near-term nuclear power plant systems
- Advanced nuclear fuel cycle processes
- Nuclear fusion

Energy infrastructure

- High-temperature superconductivity
- Transmission and distribution technologies
- Distributed generation and combined heat and power
- Energy storage
- Sensors, controls and communications
- Power electronics

Reducing emissions from energy use
Transportation

- Light vehicles-hybrids, electric, and fuel cell vehicles
- Alternative-fuelled vehicles
- Intelligent transportation systems infrastructure
- Aviation
- Transit buses-urban duty-cycle

Buildings

- Building equipment, appliances and fighting
- Building envelope (insulation, walls, roof)
- Intelligent building systems
- Urban heat island technologies

Industry
Energy conversion and utilization

- Resource recovery and utilization
- Industrial process efficiency
- Enabling technologies for industrial processes

Enhancing capabilities to measure and monitor emissions

- Hierarchical measuring and monitoring systems
  - For energy efficiency
  - For geologic carbon sequestration
  - For terrestrial carbon sequestration
  - For ocean carbon sequestration
  - For other greenhouse gas

Reducing the climate effect of non-carbon-dioxide greenhouse gas
Methane emissions from energy and waste

- Anaerobic and aerobic bioreactor landfills
- Conversion of landfill gas to alternative uses
- Electricity generation technologies for landfill gas
- Advances in coal mine ventilation air systems
- Advances in coal mine methane recovery systems
- Measurement and monitoring technology for natural gas systems

Methane and nitrous oxide emissions from agriculture

- Advanced agriculture systems for nitrous oxide emission reduction
- Methane reduction options for manure management
- Advanced agriculture systems for enteric emissions reduction

Emissions of high global-warming potential gasses

- Semiconductor industry; abasement technologies

- Semiconductor industry: substitute for processes producing gases with high global warming potential
- Semiconductor and magnesium: recovery and recycle
- Aluminum industry: perfluocarbon emissions
- Electric power systems and magnesium: substitute for SF_e
- Supermarket refrigeration: hydrofluorocarbon emissions

Nitrous oxide emissions from combustion and industrial sources

- Nitrous oxide abatement technologies from nitric acid production
- Nitrous oxide abatement technologies for transportation

Emissions of troposheric ozone precursors and black carbon

- Abatement technologies for emissions for tropospheric ozone precursors and black carbon

Source: UNFCCC (2000:63)

Table 3. Illustrative Technologies for Climate Change Adaptation

Coastal Zones:
Hard structures-dykes, sea walls, tidal barriers, detached breakwaters
Soft structures-dune or wetland restoration or creation, beach nourishment
Indigenous options- walls of wood, stone or coconut leaf, afforestation

Water Supplies:
Increase reservoir capacity
Desalinate
Improve soil conservation

Agriculture:
Change tilling practices
Build windbreaks
Line canals with plastic films

Health:
Early warning systems for heat waves
Improved public transport

Figure 1. Paradigm I: North-South Technology and Financial Flows

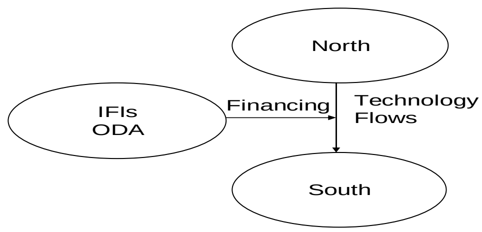

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Figure 2. Paradigm II: Global Technology, Trade and Investment Flows

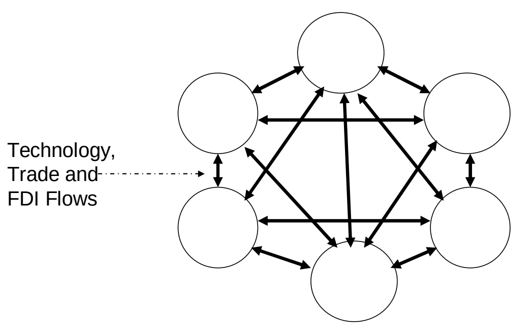

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Figure 3. Summary Comparison of Paradigms

Elements of Paradigms	**Paradigm I** North-South Technology and Financial Flows	**Paradigm II** Global Technology, Trade and Investment Flows
Flows: Geography	North-to-South	South-North South-South North-North North-South
Flows: Units of Analysis	Countries' financial flows	Firms' trade and investment in goods and services
Barriers	Technological-adminstrative capacities and IPR policies in developing countries	Trade and investment policies in all countries
Institutional Frameworks	International development banks and bilateral official development assistance	Multilateral, regional and bilateral trade and investment arrangements

Table 4. Sources of Global Investment in Gross Fixed Capital Formation

Sectors	FDI Flows %	International Borrowing %	Bilateral ODA %	Multilateral ODA %	Domestic %	Total GFCF USD bil
All sectors	17.9	17.2	0.1	0.1	64.7	7750
Ag, hunting, forest, fish	1.0	5.4	0.3	0.2	93.1	175
Mining	33.2	0.2	0.2	0.4	66.4	139
Manufacturing	22.1	6.0	0.0	0.0	71.9	1301
Electricity, gas, water	12.2	16.4	1.7	0.9	68.8	257
Transport, storage, com	16.7	16.8	0.5	0.4	65.5	889

Source: Excerpted by the author from UNFCCC (2007: Tables 35.1-31.7)

Table 5. Sources of Investment in Gross Fixed Capital Formation in Annex I Countries (2000)

Sectors	FDI Flows %	International Borrowing %	Bilateral ODA %	Multilateral ODA %	Domestic %	Total GFCF USD bil
All sectors	12.5	19.4	0.0	0.0	68.1	6014
Ag, hunting, forest, fish	0.0	8.9	0.0	0.0	91.1	104
Mining	0.8	0.3	0.0	0.0	98.9	68
Manufacturing	NA	NA	NA	NA	NA	858
Electricity, gas, water	0.0	18.5	0.0	0.0	81.4	186
Transport, storage, com	0.3	22.2	0.0	0.0	77.5	630

Source: Excerpted by the author from UNFCCC (2007: Tables 35.1-31.7)

Table 6. Sources of Investment in Gross Fixed Capital Formation in Non-Annex I Countries (2000)

Sectors	FDI Flows %	International Borrowing %	Bilateral ODA %	Multilateral ODA %	Domestic %	Total GFCF USD bil
All sectors	10.2	3.8	0.7	0.4	85.0	1654
Ag, hunting, forest, fish	1.7	0.2	0.8	0.5	96.9	68
Mining	17.8	0.0	0.4	0.1	98.9	69
Manufacturing	15.3	0.5	0.1	0.0	84.1	443

Electricity, gas, water	12.6	5.8	0.6	3.3	77.7	67
Transport, storage, com	8.9	1.5	1.7	1.4	86.43	248

Source: Excerpted by the author from UNFCCC (2007: Tables 35.1-31.7)

Table 7. Global Investment in Sustainable Energy by Technology (2006) - USD billions

Biofuels	18.2
Biomass and Waste	6.8
Solar	11.2
Wind	27.0
Other Renewables	3.1
Energy Efficiency /Other Low Carbon	4.6
Total	70.9

Source: UNEP (2007: Figure 5)

Table 8. Global Investment in Sustainable Energy by Region (2006) - USD billions

US	22.5
EU 27	27.1
Other OECD	6.3
China	6.1
India	3.7
Africa	0.2
Latin America	2.6
Other Developing	2.4
Total	70.9

Source: UNEP (2007: Figure 9)

Table 9. Climate Friendly Industries/Products in which Developing Countries are among the World's Leaders

Industries/Products	Developing Countries that are Leaders
Biofuel (ethanol)	Brazil (sugar-cane feedstock and refining processes)
Biofuel (biodiesel)	India (jatropha, next generation feedstock)
Coal gasification	China
Coal-to-synfuels	South Africa
Coal to hydrogen	China
Coal	Mexico
Compact fluorescent lamps	China, Indonesia
Heat pumps	China
Solar photovoltaic cells	China (3rd leading producer after Germany and Japan)
Solar hot water heaters	Mexico
Wind energy	China, India

Table 10. South-South Developing Country Projects involving Jatropha (a Second Generation Biodiesel Fuel), January 2006 - June 2007

Ghana and Other West African Countries with aid from the Indian Government

The Indian government plans to spend $250 mln on the development of biofuels production in 15 West African countries, Ghana's Vice President Alhaji Aliu Mahama recently said. He added that the fund will be set up by the Bank for Investment and Development (EBID) of the Economic Community of West African States. As a first step, EBID is to provide $35 mln for a jatropha biodiesel project in Ghana, in cooperation with the country's commercial banks and financial institutions. December 4, 2006

Indonesia with FDI from South Korea

[An unspecified] South Korean company in cooperation with Jakarta-based PT Tata Harapan Cemerlang plans to invest $100 mln for 30,000-50,000 ha of jatropha plantings in West Sulawesi and Sumba Island in East Nusatenggara.

Logistic services company GKE International has agreed to buy Van der Horst Biodiesel, which plans to set up two jatropha-based biodiesel plants in the country, for SGD13 mln (1$=SGD1.51435). GKE will pay SGD9 mln in cash while the remainder will be financed by issuing 36.36 mln new shares. Van der Horst plans to set up an 100,000 tonne biodiesel plant on Jurong Island by end-2008, which will be expanded to 200,000 tonnes by 2010. Additionally, the company plans to build a 200,000 tonne plant in Johor by 2011. May 09 2007 May 09 2007

Mozambique with FDI from China

Four Chinese companies plan to plant 30,000 ha of jatropha in Narmpuda in northern Mozambique for biodiesel production, Bonifácio Saulose from the Investment Promotion Center said. However, the plan has still to be approved by Mozambique's Council of Ministers, Mr. Saulose said. April 24, 2007

Philippines with FDI from South Korea

Conglomerate Samsung Corp, has stolen a march on Japanese trading rivals with plans to set up a 200,000 tonne jatropha-fuelled biodiesel plant together with a subsidiary of Philippine National Oil Co. (PNOC). October 9, 2006

Sources: Excerpts from various issues of *FO Licht's World Ethanol & Biofuels Report*, as indicated by dates at the ends of the individual items.

Table 11. Case Studies of Technology Development and Transfer among Developing Countries

Biogas Digester - China and Asia-Pacific Region Biogas Research and Training Centre (BRTC): Established in 1981 in China, the BRTC has assisted in the construction of small-scale biogas digesters for manure decomposition-methane production and training in their use. By 1990 it had been involved in the construction of more than 70 digesters in 22 developing countries and training workshops for over 270 participants from more than 71 countries. Case 19.

Bamboo Fibre Reinforced Cement Board for Carbon Sequestration - Colombia, Indonesia (and Japan): Based on research in Japan, a pilot project was undertaken in Indonesia, and an improved version based on that experience was developed in Colombia. Fibres from fast growing bamboo trees is mixed into cement, with a resulting negative carbon balance for the composite material. Case 9.

Ceramic Cookstoves - Thailand, Kenya and other countries in Africa: Stove that provides approximately 20-50% efficiency gains over conventional charcoal stoves, it was developed through a South-South collaboration involving Kenya on the basis of a design used in Thailand. Initially manufactured by a single private sector firm, use of the stoves has exceeded 700,000 homes in Kenya with additional use in other African countries. Case 1.

Source: Compiled by the author from IPCC (2008: case studies 4, 8, 9, 19)

Box 1. Foreign Direct Investments and Other International Activities by Wind Turbine Manufacturer Suzlon of India

In terms of sales, Suzlon is the fifth ranking wind turbine manufacturer in the world.

Austria: joint venture for the manufacture of generators
Belgium: joint venture for the manufacture of gearboxes with Hansen
China: manufacture of turbines, rotor blades, control systems, generators and gearboxes*
Denmark: European headquarters
Germany: gearbox technology development with REpower
Netherlands: rotor blade technology development
United States: manufacturing and repairing rotor blades

* Planned as of 2007

Source: Compiled by the author from Alavi (2007: 15) and Lewis (2007: Table 2)

Box 2. Tata Industries of India: Foreign Direct Investments, International Joint Ventures and Other International Partnerships in Transportation, Energy and Engineering related to Climate Change Mitigation

<u>Tata Motors</u>: Technology tie-ups with the Institute of Development in Automotive Engineering, SpA (Italy); Nachi Fujikoshi Corporation (Japan); Le Moteur Moderne (France); and Robert Bosch GmbH (Germany). Strategic alliances / joint ventures with Cummin Engine Company Inc (USA) for Tata Cummins; Holset Engineering Company (UK) for Tata Holset; Tata Precision Industries (Singapore); Nita Company (Bangladesh); and Jardine Matheson for Concorde Motors.

<u>Tata AutoComp Systems</u>: Technology tie-ups with Chuo Spring Company (Japan); Menzolit-Fibron (Germany); and Owens Corning (USA). Joint ventures with Ficosa Internationa (Spain); Johnson Controls (USA); MobiApps (Singapore); Nifco (Japan); Stadco (UK); Sungwoo (South Korea); T.Rad (Japan); Yazaki Corporation (Japan); Yutaka Giken (Japan).

<u>Telco Construction Equipment Company</u>: Joint ventures with Hitachi Construction Machinery Company (Japan); John Deere (USA); Pauling & Harneischfeger (USA).

<u>Voltas</u>: Tie-ups with Hitachi (Japan); Standard Refrigeration (USA); and Dunham Bush (USA). "Manufacture only" alliances with LG Electronics (South Korea) and Fedders International.

<u>Tayo Rolls</u>: Promoted by Tata Steel in collaboration with Yodogawa Steel Works and Nissho Iwai Corporation (Japan) in 1968; collaboration with Eisenwerk Sulzau-Werfen (Austria).

<u>TRF</u>: Tie-ups with Saarberg Interplan (Germany); MAN-GHH (Germany); Thyssen Rheistahl Technik GmbH (Germany); Deilmann-Haniet GmbH (Germany); and Kurimoto (Japan).

<u>Tata BP Solar India</u>: Joint venture involving the Tata Group and BP Solar.
<u>Tata Power</u>: Association with Tennessee Valley Authority (USA).

Source: compiled by the author from <u>www.tata.com</u>, accessed on 18 November 2006

Box 3. GE's Joint Ventures and Wholly-Owned Subsidiaries for Manufacturing Wind Turbines in China

- GE Energy (Shengyang) – wholly-owned subsidiary assembles wind turbines
- GE Liming Gas Turbine Component Company - wholly-owned subsidiary manufactures wind turbine components
- GE Shenyang Turbomachinery Technology Company - wholly-owned subsidiary manufactures wind turbines
- Joint Venture with Nanjing High Speed & Accurate Gear Company – development of gearboxes for wind turbines

Also: GE China Technology Center hosts GE's Asian wind energy R&D

Source: www.ge.com/research downloaded on 11 November 2006

Box 4. GE's Climate and Energy Related Activities

Global Research Centers: Locations and Examples of R&D Related to Climate Change
China, Shanghai: Power electronics and controls; Coal polygeneration technologies
Germany, Munich: Alternative energy and environmental technologies; Electrical energy systems; Advanced sensor technologies
India, Bangalore: Power electronics
United States, Niskayuna, New York: Alternative energies

Energy & Propulsion Technologies
Low-emissions combustion for gas turbines, aircraft engines, and locomotives
Fuel Cells, micro turbines, and other advanced distributed power generation systems
Computational and experimental fluid dynamics for turbo machinery and other components of aircraft engines and power plants
Cooling and sealing technologies for propulsion, power generation, and other industrial and consumer products
Propulsion technology beyond conventional turbine engines and diesels
Technology for remote monitoring and prognostics of high-value assets towards condition-based maintenance
Technologies for hydrogen production from coal, natural gas and water
Coal gasification and integrated gasification combined cycle
Methods of liquid fuel purification and conversion

Source: www.ge.com/research downloaded on 11 November 2006

Box 5. Siemens

R&D Centers
150 product development centers in 38 countries with 47,000 employees (more than 10 percent of Siemen''s total employment) – including: China, 7000; India, 2000; Germany, 22,000; United States, 1300

Business Areas and Industries related to Climate Change
Automation and control: Automations systems, Automotive, Building automation, Drives, motors, Electrical installation technology, Process automation, Sensors and measuring systems
Power: Power generation, Power supply, Power transmission and distribution
Transportation: Rail automation and electrification, Turnkey systems for rail, Integrated services for rail, Rolling stock for rail, Automotive
Services: Energy services

Source: www.siemens.com downloaded on 11 November 2006

Table 12. Illustrative Tariffs that Affect the Energy Efficiency of Buildings

	Tariff Rates (percent)*			
	Multiple walled insulating units of glass (HS 7019.90)	Other glass fibre products (HS 8419.50)	Flourescent lamps, hot cathode (HS 8539.31)	Thermostats (HS 9032.10)
Brazil	12.0	18.0	18.8	18.0
India	60.0	35.0	100.0	60.0
Mexico	11.7	9.2	15.0	15.0
Canada	15.1	1.2	9.7	5.7
EU	8.0	1.2	3.6	2.8
Japan	0.0	0.0	0.0	0.0
United States	5.8	3.4	3.2	3.6

* Applied MFN rates, c. 2000; HS = Harmonized System of Tariff Classifications
Source: Compiled by the author from OECD (2001: Annex 3); and Steenblik (2006: 54-55, 70)

Table 13. Tariffs and Non-Tariff Barriers on Goods in Four Select Categories*

Product Categories	Compact Fluorescent Lamps		Wind Energy		Solar Voltaic		Clean Coal	
Developing Countries among World's Top Ten Exporters	China Indonesia		China		China China-Taiwan Malyasia South Korea		Mexico	
Importing Country	Avg. Applied Tariff %	Avg. Applied NTBs Tariff Equiv. %**	Avg. Applied Tariff %	Avg. Applied Tariff %	Avg. Applied NTBs Tariff Equiv. %**	Avg. Applied NTBs Tariff Equiv. %**	Avg. Applied Tariff %	Avg. Applied NTBs Tariff Equiv. %**
Brazil	18	96	14	14	18	53	14	145
China	8	NA	8	15	10	NA	15	25
India	15	102	15	15	15	41	15	NA
Mexico	15	NA	15	12	13	62	12	NA
So. Africa	NA	NA	NA	0	12	NA	0	125

* The Harmonized System codes for the product groups are as follows:

clean coal technologies (HS codes 840510, 840619, 841181, 841182, 841199)

energy efficient lighting (HS code 853931)

wind energy (HS codes 848340, 848360, 850230)

solar photovoltaic systems (HS codes 850720, 853710, 853931, 8541409)

** "The data on non-tariff barriers (NTBs) are derived from the World Bank's trade database. …The NTBs are calculated by transforming all the information on non-tariff barriers into a price equivalent. The ad-valorem equivalent (AVE) of the core NTBs thus calculated includes price and quantity control measures, technical regulations, as well as monopolistic measures, such as single channel for imports" (World Bank, 2008).

Source: Compiled by the author from World Bank (2008)

Table 14. Interactions of Types of Wind Energy Products and Types of Barriers to International Trade, Investment and Technology Transfer

Types of Products: Goods & Services	**Types of Barriers to International Trade, Investment and Technology Transfer**		
	Specifically Targeted	Defined Categories for Product Groups	Generic Across Product Groups
Climate Change-Specific Good/Service: Wind mill generators	Tariffs on imported wind mill generators	Tariffs on blades of various types	FDI local joint venture requirements for manufacturing facilities
Dual Use: Electrical wires	Tariffs on electrical wires	Safety certification requirements for electrical goods	Import inspection policies
General: Construction engineering services	Restrictions on cross border trade in construction engineering services	Licensing of engineering services firms	Restrictions on movement of natural persons

Source: Developed by the author from information in Barton (2007: 20-30); also see Lewis (2007).

Box 6. Excerpt from the Bali Action Plan

The Conference of the Parties …1. *Decides* to launch a comprehensive process to enable the full, effective and sustained implementation of the Convention through long-term cooperative action, now, up to and beyond 2012, in order to reach an agreed outcome and adopt a decision at its fifteenth session, by addressing, inter alia:

…

(d) Enhanced action on technology development and transfer to support action on mitigation
and adaptation, including, inter alia, consideration of:

> (i) Effective mechanisms and enhanced means for the removal of obstacles to, and provision of financial and other incentives for, scaling up of the development and transfer of technology to developing country Parties in order to promote access to affordable environmentally sound technologies;
> (ii) Ways to accelerate deployment, diffusion and transfer of affordable environmentally sound technologies;
> (iii) Cooperation on research and development of current, new and innovative technology, including win-win solutions;
> (iv) The effectiveness of mechanisms and tools for technology cooperation in specific
> sectors; …

Source: www.unfccc.int, accessed on 29 March 2008

Table 15. Existing International Institutional Arrangements concerning Climate Change and Trade (not exhaustive lists)

	Climate Change	Trade & Investment
Multilateral	FCCC/KP Other UN agencies IFIs GEF	WTO: GATT GATS TRIPs DSU
Regional	APP	APEC EU Mercosur NAFTA Others
Bilateral	US-Brazil, Sweden, …. EU-………… Japan-……… Others	FTAs, BITs
Plurilateral/Sectoral Aviation Shipping	 None None	 International Civil Aviation Organization (ICAO) International Maritime Organization (IMO)

Table 16. Methods of International Technology Transfer, Climate Friendly Technology Examples, and Coverage in WTO

Methods	Goods	Services
Production in exporting country/consumption in importing country	GATT: tariffs and non-tariff barriers	GATS: "consumption abroad"
Foreign direct investment, including joint ventures	GATT/TRIMs only	GATS: "commercial presence" (i.e. FDI)
Temporary relocation of employees	Not covered	WTO/GATS: "movement of natural persons"
International migration of skilled people	Not covered	Not covered
Licensing	TRIPs	TRIPs