'This book is the story of why we can all be optimistic about the future if we are willing to be brave and dedicated world citizens.' Mario Molina, Nobel Prize in Chemistry

TECHNOLOGY TRANSFER FOR THE OZONE LAYER

Lessons for Climate Change

Stephen O. Andersen, K. Madhava Sarma and Kristen N. Taddonio

earthscan
from Routledge

Advance praise for ***Technology Transfer for the Ozone Layer***

'Imagine the pride of earning the Nobel Prize for warning that CFCs were destroying the ozone layer. Then imagine that citizens, policymakers, and business executives heeded the warning and transformed markets to protect the earth. This book is the story of why we can all be optimistic about the future if we are willing to be brave and dedicated world citizens.'

MARIO MOLINA, Nobel Laureate in Chemistry and Professor, University of California

'In 2002 I characterized Andersen and Sarma's *Protecting the Ozone Layer* as one of the most impressive environmental books ever written. Now, with Taddonio, they have produced a timely encore that should become one of the most important books for addressing climate change. This authoritative and meticulously researched treatise cuts to the heart of the problem: the crucial issues of technology research, development and diffusion that have been largely lost in the hot air of climate rhetoric. The authors rightfully put them centre-stage, and draw on the highly relevant success of the Montreal Protocol to provide detailed prescriptions for achieving an indispensable global energy technology revolution.'

AMBASSADOR RICHARD BENEDICK, US chief negotiator of the Montreal Protocol and author of *Ozone Diplomacy*

'A major global achievement in the field of scientific understanding and effective policy has been the set of initiatives taken to save the ozone layer, which provides inspiration and a useful model for action in the field of climate change. This book is extremely valuable reading for policymakers and scholars alike particularly in the context of the challenge of climate change being faced globally.'

R. K. PACHAURI, Chairman, Intergovernmental Panel on Climate Change (IPCC) and Director General, The Energy and Resources Institute (TERI)

'2007 is the 20th Anniversary year of the signing of the Montreal Protocol and there is cause for great celebration for the leadership of both developing and developed countries that led to the proper implementation of the Protocol. This book gives an authoritative account of how impossible challenges to the transfer of ozone-friendly technologies were overcome for the good of human society and ecosystems.'

MOSTAFA K. TOLBA, Under-Secretary-General, United Nations, and Executive Director, United Nations Environment Programme, 1976–1992

'The lessons documented in this book show that solutions to climate change are attainable and in the global economic interest – if we accept the challenge and make the commitment to deal with it.'

ALAN MILLER, International Finance Corporation (IFC)

'This book provides a forward-looking, substantive account of how technology transfer, at its best, collaboratively and cost-effectively enables countries to tackle the ozone layer issue – it demonstrates the relevance of lessons learned from the Montreal Protocol to environmental issues faced today.'

MARIA NOLAN, Chief Officer of the Multilateral Fund Secretariat

'The success of the Montreal Protocol has been supported by unprecedented technology development and transfer under the international collaboration. Japanese chemists and engineers are very proud of their voluntary participation in protecting the ozone layer for future generations. We believe the lessons learned during these twenty years help the technological challenge for the climate change. Lift your spirits up by reading how technology transfer can save the Blue Planet again.'

MASAAKI YAMABE, National Institute of Advanced Industrial Science and Technology, and Asahi Glass Company, Japan

'The authors have dedicated their entire personal capacity and lives to the fight for a better environment for all. Without their intelligence and dedication, the Montreal Protocol's unique success would not be there. In this book they extend their wisdom and experience to guide actions on our most serious environmental challenge: climate change. Having negotiated intensively in both of the environment regimes for more than a decade, I can assure you that this guidance is badly needed. I urge everyone to study carefully the valuable lessons from these eminent writers and implement them expeditiously.'

JUKKA UOSUKAINEN, Acting Director General, International Affairs Unit, Ministry of Environment, Finland

'Stephen Andersen and Kristen Taddonio of the EPA and Madhava Sarma of the Ozone Secretariat (retired) do an excellent job showing the many ways that voluntary partnerships speed global environmental protection. Programmes like the Energy Star label on efficient products and initiatives under the Montreal Protocol have produced dramatic results. Imagine what we can accomplish as we continue to transfer technology to protect the climate.'

KATHLEEN HOGAN, Director, EPA Climate Protection Partnerships Division

'A highly informative, well researched compendium of technology transfers effected under the Montreal Protocol, written by authors who have traversed the length and breadth of this successful environment treaty. Stakeholders of current and future global environment treaties will be vastly benefited when they study the whole process of technology transfers effected under the Montreal Protocol to phase out ozone depleting substances.'

ARUN BHARAT RAM, Chairman and Managing Director, SRF Limited (a leading Indian chemical company)

Technology Transfer for the Ozone Layer

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and Kristen N. Taddonio

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Director of Strategic Climate Projects, Climate Protection Partnerships Division, US Environmental Protection Agency

Stephen O. Andersen began work on climate and ozone layer protection in 1974 as a member of the Climatic Impact Assessment Project on the effects of supersonic aircraft. With K. Madhava Sarma, he is author of *Protecting the Ozone Layer: The United Nations History* and, with Durwood Zaelke, *Industry Genius: Inventions and People Protecting the Climate and Fragile Ozone Layer*. Prior to joining the US Environmental Protection Agency (EPA), he worked for environmental and consumer non-governmental organizations (NGOs) and was a professor of environmental economics. In 1986, he joined the fledgling EPA Stratospheric Protection team, working his way up to Deputy Director. Since 1988, he has been Co-chair of the Technology and Economic Assessment Panel and has also chaired the Solvents Technical Options Committee, the Methyl Bromide Interim Technology and Economic Assessment and the Task Force on the Implications to the Montreal Protocol of the Inclusion of HFCs and PFCs in the Kyoto Protocol. He was co-editor of the IPCC/TEAP Special Report 'Safeguarding the Stratospheric Ozone Layer and the Global Climate: Issues Relating to Hydrofluorocarbons and Perfluorocarbons'. He pioneered voluntary programmes to phase out CFC food packaging, recycle CFCs from vehicle air conditioning, halt testing and training with halon, and accelerate CFC solvent phaseout in electronics and aerospace. He created the EPA ozone and climate protection awards and helped found the Industry Cooperative for Ozone Layer Protection and the Halons Alternative Research Corporation. He helped negotiate the phaseout of CFC refrigerator manufacturing in Thailand and the corporate pledge to help Vietnam avoid dependence on ozone-depleting substances (ODSs). He served on the team that commercialized no-clean soldering and the team phasing out ODSs from solid rocket motors. He is the recipient of numerous awards, including the 1990 EPA Gold Medal, the 1995 Fitzhugh Green Award, the 1995 UNEP Global Stratospheric Ozone Protection Award, the 1996 Sao Paulo Brazil State Ozone Award, the 1998 US

EPA Stratospheric Ozone Protection Award, the 1998 UNEP Global 500 Roll of Honour, the 1998 Nikkan Kogyo Shimbun Stratospheric Protection Award, the 1999 Vietnam Ozone Protection Award, the 2000 Mobile Air Conditioning Society Twentieth Century Award for Environmental Leadership, the 2001 US DoD Award for Excellence and the 2007 US EPA Best-of-the-Best Stratospheric Ozone Protection Award. He has a PhD from the University of California, Berkeley.

K. Madhava Sarma

formerly Executive Secretary, Secretariat for the Vienna Convention and the Montreal Protocol, United Nations Environment Programme

K. Madhava Sarma is currently a consultant on ozone issues and integration of the common aspects of global environmental treaties for greater synergy. With Stephen O. Andersen, he authored *Protecting the Ozone Layer: The United Nations History* (Earthscan, co-published by UNEP, 2002). He was the Executive Secretary of the Secretariat for the Vienna Convention and the Montreal Protocol from 1991 to 2000. During his tenure as Executive Secretary, he served the Parties to the Protocol through the turbulent Meetings of the Parties in Copenhagen, Vienna, Montreal, and Beijing – including three replenishments of the Multilateral Fund for the Implementation of the Montreal Protocol. He streamlined the administration of the institutions of the Protocol, the reporting requirements and other administrative obligations so that Parties could devote their full attention to resolving challenging political issues. Prior to being recruited to head the Secretariat, Madhava Sarma was a senior member of the Indian diplomatic team involved in the Montreal Protocol negotiations between the first and second Meetings of the Parties (1989–1991). During this time, he was often an effective spokesman for the developing country perspective and cosponsored many of the provisions of the London Amendment that satisfied developing countries while creating enforceable obligations to protect the ozone layer. He made other significant contributions as the senior Indian official looking after environmental policy, law, institutions and international cooperation, including responsibility for all global environmental issues. Prior to joining the national Government of India, he served (as a member of the Indian Administrative Service) as Head of District Administration, State Water Supply Board, and as Secretary to the Government, Irrigation and Power. During this state tenure, he was responsible for planning and implementation of many water supply, irrigation and energy projects. He earned the 1996 US EPA Stratospheric Ozone Protection Award and a 1995 award from UNEP 'For Extraordinary Contributions to Ozone Layer Protection', and the 2007 US EPA Best-of-the-Best Stratospheric Ozone Protection Award.

Kristen N. Taddonio

Project Director, Climate Protection Partnerships Division, US Environmental Protection Agency

Kristen N. Taddonio is Manager of Strategic Climate Projects at the US Environmental Protection Agency (US EPA) Climate Protection Partnerships Division. She organizes public–private partnerships for environmental innovation, harmonizes international standards to speed technology market penetration, and directly promotes technology transfer with information, leadership pledges and conferences. In the Climate Protection Partnerships Division she brought together a team of international experts from industry, government, military, and standards organizations who are removing global barriers to climate-friendly refrigerants. The success of her team will allow vehicle manufacturers to market environmentally superior technology worldwide with confidence and safety. Her partners are from Australia, Austria, Belgium, France, Germany, India, Italy, Japan, Netherlands and the United States. At the EPA, she manages an annual budget of more than US$600,000 and organizes the annual Climate Protection Awards, which were established in 1998 to recognize exceptional leadership, outstanding innovation, personal dedication and technical achievements in climate protection. Prior to her latest promotion, she was a technical writer and a marketing associate for the Energy Star programme for new homes. She earned a Masters Degree in International Science and Technology Policy and a Bachelors Degree in International Environmental Resources from the George Washington University's Elliot School of International Affairs, where she graduated *summa cum laude*. She has also earned degrees in Scientific and Technical Communication and Liberal Arts. Her papers have been featured in plenary sessions of conferences and workshops in Austria, France, India, Italy, Japan and the US. She is Co-chair of the United Nations Task Force on the Legacy of the Technology and Economic Assessment Panel (TEAP) of the Montreal Protocol (Report published April 2007, United Nations Environment Programme, and Nairobi, Kenya). In 2007, the Mobile Air Conditioning Society–Worldwide presented Kristen Taddonio with the Government Partner of the Year Award.

Foreword

Throughout the world, the Montreal Protocol is viewed as a great success and a tribute to institutions, countries, and individuals that made it happen. We at the Global Environment Facility (GEF) are proud of our role in supporting countries with economies in transition (CEITs) in their efforts to implement the Montreal Protocol. We are encouraged by these countries' successes and welcome the opportunity to show how technology transfer and financing can solve the many daunting challenges of global environmental protection.

The GEF – the largest funder of environmental protection in developing countries and economies in transition – was created in 1991, at a time when it was clear that Russia and the Newly Independent States and the other countries of Central and Eastern Europe would need the global community's support to meet their obligations to phase out ozone-depleting substances under the Montreal Protocol.

Responding to the appeal of the Parties to the Protocol, the GEF provided financial assistance to them at a crucial juncture and enabled them to implement the Protocol. In 15 years, from 1991 to 2006, these countries have decreased their consumption of ozone-depleting substances from about 296,000 tonnes to 350 tonnes – a reduction of over 99 percent.

Global environmental problems cannot be treated in isolation. At the GEF, we increasingly work with countries to intervene across domains to address climate change, biodiversity conservation, sustainable land management and chemicals management, including pollution of international waters from persistent organic pollutants (POPs).

The GEF strategies for climate change, POPs and ozone layer-depletion are indicative of the flexibility that we exercise. Within each domain of intervention, project developers are encouraged to seek synergies and co-benefits with the other areas: for example, between ozone and POPs, or between climate change and ozone. This ability to work across global environmental issues is one of the greatest strengths of the GEF.

There are two potential ways in which the phaseout of ozone-depleting substances might increase the risk of climate change: using substitutes that have a high global warming potential; and introducing less energy-efficient technologies. Therefore, the focus of GEF's work has been to help the countries transfer from ozone-depleting substances to both ozone-safe and climate-safe options. The GEF funds the conversion to technologies that have the least impact on global warming while being technically feasible, environmentally sound and economically acceptable.

The book also points out another important dimension of GEF's work: bridging the environment and development for sustainable development. It shows that technology conversions in many enterprises were instrumental in helping a number of sectors to modernize and adapt to a market economy.

I am pleased that the authors are recording this vital technology transfer story. A performance study of GEF has praised the Montreal Protocol process for its emphasis on clear goals and for creating an enabling environment for alternatives. The authors of this book have succeeded in bringing out the best from this process. I hope that the stakeholders of climate and other treaties will examine these lessons and adopt those that are suitable for their circumstances.

Monique Barbut
CEO and Chairperson
Global Environment Facility
Washington DC
June 2007

Preface

This is the first authoritative account of how technology was transferred worldwide under the Montreal Protocol. It tells the remarkable story of how governments, industry, consumers and the concerned public can, when faced with an environmental change crisis that threatens the health of the planet, work quickly and creatively to transform markets. As such it holds lessons on how to deal with other mutual and common challenges facing the environment, livelihoods, economic stability and human health across a wide range of spheres.

The story of the Montreal Protocol is worth repeating in all its detail. The Montreal Protocol of 1987 was the first convention based on the precautionary approach and the concept of a 'common but differentiated responsibility'. The preamble of the Protocol says the Parties to the Protocol are:

> Determined *to protect the ozone layer by taking precautionary measures to control equitably total global emissions of substances that deplete it, with the ultimate objective of their elimination on the basis of developments in scientific knowledge, taking into account technical and economic considerations and bearing in mind the developmental needs of developing countries,*
>
> Acknowledging *that special provision is required to meet the needs of developing countries, including the provision of additional financial resources and access to relevant technologies, bearing in mind that the magnitude of funds necessary is predictable, and the funds can be expected to make a substantial difference in the world's ability to address the scientifically established problem of ozone depletion and its harmful effects,*

These strategies were later made explicit in the 1992 Earth Summit in Rio de Janeiro as Principles 7 and 15 of the Rio Declaration and have been followed by virtually every environmental Convention since.

Piloted by UNEP, the Montreal Protocol allowed developing countries more time than developed countries to implement the control measures so that alternative technology would be mature and affordable. Developing countries had the advantage of 'leapfrogging' over alternatives that entered the market early but were soon made obsolete by technical progress. In 1990, on the urging of developing countries, developed countries agreed to finance the incremental costs of the phaseout in developing countries with its own financial mechanism called the Multilateral Fund. In 1991, the Global Environment Facility (GEF) was created by the Governments to deal with a wide range of global environmental issues, including ozone depletion. The GEF financed the incremental costs of those eligible countries not qualifying for financing under the MLF, including the countries of Eastern Europe and central Asia with economies in transition. The original control measures of the 1987 Protocol were repeatedly strengthened by the Parties to the Protocol on the basis of periodic scientific and technological assessments to provide for the phaseout of nearly a hundred ozone depleting chemicals on a specified time schedule.

The success of the Protocol is now acknowledged by all, even though the phaseout of the ozone-depleting chemicals is by no means complete. 190 governments have ratified the Protocol and are actively committed to phasing out ozone-depleting chemicals. The Fund to date has granted more than US$2.1 billion to the developing countries to switch to ozone-friendly solutions. The GEF has assisted the CEIT to the tune of US$200 million. Technological cooperation over the last 20 years has led to outstanding reductions of over 95 per cent in the consumption of ozone-depleting chemicals. Continuing scientific observations through satellites, balloons and ground-based observation have confirmed this reduction, as elaborated in the periodic reports of the Scientific Assessment Panel.

Protection of the ozone layer involved a large number of stakeholders. Many United Nations organizations did their part, including: the United Nations Development Programme (UNDP); United Nations Environment Programme (UNEP); United Nations Industrial Development Organization (UNIDO); World Health Organization (WHO); World Meteorological Organization (WMO); Food and Agriculture Organization (FAO); and Regional Economic and Social Commissions. International financial institutions, such as the World Bank and the Global Environment Facility, and national financial institutions also played an invaluable part in implementation. Industry and industrial organizations eschewed their usual competitive spirit and shared technologies and techniques to phase out ozone-depleting chemicals. Non-governmental organizations not only kept an alert eye on the issue and sounded the alarm when necessary, but also developed ozone-safe technologies and spread awareness about such technologies. National governments employed many regulatory, economic and policy instruments to achieve the phaseout as planned.

Does the success of the Montreal Protocol process suggest any advice for other global environmental treaties? While the treaties differ from one another, there are many common strands among them. Most, if not all, treaties aim at replacing some of the current environment-unfriendly technologies with environmentally sound technologies. The challenges posed to the Earth's environment by some issues (like climate change) are so serious that the world community has to adopt the new technologies as soon as possible in all the countries.

This is precisely the challenge met by the Montreal Protocol process. It would be sensible for the world community to study the process and adopt its useful features so that time is not lost by reinventing the wheel with every convention. This study will also be relevant to UNEP's Bali Strategic Plan for Technology Support and Capacity-building.

I am grateful to Stephen O. Andersen, who has been a co-chair of the Montreal Protocol's Technology and Economic Assessment Panel (TEAP) since its inception 18 years ago; Madhava Sarma, who served as the Executive Secretary of the Secretariat for the Vienna Convention and the Montreal Protocol for more than nine years; and to Kristen Taddonio, for agreeing to put together this book. It was a labour of love for them. They obtained contributions to this study from many of the people who made it a triumph. It is a timely contribution on the occasion of the twentieth anniversary of the Montreal Protocol.

I hope this history and analysis will please all those who contributed to the success of the ozone agreements, serve as an authentic record of one of the world's great achievements and assist other Conventions in their way forward.

Achim Steiner
Executive Director
United Nations Environment Programme
Under Secretary-General, United Nations

Acknowledgements

Many individuals helped us to compile this book. Foremost, we are grateful to Mr Len Good, the former Chairman, Global Environment Facility (GEF), for his ready support to our research and writing on the topic of this book. His successor, Ms Monique Barbut, was earlier the head of the United Nations Environment Programme (UNEP) Division of Trade, Industry and Economics and was equally encouraging when we explained the idea behind this book to her. Her support continued when she took over as Chief Executive Officer and Chairperson, GEF. We are grateful for her thoughtful Foreword to this book. Dr Kathleen Hogan (Director of the EPA Climate Protection Partnerships Division) inspired the hard work.

We are grateful to Mr Durwood Zaelke and Mr Scott Stone at the International Network for Environment Compliance and Enforcement (INECE) for their substantial contributions of time and logistics. The United States Environmental Protection Agency (US EPA) sponsored Mr Madhava Sarma's investigation of military leadership in ozone and climate protection and allowed Dr Stephen Andersen and Ms Kristen Taddonio to pursue this labour of love. Mr Marco Gonzalez, Executive Secretary of The Ozone Secretariat and his able Administrative and Finance Officer Ms Ruth Batten enthusiastically helped us. Mr Achim Steiner, Executive Director of UNEP, set the stage and Mr Gonzalez put the Protocol in a global context with their authoritative Preface and Introduction. We are honoured by the kind endorsement on the front cover by Nobel Prize winner Dr Mario Molina (University of California) and on the back cover by Ambassador Richard Benedick (US chief negotiator of the Montreal Protocol), Dr Kathleen Hogan (US EPA), Mr Alan Miller (International Finance Corporation), Ms Maria Nolan (Multilateral Fund Secretariat), Dr Rajendra K. Pachauri (Intergovernmental Panel on Climate Change), Dr Mostafa K. Tolba (former Under-Secretary-General, United Nations, and Executive Director, UNEP), Mr Jukka Uosukainen (Finland Ministry of Environment), and Dr Masaaki Yamabe (Japan National Institute of Advanced Industrial Science and Technology).

We have the greatest respect for Ms Lani Sinclair – our experienced editor for this and the previous book (*Protecting the Ozone Layer: The United Nations History*) – who ironed out our English and helped us clarify our thoughts. Earthscan and their editorial team – Mr Hamish Ironside, Mr Robert West, and Ms Alison Kuznets – worked beyond the call of duty with recommendations that strengthened the presentation, accuracy and style. Special thanks to Ms Samira DeGobert for guiding our choice of art and graphics.

We appreciate the work of Mr Rajendra Shende and Mr Tilman Hertz and their colleagues Mr Etienne Gonin, Ms Samira de Gobert, Mr Jim Curlin, Mr Yerzhan Aisabayev and Ms Nirupa Ram of UNEP for their informed chapter on Awareness and Capacity Building. We are grateful to Dr Melanie Miller and Ms Marta Pizano for their chapter on technology transfer for eliminating methyl bromide. Mr János Maté made considerable contributions to the Air Conditioning and Refrigeration chapter and to the Awareness and Capacity Building chapter.

The manuscript was reviewed by Mr Scott Stone and Mr Durwood Zaelke (INECE) and the chapters on technology transfer were reviewed by Ms Maria Nolan (Executive Officer of the MLF), Mr Tony Hetherington (Retired MLF Deputy Chief Officer). Their perceptive comments and amendments to the text strengthen the findings. In addition, each chapter was reviewed for technical accuracy and clarity by experts. We are particularly indebted to Mr Geno Nardini, Mr Jose Pons, Dr Helen Tope and Dr Ashley Woodcock for the Aerosol and Medical Products chapter; to Dr Radhey Agarwal and Mr Stephan Sicars for the Air Conditioning and Refrigeration chapter; to Dr Mike Jeffs and Ms Sally Rand for the Foams chapter; to Mr David Catchpole and Dr Dan Verdonik for the Halons chapter; to Mr William J. Van Houten, Mr Dave Koehler, Dr David J. Liddy, Mr William Nicholls, Mr E. Thomas Morehouse, Mr Peter Mullenhard, and Mr Ronald W. Sibley for the Military chapter; and to Mr Jorge Corona, Mr Brian Ellis, Dr William Kenyon, Mr Darrell Staley, and Dr John Stemniski for the Solvents chapter.

Two dozen of the most respected practitioners of ozone-safe technology transfer contributed text that illustrates how daunting technical and business challenges are overcome. These perspectives are contributed by: Dr Radhey Agarwal (India Institute of Technology), Mr Atul Bagai (UNEP) OzonAction South Asian Network), Mr Natarajan Balaji (UNEP OzonAction South Asian Network) Dr Tom Batchelor (TouchDown Consulting), Mr Ross Bowman (Thiokol Corporation), Mr Gilbert F. Decker (US Army), Mr Yuichi Fujimoto (Japan Electrical Manufacturer's Association), Mr Ramachandran Gopichandran (Centre for Environment Education, Ahmadabad), Mr Kiwohide Hata (Matsushita Electric Company), Dr Richard Helmick (US Naval Sea Systems Command), Mr Bill Holder (US Air Force), Dr Mike Jeffs (European Diisocyanate and Polyol Producers Association), Mr Donald Kaniaru (International Network for Environment Compliance and Enforcement), Mr Osami Kataoka (Daikin Industries), Ms Bella Maranion (US EPA), Mr János Maté (Greenpeace), Mr Alan S. Miller (International Finance Corporation), Mr Toshiyuki Miyajima (Seiko Epson), Mr E. Thomas Morehouse (Institute for Defense Analyses), Mr Hideo Mori, (Otsuka Pharmaceutical Company), Mr Peter Mullenhard (Science Applications International Corporation), Mr Naohiro Yamamura (Japan Ministry of Economy, Trade and Industry), Mr Steve Newman (National Aeronautics and Space Administration), Mr Jeffery J. Norton (US Air Force), Mr Tsutomu Odagiri (Japan Industrial Conference on Cleaning), Mr Akira Okawa (Japan Industrial Conference for Ozone Layer and Climate Protection), Ms Sally Rand (US EPA), Dr Akira Sekiya (National Institute of Advanced Industrial Science and Technology), Dr Shunichi

Samejima (Asahi Glass Foundation), Mr Rajendra Shende (UNEP DTIE), Mr Darrel Staley (Boeing Company), Mr Scott Stone (INECE), Mr Shigehiro Uemura (Japan Industrial Conference for Ozone Layer and Climate Protection), Mr Gary Vest (US Department of Defense, retired), Dr Masaaki Yamabe (National Institute of Advanced Industrial Science and Technology), Mr Robert L. Walker (US Army), and Mr Durwood Zaelke (INECE).

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Also, a special thanks to the Intergovernmental Panel on Climate Change, the Science and Development Network, UNCTAD, the Montreal Protocol Secretariat, and other international organizations for allowing us to quote from their publications and reports and to Dr Carlos Montalvo Corral for granting permission to quote from his book, *Environmental Policy and Technological Innovation: Why Do Firms Adopt or Reject New Technologies?*.

We thank Dr Janet Andersen and Ms K. Ramalakshmi, Dr Stephen Andersen's and Mr K. Madhava Sarma's respective spouses, for their constant support and encouragement and Ms Kristen Taddonio's friends and family for ongoing encouragement and support. Ms Gouthami, one of the daughters of Mr Sarma, deserves his thanks for providing him with the necessary facilities for writing for a considerable time period.

We have benefited substantially from the many contributions and for the review of our drafts by experts, but we are responsible for any errors or omissions in this book.

This book has not been subjected to publication review by the US Environmental Protection Agency (EPA) or the Global Environment Facility (GEF) and therefore does not necessarily reflect the views of the EPA or GEF; no official endorsement should be inferred. The views expressed by individual authors are their own. Mention of trade names, products, or services does not convey official EPA, GEF, or author approval, endorsement, or recommendation.

Stephen O. Andersen, K. Madhava Sarma and Kristen N. Taddonio

Introduction

The Ozone treaties have been extraordinarily fortunate, born under the right stars as it were. There are thousands of inviduals and institutions connected to the ozone layer issue over the past 33 years and each of them works with missionary zeal to protect the ozone layer. The treaties owe their success to this zeal, which continues to this day.

First came the scientists. Two chemists at the University of California at Irvine – Mario J. Molina and F. Sherwood Rowland – were the first to discover the link between CFCs and ozone depletion. They also made a passionate plea for practical action, and this gave rise to a ban on CFCs in aerosols by many countries. This also led to diplomatic action by UNEP beginning in 1977. Ever since, the scientists, through their many startling discoveries – the 'ozone hole', the 'smoking gun' – and through the four-yearly assessments organized by UNEP and WMO, kept the world community informed and educated on the policy options available. For the first time, scientists played a direct part in diplomatic negotiations and helped the governments not only to understand the phenomenon of ozone depletion and its adverse effects, but also to give concrete policy options, with each option leading to a particular impact on the ozone layer.

The technologists were on hand to analyse the technical and economic feasibility of alternatives, so that governments could make up their minds after weighing all the consequences – environmental, technical and financial.

The industry threw their awesome talent into discovering alternatives to the ozone-depleting substances and spreading these alternative technologies and processes throughout the world.

Many professionals throughout the world joined the effort and contributed their best. The NGOs not only contributed their watchful attention but also helped in bringing to light the hitherto unnoticed ozone-safe technologies.

The depletion of the ozone layer was by far the most serious global environmental problem ever faced by humanity. The objective of the ozone treaties was certainly a difficult one: to persuade the entire world to give up the use of many profitable chemicals that had been praised as wonder chemicals. Those to be persuaded were not only governments, but also the producers of these chemicals, all major multi-national giants of industrialized countries and thousands of industries that used these chemicals considered to be 'irreplaceable'. Behind them were the billions of consumers who wanted and needed the products that contained ozone-depleting chemicals: refrigerators, air conditioning, firefighting equipment and foams.

UNEP had to convince the world that once the depletion was started there would be no place for humanity to hide. The UNEP and its successive Executive Directors, and particularly Dr Mostafa Tolba, shed the image of 'neutral' UN organizations and pushed the diplomats of the world to arrive at the ozone treaties and to strengthen them continuously. The other UN organizations, such as the UNDP, World Bank, UNIDO and WHO, lent their combined might to the goal of saving the ozone layer. The Multilateral Fund created by the Montreal Protocol has worked wonders to enable every developing country in the world to join the effort. When the countries of Eastern Europe and Central Asia faced great economic and political problems, the Global Environmental Facility stepped in to ensure that those countries phased out the ozone-depleting substances, despite their troubles.

The implementation of the Protocol over the last 20 years has led to outstanding reductions of over 95 per cent in the consumption of ozone-depleting chemicals through changing to ozone-safe technologies according to the timetable set by the Montreal Protocol. What was the process that led to such a success throughout the world? Can it be replicated in other situations of threat to global environment? These questions are very relevant in this year of the twentieth anniversary of the Montreal Protocol. The lessons would be useful to the future actions of the Protocol in completing the remaining tasks of the phaseout. Perhaps other multilateral agreements could also gain some advantage by studying the process of the Montreal Protocol.

I am grateful to the authors who have taken the trouble over the past two years to prepare this insightful study into the ways and means of effectively transferring information, knowledge and technology, and supporting national capacity-building within the Ozone Layer Protection Treaties.

Marco Gonzalez
Executive Secretary
Secretariat for the Vienna Convention and its Montreal Protocol
UNEP

1

Prologue

This book is a sequel and complement to *Protecting the Ozone Layer: The United Nations History*. It is an account of how technology was developed, commercialized and transferred to companies in 190 countries – rich and poor, east and west, and north and south – in order to halt, within a prescribed time schedule, the production and use of chemical substances that destroy the ozone layer.

Throughout its existence, the United Nations has been at the forefront of efforts to protect the global environment. The making of environmental law has been an essential part of that undertaking. Today there are nearly 270 environmental treaties, covering issues such as marine and air pollution, hazardous waste, biodiversity, desertification, and climate change. Development, commercialization and transfer of environmentally sound technologies are the crux of these treaties, and this includes the ozone treaties.

Among the most successful of these treaties are the ozone agreements brokered by the United Nations Environment Programme (UNEP): the Vienna Convention for the Protection of the Ozone Layer (1985) and its Montreal Protocol on Substances that Deplete the Ozone Layer (1987).

In recent years there have been several debates in the international forums of the United Nations and the World Trade Organization on the obstacles to transfer of, and change to, environmentally sound technologies, particularly for the developing countries. These obstacles encompass institutional, social, political, technical and economic factors. The UNEP Bali Declaration is the latest consensus of governments on this issue. Experience regarding ozone-friendly technologies is now more than 20 years old. This book analyses this experience, in the hope that it will both benefit the Montreal Protocol, since there is much more to be done to achieve its objectives, and help the global environmental agreements that protect climate: the United Nations Framework Convention on Climate Change (UNFCCC) of 1992 and the Kyoto Protocol to the UNFCCC of 1998.

There will be some who will protest that the climate treaties do not need advice or that, if they do need advice, the Montreal Protocol experience is not relevant to the climate treaties since the issues are very different. We agree that the issues are different, as indeed any two issues are. However, in this book we hope to convince you and others responsible for protecting the climate that the lessons of the Montreal Protocol process are transferable to many situations. It is a fact that climate change is already occurring. Scientists have noted the existence of change, as well as the adverse effects thereof. They have, through the reports of the Intergovernmental Panel on Climate Change, given dire warnings about the consequences of greenhouse gas emissions from human activities, and have urged the world to take urgent action. It is also a fact that the climate treaties have not achieved much so far. The UNFCCC is now 15 years old, the Kyoto Protocol 9, and the progress made by these treaties is miniscule compared to the progress made by the Montreal Protocol at a similar time stage. The immense complexity of the issues involved may be one reason for the lack of results. However, we will demonstrate that the issues involved in the phase-out of ozone-depleting substances (ODSs) were also complex. Despite this complexity, stakeholders' determined efforts are currently phasing out 96 ozone-depleting substances used by 240 industry sectors in thousands of products, and the phaseout is proceeding ahead of the schedule set by the Montreal Protocol. We include detailed sector-wise accounts of this phaseout to shed light on the lessons of the Montreal Protocol process, but a technically disinclined reader can skip the technical details and still keep track of the creativity displayed by thousands of ozone actors in order to resolve the problems that arose.

The Montreal Protocol experience dispels many myths and reveals many surprises. It will surprise you to learn that technologies to protect the ozone layer came from many parts of the world even before the Protocol entered into force; that concern for future generations motivated unprecedented access to intellectual property (often without charge); that military organizations motivated technical solutions to the most challenging applications; that the cost of financing the incremental costs of technology for countries with economies in transition and developing countries was far less than anyone imagined; and that specialized institutions can outperform large industrial and financial institutions normally charged with carrying out international technology projects.

Governments, scientists, industry, non-governmental organizations and the United Nations system set aside their differences and came together to fight against the catastrophic threat of stratospheric ozone depletion. However, the picture is not perfect, and some mistakes were made. We hope that this book will help others to avoid these mistakes in the future.

Technology change generally came about first in developed countries and only then in other countries, as the Protocol gave a period of grace to developing countries in recognition of the 'common but differential responsibility' principle. The industries that used the ozone-depleting substances are very diverse: the air-conditioning, refrigeration, firefighting, solvent, agriculture, aerosol product and foam sectors were the major ozone-depleting substance consumers, but ODSs were used in thousands of other small applications as well. There were many large enterprises that had the resources to develop new and innovative ozone-friendly technologies, but there were also many small enterprises that needed to be educated on such technologies and how to access them. The governments of developed countries implemented many policies, regulations, awareness and education campaigns, and financial incentives and disincentives to promote ozone-safe technologies. These were later followed by the developing countries, who introduced additional policy innovations. A considerable body of literature has been published by governments as well as by scholars. We have relied on these studies to discern some key features of technology change in the countries involved.

The developing countries are eligible for assistance from the Multilateral Fund, which the Protocol set up in 1991 under Article 10, to meet the incremental costs of implementing ozone-depleting substance control measures. As of March 2007, the Fund has approved 5520 projects, with total funding of over US$2.1 billion in assistance to 143 developing countries. We have analysed the completion reports of about 1000 such projects in order to find answers to the many questions on the various facets of technology change.

When the Protocol was signed in 1987, most Eastern European and Central Asian countries were either part of the USSR or members of the political alliances led thereby. They had communist economic systems. The Meeting of the Parties to the Protocol did not consider these countries to be developing countries. The 1989 political upheavals led to the break-up of the USSR and the collapse of communist governments, and the new governments, more or less, chose the market economy path of the industrialized West. This transition took some time and resulted in the economic collapse of many of these countries, and there was concern that they might be unable to implement the Montreal Protocol control measures. The Global Environment Facility (GEF) here came to their rescue by providing assistance to make the change to ozone-friendly technologies. We have analysed the GEF project completion reports for these countries as well.

In addition to our analyses, we asked many experts on technology change to give their own accounts – from their individual, organization, sector or country point of view – of the problems of technology change and transfer, and the solutions. The accounts of the many that responded to our request have been integrated with our analysis.

We believe that this book is the first of its kind: a comprehensive analysis of environment-friendly technology change that actually occurred throughout the world and in a relatively short period of time. Previous publications on technology transfer for environmental protection have mostly been limited to case studies. We believe that our findings will change many existing perceptions about technology transfer and influence the debate about technology change. We also believe that this book will assist with the implementation of other environmental conventions, particularly those relating to climate change.

2

Contours of Technology Transfer

Introduction

International efforts to encourage technology cooperation and transfer for environmental protection began in the 1970s. At the 1972 United Nations Conference on the Human Environment, political leaders called upon the global community to make technologies more available to developing countries.[1] Since the beginning of the 1980s, technology transfer has become an increasingly important issue due to mounting global environmental problems. Developing countries demanded technology transfer as a condition of participation in the control measures of the Montreal Protocol on Substances that Deplete the Ozone Layer, and today technology transfer is included in over 80 regional and international agreements, including Agenda 21, the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, the Organisation for Economic Co-operation and Development (OECD) Environmental Strategy, the Convention on Biological Diversity (CBD) and the United Nations Convention to Combat Desertification (CCD).[2]

This book is among the first to study the success of the Montreal Protocol in technology transfer, with the goal of guiding other technology transfer efforts, particularly for climate protection.

Technology Transfer as a Positive Measure

Multilateral environmental treaties have historically used a variety of tools to achieve their objectives. Among these tools are voluntary agreements, trade measures and enforcement measures designed to encourage compliance. Such treaties include 'positive measures' designed to help countries meet their commitments. Technology transfer provisions fall into this category and are included in many multilateral environmental agreements (see Box 2.1).[3]

What is Technology Transfer?

Technology transfer is the intentional 'passing-on' of technology or know-how from one party to another, commonly by purchase, investment or agreements for cooperation (see Box 2.2). There are three distinct components of technology that can be transferred:

Box 2.1 Technology transfer in the Montreal Protocol, UN Framework Convention on Climate Change and Kyoto Protocol

The Montreal Protocol

According to Article 10A of the Montreal Protocol, 'each Party shall take every practicable step, consistent with the programmes supported by the financial mechanism, to ensure that the best available, environmentally safe substitutes and related technologies are expeditiously transferred to Parties operating under paragraph 1 of Article 5 [developing countries]', and that 'transfers [...] occur under fair and most favorable conditions.'

The United Nations Framework Convention on Climate Change

Article 4.5 of the United Nations Framework Convention on Climate Change (UNFCCC) states that developed country Parties should 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', that they should 'support the development and enhancement of endogenous capacities and technologies of developing country Parties', and calls on other Parties and organizations to assist in facilitating the transfer of such technologies.

The Kyoto Protocol

The importance of technology transfer was also recognized by the Kyoto Protocol of 1997 in Article 10c, which asks all Parties to 'cooperate in the promotion of effective modalities for the development, application and diffusion of, and take all possible steps to promote, facilitate and finance, as appropriate, the transfer of, or access to, environmentally sound technologies, know-how, practices and processes pertinent to climate change, in particular to developing countries, including the formulation of policies and programmes for the effective transfer of environmentally sound technologies that are publicly owned or in the public domain and the creation of an enabling environment for the private sector, to promote and enhance the transfer of, and access to, environmentally sound technologies.'

1. physical assets, such as industrial plants, machinery, and equipment;
2. information, both technical and commercial, relating to process know-how, choice of technology, engineering design and plant construction, organization and operating methods, quality control, and market characteristics; and
3. human skills, especially those possessed by specialized professionals and engineers.

Some technologies are 'plug-and-play', requiring only minor tailoring to local circumstances. However, most manufacturing and environmental technologies require a significant amount of learning on the part of the technology user. Technology transfer is not achieved until the transferee understands and can use the technology. Although the literature tends to focus on technology transfer from developed countries to developing countries – 'north to south' – technol-

Box 2.2 Definitions of technology transfer

Some authors narrowly define 'technology transfer' as the transfer of technical knowledge from one place to another. Others, such as the Intergovernmental Panel on Climate Change (IPCC) (2001)[4], broadly define it as the transfer of technical knowledge and its utilization, dissemination and diffusion. Indicative definitions of technology transfer include:

> *the process by which commercial technology is disseminated. This involves the communication, by the transferor, of the relevant knowledge to the recipient.* (United Nations Conference on Trade and Development (UNCTAD), 2001)[5]
>
> *any process by which one party gains access to a second party's information and successfully learns and absorbs it into his production function.* (Maskus, 2004)[6]
>
> *most fundamentally a complex process of learning.* (Levin, 1993; Kranzberg, 1986)[7]
>
> *a broad set of processes covering the flows of know-how, experience and equipment […] amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations and research/education institutions. […] It comprises the process of learning to understand, utilize and replicate the technology, including the capacity to choose it and adapt it to local conditions and integrate it with indigenous technologies.* (IPCC, 2001)[8]

ogy transfers actually take place within and between all countries. Andersen and Sarma (2002)[9] and IPCC (2001)[10] catalogue technologies invented in developing countries and transferred 'south to north' and 'south to south' for the protection of the stratospheric ozone layer. This overlooked perspective is elaborated in Chapter 13, where the case is made that the technology necessary to protect the climate and other global environment resources is just as likely to come from developing countries as from developed.

Although some sources, such as IPCC (2001),[11] combine the concepts of technology transfer, technology diffusion and technology commercialization, most of the literature distinguishes between the three. In general, 'transfer' of a technology refers to its transmission to another party, 'technology diffusion' refers to the extent to which a technology is utilized (in other words to the number of people or firms that have adopted the technology), and 'technology commercialization' refers to a technology's transition from the developmental stage to the marketplace. Some authors refer to technology commercialization as 'vertical technology transfer'.

Early lessons in technology transfer

Although many international environmental agreements have included provisions for technology transfer, experts observe that these provisions have been

Box 2.3 From technology transfer to technological learning and capabilities

The initial emphasis in the analysis of international technology transfer, in discussions among policy analysts up to the late 1970s, was on its costs and on whether the choice of technologies was appropriate to the local conditions in developing countries.

Little attention was given in this analysis to the absorptive capacities and domestic technological learning of those who acquired foreign technologies – in other words to the processes involved in assimilating imported technologies and putting them to work efficiently. The underlying assumption seemed to be that once a technology was acquired, its absorption and implementation took place almost automatically and effortlessly. However, it is now widely accepted that this is not the case. The acquisition and absorption of foreign technologies, and their further development, are complex processes that demand significant efforts on the part of those that acquire them.

Several factors contribute to this complexity. First, the acquisition and mastery of technology are both costly and time-consuming. Second, acquired technologies often need to be adapted to local conditions. Third, technologies are not commodities that can be transferred as complete ready-to-use sets; they also contain tacit components that are not easily codified and transmitted in written documents and require extensive learning efforts to be properly understood. In other words, technologies do not consist only of machines and other bundles of hardware; technology is knowledge in different forms, of which hardware is only one element. While machines can be easily transferred, other components cannot; and these also need to be mastered.

This increased understanding of the process of technological development has contributed to shifting the attention of academics and policy researchers from the narrow transfer of technology as such to the associated technological learning efforts and mastery of the acquirers. In this respect, despite its common use, the term 'technology transfer' can be misleading, as it appears to represent the acquirer as a passive receiver of technologies developed elsewhere and technology as something that can be easily transferred in a 'plug-and-play' mode.

In fact, the two processes – the acquisition of foreign technologies via technology transfer on the one hand, and domestic technological learning on the other – are complementary and intertwined. The absorptive capacities of the acquirer are fundamental in laying the foundations for the efficient assimilation of foreign technologies. At the same time, the acquirer of foreign technologies is not a passive receiver, and further technological learning is necessary to make the technologies work efficiently, as well as to develop them further.

Source: Science and Development Network.[12]

historically unsuccessful, with the conspicuous exception of the Montreal Protocol. Both the International Environmental Technology Centre and the United Nations Environment Programme suggest that technology transfer in support of sustainable development 'failed to fulfil expectations and meet clearly evident and pressing needs'.[13] The United Nations Commission on Sustainable Development gives low marks to technology transfer:

> *Hopes for accelerated transfer and diffusion of environmentally sustainable technologies remain largely unfulfilled despite the extensive acceptance that resource-efficient and cleaner technologies will benefit all.*[14]

Lack of attention to local conditions (see Box 2.3) and inattention to market incentives are two reasons commonly offered for this lack of success.

In documenting the history of international approaches to technology transfer, UNCTAD and the World Trade Organization (WTO) report that governments gradually shifted from regulatory approaches to market-based methods to encourage technology transfer. The underlying philosophy of the regulatory approach is that countries should screen technology transfer agreements between foreign and domestic companies and discourage 'unfair' practices, such as export restrictions, by the former. Regulatory approaches encourage transfer of technology from multinational corporations to locally owned businesses and use regulation to remedy any inequalities that might result. The underlying philosophy of the market-based approach, on the other hand, is that 'technology transfer is best achieved in an environment where intellectual property rights are fully protected as private commercial property and in which the market for technology is maintained in as competitive a condition as possible.'[15] Market-based approaches tend to encourage technology transfer from a foreign-owned enterprise to its (often wholly owned) local affiliates, and therefore require no correction for inequalities.

Some academics suggest that regulatory approaches actually discourage technology transfer by putting excessive restrictions on technology owners. According to UNCTAD:

> *The major disadvantage may be that such a regulated approach could be perceived as creating commercial disincentives for trans-national corporations, as the principal owners of technology, against the dissemination of that technology to developing host countries. [In particular] additional costs may arise as a result of intervention in the bargaining process through protective contractual requirements aimed at the promotion of the interests of independent local technology recipients. The imposition of extensive performance requirements could be perceived as limiting the commercial return on the transfer transaction.*[16]

Although market-based approaches have shown promising results for some technologies, some experts warn that such approaches may not work as well for the transfer of environmentally sound ones. For example, the OECD argues that the 'general trend away from public sector to private sector finance for channelling technology' is a concern for the transfer of environmentally sound technologies. This is because there are fundamental differences between the transfer of environmentally sound technologies and the transfer of other technologies (see Table 2.1). Environmental technology transfer is 'more reliant on public funds than on private investment'.[17] Furthermore, companies may not have incentives to develop environmental technology because the benefit they create – enhanced environmental quality – is in the realm of public goods. Therefore firms may need public funds to stimulate research and development on environmental technologies.

In recent years, more emphasis has been placed on the various stakeholders, pathways, stages and barriers that influence the technology transfer process.

Table 2.1 *Similarities and differences between environmental technology and other technologies*[18]

	Environmental technology	*Other technologies*
Main drivers	Regulation, public policy, multilateral environmental agreements	Market forces: demand, competition, production bottlenecks, etc.
Finance	Public funding important	Largely private funding, including reinvested earnings, venture capital and sales of stocks
Location of research and development (R&D)	More often in universities, public R&D institutes and laboratories	Mainly enterprise-based
Mechanisms for transfer	Transfer to private sector, emerging role of public–private sector partnerships	New structures through inter-firm R&D collaboration as well as partnerships of firms with public R&D
Commercialization	Increasingly private, many small and medium-sized enterprises involved, need for support structures and incentives	Generally private
Application	Often site- or location-specific applications, some environmentally sound technologies could be applied globally (e.g. CFC substitutes)	Increasingly global
Transfer to developing countries and countries with economies in transition	Private commercialization, official development assistance, sometimes funding from multilateral sources (e.g. Multilateral Fund under the Montreal Protocol or funding from the Global Environment Facility)	Almost exclusively through private commercialization

Technical and environmental experts have identified certain stages that occur within most technology transfers (see Box 2.4), but have not identified preset strategies to enhance technology transfer, and generally conclude that technology transfer must be tailored to the specific barriers, interests and influences of specific stakeholders.[19]

Box 2.4 Stages of technology transfer

The IPCC identifies certain stages in technology transfer, but notes that they do not always occur in a linear fashion. Stages include the identification of needs (assessment), choice of technology, negotiation of conditions of transfer, agreement, implementation, evaluation and adjustment to local conditions, and replication. These stages appear regardless of whether the technology transfer is driven by governments, the private sector or communities.

Government-driven pathways

Assessment = technology assessment by governments involved in the transfer.
Agreement = governmental agreement or government agency mandate.
Implementation = project implementation.
Evaluation/adjustment = project or programme evaluation.
Replication = replication of the project.

Private sector pathways

Assessment = market opportunities or needs assessment,
or persuasion by third parties.
Agreement = contracts and financing.
Implementation = investments or purchases.
Evaluation/adjustment = profitability or service quality.
Replication = reinvestment or repurchase.

Community-driven pathways

Assessment = public pressure.
Agreement = consensus.
Implementation = collective action or joint management.
Evaluation/adjustment = localization.
Replication = diffusion of technology or practice.

Source: Andersen et al (1998)[20]

Pathways and Stakeholders

It is important to examine the pathways by which technology is transferred and the stakeholders involved in the process. The IPCC breaks down the technology transfer pathways into three categories: government pathways, private sector pathways and community-driven pathways:

> *Government-driven pathways are technology transfers initiated by governments to fulfil specific policy objectives; private-sector-driven pathways primarily involve transfers between commercially oriented private-sector entities; and community-driven pathways are those technology transfers involving community organizations with a high degree of collective decision-making.*[21]

Other authors use two pathway categories: market (or commercial) channels and non-market (or non-commercial) channels.[22] Market channels are those which involve some form of formal transaction, such as foreign direct investment, joint ventures, licensing, franchising, management contracts, marketing contracts, technical service contracts, turnkey contracts and international subcontracting. Non-market technology transfer channels have no formal arrangements; they occur when information is transferred through technical journals and the like.

Government pathways of technology transfer

Although the vast majority of technology transfer occurs through private sector channels, governments also provide pathways for technology transfer. Many governments support the development of environmentally sound technologies that can be freely distributed to domestic or international firms. This pathway of technology transfer 'can be an important means for governments to catalyse private sector technology transfer'.[23]

Governments also influence private sector pathways of technology transfer by creating policies and regulations that shape the environment in which technology transfer occurs. These policies can encourage technology transfer or inhibit it, depending on how they are designed. For example, strong domestic environmental regulations and financial incentives such as taxes or subsidies increase the demand for environmentally sound technologies. In addition, strict but flexible regulatory regimes, such as those that focus on performance standards and outcomes, can encourage innovation and drive technological development.[24] In extreme circumstances, governments can facilitate technology transfer through 'command and control' measures that compel the use of certain technology and make licensing compulsory.

Private sector pathways of technology transfer

The private sector develops, owns and controls the vast majority of technology and technical innovations; consequently, it plays the most important role in technology transfer.[25] Recognizing this, international environmental agreements frequently call for increased collaboration with the private sector for the purpose of transferring environmentally superior technology. Some of the most important pathways through which the private sector transfers technology are trade in goods and services, foreign direct investment, licensing, joint ventures, and cross-border movement of personnel.

Trade in goods and services (includes purchases, sales, exports and imports)
One important way that firms acquire technology is by buying it. However, the mere acquisition of a technology does not assure its effective transfer; it may need to be adapted to meet the purchasing firm's needs, and depending on the purchasing firm's technical capabilities, after-sales service and training may be necessary.

Foreign direct investment
Foreign direct investment is the most commonly identified channel of market-based international technology transfer. Multinational enterprises introduce new

knowledge, tools, techniques and technologies by directly investing in new productive capacity or acquiring and updating facilities in another country. In the most successful cases, foreign direct investment transfers technology and builds indigenous capacity by creating new infrastructure and training local workers.

Licensing

Licences are agreements that sell the right to use certain proprietary knowledge in a defined way. They typically involve a contract in which a product's manufacturer (or the firm that owns the proprietary rights) grants permission to manufacture that product (or make use of that proprietary material) in return for specified royalties or other payment or access through cross-licensing of other proprietary knowledge.[26] Licensing is often used where there is a barrier to trade or when the owner of the technology considers foreign investment too difficult, too risky or too far from their business plan. Licensing opens the possibility for an enterprise to transfer technology to a foreign market where it would otherwise be unavailable.

Joint ventures

A joint venture is a business in which two or more parties undertake an economic activity together. The joint venture agreement typically specifies the contribution of each partner and the distribution of profits. Joint ventures spread costs and risks, improve access to financial resources, achieve economies of scale, provide access to new technologies and customers, and allow different parties to learn new skills from each other.

Cross-border movement of personnel

When firms relocate or engage in foreign direct investment, they usually send managerial and technical staff to new locations to provide training and supervision. Indeed, 'many technologies cannot be effectively or affordably transferred without the complementary services and know-how of engineers and technicians that must be on-site for some period of time'.[27] In addition, experts familiar with specific technology take those skills to new jobs or start their own companies producing variations of the technology they previously mastered.

Non-market pathways of technology transfer

Not all technology transfer occurs through market interactions. Non-market pathways involve the acquisition of technology without the consent of the provider. Examples of non-market technology transfer pathways include public education, internet searches, industrial espionage, end-user or third-country diversions, imitation, and reverse engineering. Technology transfer also occurs when experts describe their results in technical papers, patent disclosures and other publications, and when employees move between firms or migrate to other regions.[28]

Imitation

Imitation is among the most significant non-market channels of technology transfer. It occurs when 'a rival firm learns the technological or design secrets of another firm's formula or products'.[29] This can be accomplished through simple trial and error, but more often it is achieved through reverse engineering. The legality of imitation products depends on the strength of intellectual property rights legislation and is sometimes a major issue in international trade negotiations.

Data in patent applications and test data

Patent applications and test data contain important technological information. By studying patents, rival firms may be able to sidestep or bypass existing patents or may be able to employ the patented technology without being discovered. Either way, the information contained in patent applications and test data is a productive avenue for the transfer of knowledge and technology.

Employee mobility and migration

When employees change jobs, they take their technological knowledge and skills with them. Their prior knowledge and skills may also help to catalyse new technological developments in their new places of employment, where there may be a cross-fertilization of knowledge.

Technology transfer also occurs when employees migrate temporarily to acquire training or when assigned short-term duties. In addition, private and public sector employees transfer knowledge when they serve on international committees such as the Montreal Protocol Technology and Economic Assessment Panel (TEAP) and its Technical Options Committees (TOCs). The lessons learned constitute a long-lasting form of knowledge transfer. However, clearly the knowledge acquired when experts migrate to a new location will only be transferred back to the original location if they return. Technology transfer is not efficiently accomplished for developing countries if higher foreign standards of living result in a 'brain drain' of the best students and experienced technical experts.

Community pathways of technology transfer

Geographic, sectoral or professional communities can provide a pathway for technology transfer. Community-driven pathways for technology transfer are 'initiated and led by community organizations and entities with a high degree of collective decision making'.[30] Communities can put pressure on the private sector to change practices or utilize different technologies; often this is enough to create change even in the absence of government pressure. Communities can also sponsor meetings, workshops and other public forums where attendees can learn about new technology, creating another possible pathway for transfer. An example in the case of the ozone layer is the Greenfreeze refrigerator, which was promoted by the international environmental non-governmental organization (NGO) community, leading to the widespread adoption of this technology, which is climate-friendly and free of ozone depleting-substance.

Stakeholders

It is just as important to study the stakeholders involved in technology transfer as it is to study the technologies themselves. The actions and interactions of stakeholders determine the rate and direction of technology change. There are many stakeholders involved in technology transfer, including businesses, governments, educational and research institutions, financiers, consumers, the media, and NGOs. When these stakeholders are well established and well connected, knowledge will flow quickly and easily between them, speeding technology transfer (see Table 2.2).

The private sector enterprise is perhaps the most important stakeholder in the technology transfer process, and many theories attempt to explain the factors that lead enterprises to adopt or reject new technologies. One popular theory, introduced by Carlos Corral, hypothesizes that any enterprise contemplating a change of technology is influenced by three factors: risk, social pressure and enterprise capability.[31] One risk is that an enterprise's current operations will have an unacceptable environmental impact. Another risk is that the enterprise will fail to capture significant benefits of the alternative clean technological portfolio. The final risk is the possible negative consequences of action or inaction. This risk depends on the enterprise's market niche, the capability of government regulators, customer willingness to pay, the growth opportunity of adapting the new technology, the costs of new technologies and the financial risks.

The main sources of social pressure for technology change are regulation, industrial standards, market position, market forces, customers' expectations and demands, and public concerns. The most important determinants of change are the firm's current technological capabilities, the availability of technological opportunities, collaboration with research institutions, collabora-

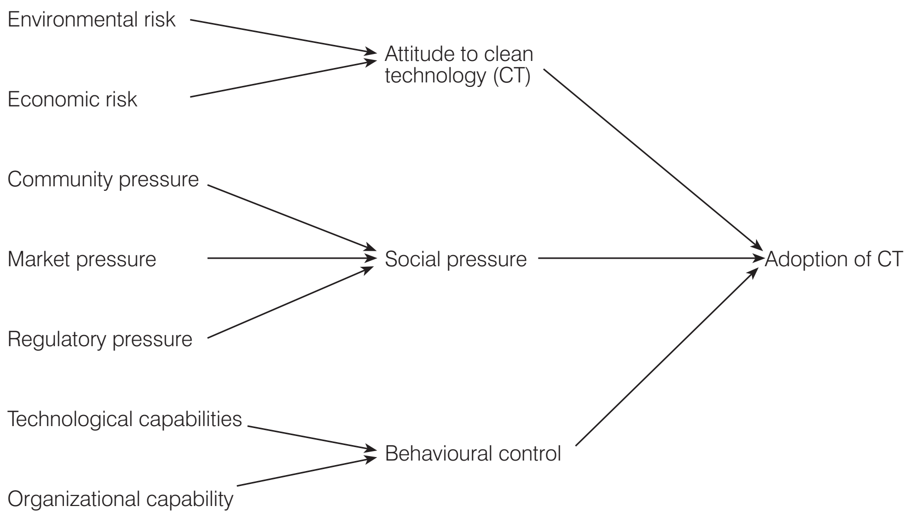

Figure 2.1 *Factors that lead enterprises to adopt or reject new technologies*

Table 2.2 *Stakeholders*

Stakeholders	*Motivations*	*Decisions or policies that influence technology transfer*
Governments	• Compliance with international treaties • Development goals • Environmental goals • Competitive advantage • Energy security	• Tax policies (including investment tax policy) • Import/export policies (including bans on manufacture or import of products made with or containing ozone-depleting substances) • Innovation policies • Education and capacity-building policies • Regulations and institutional development • Direct credit provision
Private sector	• Profits • Market share • Return on investment • Sustainable operations • Company reputation and respect • Public service and community health	• Technology R&D/commercialization decisions • Marketing decisions • Capital investment decisions • Skills/capabilities development policies • Structure for acquiring outside information • Decisions to transfer technology • Choice of technology transfer pathway • Lending/credit policies (producers, financiers) • Technology selection (distributors, users)
Donors	• Development goals • Environmental goals • Return on investment	• Project selection and design criteria • Investment decisions • Provision of technology, equipment, technical assistance and training • Procurement requirements • Conditionalities
International institutions	• Development goals • Environmental goals • Policy formulation • International dialogue	• Policy and technology focus • Selection of participants in forums • Choice of modes of information dissemination
Research organizations	• Basic knowledge • Applied research • Teaching • Knowledge transfer • Perceived credibility	• Research agenda • Technology R&D/commercialization decisions • Decision to transfer technology • Choice of pathway to transfer technology
Media	• Information distribution • Education	• Acceptance of advertising • Promotion of selected technologies • Educational curricula
NGOs	• Special interests • Collective welfare	• Promotion of selected technologies • Lobbying for technology-related policies
Individual consumers	• Welfare • Utility • Expense minimization	• Purchase decisions • Decision to learn more about a technology • Selection of learning/information channels • Ratings of information credibility by source

Source: Adapted from Intergovernmental Panel on Climate Change (2001).[32]

tion and influence with suppliers, perceived internal control of the firm, and learning capability. This is summarized in Figure 2.1.

Facilitating Technology Transfer for Environmental Protection: Theory and Observations

The environmental and technology transfer literature offers many suggestions about how to facilitate technology transfer and cooperation for environmental protection. Common themes include sensitivity to stakeholder needs, enabling environments and national settings, economic incentives, information-based policies, regulation, capacity-building, intellectual property protection, and financial assistance.

Sensitivity to stakeholder needs

Experts agree that successful publicly sponsored technology transfer projects are sensitive to stakeholder needs. Projects are unsuccessful when managers fail to appreciate the motivations, constraints or limitations of one or more key stakeholders in the technology transfer project. A notable technology transfer failure occurred under the Montreal Protocol in the transfer of refrigerant recovery and recycling technology from developed countries to the Czech Republic. Project planners failed to realize that poorly paid technicians would prefer to recover and re-sell refrigerant on the street rather than bring the refrigerant to the reclamation facility for purification. The failure to bring in the refrigerant made the reclamation facility uneconomic, and the sale of unpurified refrigerant resulted in large-scale damage to refrigeration and air-conditioning equipment from the use of unpurified refrigerant.[33]

The IPCC and others[34] recommend analysis prior to the start of a project to identify the motivations, desires and constraints of all parties involved in the technology transfer process. To illustrate this point, the IPCC summarized key stakeholders and their motivations in its special report on technology transfer. This summary is given in Table 2.2.[35]

Enabling environments and national settings

Technology transfer is more likely to succeed in a country with a well-developed national system of innovation, combined with public or regulatory pressure to stimulate change. Conversely, technology transfer is less likely to succeed when national innovation systems are weak and there is little pressure to drive technology change. National systems of innovation are generally defined as a network of institutions that influence the rate and direction of technical progress within a country. The OECD elaborates on this topic in its influential report 'National innovation systems'.[36]

The national system of innovation depends on business, government and educational institutions. Their actions and interactions determine the rate and