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BEST PRACTICES AND AVAILABLE TECHNOLOGIES IN THE 3RS – ACHIEVING ECONOMIC GROWTH WHILE IMPROVING RESOURCE EFFICIENCY

(Background Paper for Plenary Session 1 of the Provisional Programme)

Final Draft

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1. Introduction

Asia-Pacific is beginning to groan under the weight of its rapidly increasing urban and industrial waste. Of particular concern are municipal solid waste, electronic waste (e-waste), medical waste, plastics, construction and building demolition waste, and household hazardous and organic waste. Without proper management, these waste streams have adverse effects on human health, ecosystems, and environmental quality, and threaten to undermine the benefits of the region's rapid economic growth. The volume of waste seems to grow in a linear fashion with industrial production and its ever-increasing demands for natural resources. Decoupling economic growth from this burgeoning natural resource consumption and waste issue has become a priority for most countries in the Asia-Pacific region. The "reduce, re-use, recycle" (3Rs) approach is a key policy tool in achieving this outcome, and several countries have adopted national 3R strategies and related laws, regulations, and programs. In addition, UNIDO has launched a Green Industry Initiative which "foresees a world where industrial sectors minimize waste in every form, utilize renewable resources as inputs materials and fuels, and take every possible precaution to avoid harming workers, communities, climate or the environment"—the very essence of the 3Rs approach (UNIDO 2011).

To share experience on best practices, technologies, and policy instruments, a Regional 3R Forum in Asia was formed in November 2009. The inaugural meeting from 11-12 November, 2009, held in Tokyo, provided the overall direction and priorities for promotion of the 3Rs approach (http://www.uncrd.or.jp/env/spc/docs/tokyo_3r_statement.pdf). A Second Meeting of the Regional 3R Forum was held in Kuala Lumpur, Malaysia, from 4-6 October 2010 (the agenda and concept note are online at http://www.uncrd.or.jp/env/3r_02/doc/concept_note_3R_.pdf, with the Chair's summary at http://www.un.org/esa/dsd/resources/res_pdfs/csd-19/BackgroundPaper17KualaLumpur.pdf). The second meeting covered (i) transitioning to a green economy; (ii) partnerships for a low carbon and resource-efficient society; (iii) options for small and medium enterprises and the informal sector; and (iv) implementing 3R strategies and programs.

The Third Meeting of the Regional 3R Forum in Asia is planned for 5-7 October 2011 in Singapore, with the following objectives:

(a) "Address 3R technologies (including technologies that reduce virgin material input as well as technologies that encourage use of recycled resources);
(b) Address and identify policies and institutional frameworks for the promotion of the 3Rs technologies, including those that contribute to attracting investment and promoting business to business technology transfer;
(c) Address and identify opportunities for collaborative actions and partnerships including bilateral, multilateral and regional supporting mechanisms to promote 3R technology transfer; and
(d) Contribute towards enhanced regional input to the UNCSD 2012 (Rio+20) by addressing 3R technologies towards Green Economy."

The expected outcomes of the Forum include elevated awareness of available 3R technologies and their benefits—the topic of this background paper. Other expected outcomes are policy and institutional requirements for 3R technologies, partnerships for technology transfer, and contributions towards the regional inputs to the United Nations Conference on Sustainable Development (Rio+20) in 2012.

This background paper addresses resource efficient 3R technologies (both in upstream production processes as well as in downstream waste management), highlighting the wide range of benefits not only for the enterprises that apply such technologies but also for the three pillars of sustainable development. A number of case studies from various countries illustrate that this region can achieve multiple benefits by promoting the transfer and wider application of available 3R technologies.

As background, some useful definitions of the 3Rs are as follows (UNCRD 2010):

Reduce: "using things that you already have until the very end of their life cycle" and avoiding waste generation (by being careful about what you buy, buying "green" products, and buying only what you really need).

Reuse: re-utilizing goods and materials that are already in circulation (by choosing products that can be refilled or repaired, using goods for a lower purpose once the original use can no longer be satisfied, and sharing or giving away products that you no longer need).

Recycle: re-utilizing wastes as valuable resources (by sorting wastes into recyclable portions, extracting useful materials from waste, and using products made from recycled materials).

The Ministry of Environment, Japan (MOEJ) defines 3Rs as "(i) reduce – choosing to use things with care to reduce the amount of waste generated; (ii) reuse – repeated use of items or parts of items which still have useable aspects; and (iii) recycle – use of waste itself as a resource" (MOEJ 2005). Waste minimization is achieved by prioritizing reduce, followed by reuse, and finally by recycling.

The US Natural Resources Defense Council (NRDC) defines "reduce" as using fewer resources in the first place (by cutting back from where you are now) and "reuse" as, before you recycle or dispose of anything, consider whether it has any life left in it. Some examples of individual actions aimed at reducing use of resources that were suggested by NRDC included (i) buying products from recycled materials; (ii) choosing electronics, appliances, and cars that are energy efficient, or even sharing them with a neighbour or friend; (iii) buying locally produced goods, to reduce the energy used in transport; (iv) avoiding products made with materials derived from destructive extraction or production processes; (v) avoiding over-packaged goods; (vi) avoiding things made with toxic chemicals; (vii) cutting back on water and electricity use; and (viii) eating less meat. Examples for reuse include (i) using a jam or coffee jar to store leftovers; (ii) composting food scraps for a home garden; (iii) using an old shirt as a pyjama top; (iv) using an opened envelope for a shopping list; (v) sharing magazines and books; (vi) trading DVDs or other products on eBay; (vi) repairing a dishwasher or washing machine; (vii) upgrading a computer; (viii) donating a cell phone to charity; and (ix) returning reusable bottles (Eisenberg 2008).

Technology for 3Rs applies at all stages of the product cycle, from design, manufacture, by-products and waste minimization in the manufacturing stage, and purchasing, use, and disposal on the part of consumers. Governments have a particular role in legislation and policy, setting standards, reducing subsidies for environmentally unsound practices, implementing green procurement, and coordinating waste disposal practices. Governments can also help to close the loops between producers and consumers through new business opportunities such as UNIDO's chemical leasing approach, where businesses sell the services provided by chemicals, thus reducing ineffective use and overconsumption of chemicals and adding to bottom line profits.

In many ways, 3Rs is related to similar initiatives like resource efficiency, cleaner production, green industry, waste minimization and pollution prevention. Some related topics and their definitions include:

(i) Cleaner production – "the continuous application of an integrated preventative environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment" (UNIDO/UNEP/SECO 2010);

(ii) Resource efficiency – "the efficiency with which we use materials and energy throughout the economy, i.e. the added value per unit of resource input or emissions output" (UNEP/CSIRO 2011); and

(iii) Waste minimization – is a “waste management approach that focuses on reducing the amount and toxicity of hazardous waste that is generated” (LSUHSC 2005).

Chapter 2 highlights the 3R technologies in the context of resource efficiency – how 3R technologies in production processes and in waste management (including recycling) contribute to improving resource efficiency by reducing material input, reducing by-products and waste in the production processes, maximising the use of waste as resource, and minimising the amount of waste that ends up in the landfill. Chapter 3 focuses on the wide range of benefits which can be gained through 3R technologies, which may include the benefits to the enterprises (cost saving, CSR, international competitiveness), national economy (green jobs, greening the economy, circular economy, green growth, sound material-cycle society), society (less health risks and long-term health benefits), and environment (better quality of air, water, land, and low carbon society). Chapter 4 presents successful cases of introducing 3R technologies. Cases are selected from industrialized countries and developing countries from different parts of the world. Cases represent various sectors and scale of the enterprises (large, medium, and small). For each case, supporting policies, the costs involved in introducing the technologies, along with the benefits (economic, environmental and other) are addressed. Chapter 5 discusses how governments could create a conducive policy environment that promotes 3R technology transfer, adaptation and diffusion (scaling up inside the country). The final chapter summarizes the findings and provides concrete recommendations for the governments and for possible inclusion in the outcome document for the 3R Forum.

2. 3Rs Technologies and Resource Efficiency

Global waste generated in 2000 was 12.7 billion tonnes—projected waste levels in 2050 are 27 billion tonnes.
MOEJ (2008a) The World in Transition, and Japan’s Efforts to Establish a Sound Material-Cycle Society. Ministry of Environment, Tokyo, Japan.

At the heart of the 3Rs approach is a belief that sustainable development is only approachable through dematerialization of economic activities (i.e. decoupling energy and materials use from economic growth) and preservation of natural capital (Bartelmus and Vesper 2000). Resource decoupling is “reducing the rate of use of (primary) resources per unit of economic activity”, while impact decoupling is “increasing economic output while reducing negative environmental impacts” (UNEP 2011). Relative decoupling (lower resource or environmental impacts than the relevant economic indicator) is also distinguished from the more difficult to achieve absolute decoupling (where “resource use declines, irrespective of the growth rate of the economic driver”) (UNEP 2011). For nearly two decades, UNIDO and UNEP have helped to establish cleaner production centers in 47 countries focused on providing access of developing countries to advanced technologies that will assist businesses in achieving resource decoupling as well as improving environmental performance.

Achieving US or European standards of living globally without changing existing production and consumption patterns would require 2-3 additional planets to provide the necessary resources (King et al. 2010). Using the normative concept of global equity stemming from available environmental space or equal per capita access to energy and materials, the Wuppertal Institute posits a global goal of Factor 4—doubling wealth and human welfare while halving Total Material Requirement (TMR).[1] For developed countries, under current production modalities, this equates to Factor 10, thus creating additional environmental space for developing countries (Bartelmus 2002). In fact, TMR per capita has been leveling off for industrialized countries at 75-85 t/a (Japan is only 45 t/a), while Gross Domestic Product (GDP) has continued to grow, suggesting some decoupling (maybe also outsourcing manufacturing to

[1] As a rule of thumb TMR is about twice the actual amount of resource used (UNEP 2011).

developing countries), but still a long way from Factor 4 or Factor 10 (Bartelmus and Vesper 2000). To achieve sustainability, resource use per capita needs to fall to 5-6 t/a, just above the current level in developing countries like India (UNEP 2011). According to UNEP's International Resource Panel, "radical innovation will be required to achieve resource and impact decoupling" (UNEP 2011).

Material intensity of products is seen as a proxy of environmental degradation in a single throughput economy, where standard production processes generate huge amounts of waste and by-products and a product is used once and then thrown away. Resource productivity focuses on "new technology to reduce material inputs while generating the same or even better services from outputs" but because of the potential rebound effect (simply consuming more from the savings) efficiency in production processes needs to be combined with "sufficiency in final consumption" (Bartelmus and Vesper 2000).

The capitalist economy effectively weeds out businesses that are no longer competitive. To remain competitive, companies thrive on innovation, which is why they often spend a large proportion of their income on research and development. Fortunately, this producer behavior is perfectly matched by consumers, who thrive on novelty, and the desire to be the first to own some new product (Bartelmus and Vesper 2000). One only has to observe the long lines in front of stores to be the first to own a new cellular phone or computer to be convinced of this reality. Companies have also found the perfect match for assuaging the guilt of dumping an old but still useable product, by building in planned obsolescence, often just after the warranty period has expired. Sufficiency in final consumption, therefore, is partly negated by advertising (which drives brand switches as well as increased consumption), the availability of long-lasting and environmentally sound products on the market, and the psychological basis of mass consumption (King et al. 2010). These are all powerful forces that the 3Rs approach is attempting to combat.

Chapter 4 of Agenda 21 stated that "changing consumption patterns will require a multi-pronged strategy focusing on demand, meeting the basic needs of the poor, and reducing wastage and the use of finite resources in the production process (United Nations 1992). In most economies, at least 80% of the national economy can be attributed to private consumption (including government consumption which is mostly for the people), and with a trade deficit it often increases to over 100% (Lorek and Spangenberg 2001). Resource usage due to production and consumption is a proxy for environmental pressures, so households are both victims of environmental hazards, as well as co-producers. A focus on resource efficiency, therefore, needs to examine which sectors are most responsible for material extraction, energy consumption and land use, and the resulting environmental degradation from production and consumption in these sectors. In most economies, the construction and housing, food, and transport sectors account for nearly 70% of material, energy, and land use, so they should be prime targets for achieving resource efficiency (Lorek and Spangenberg 2001). Dematerialization in these sectors should decrease raw material inflows economy-wide and reduce outflows of wastes and toxic materials (Bartelmus 2002).

2.1 Reduce

For companies, reducing material and energy use, often characterized as "eco-efficiency", is seen as an opportunity for innovation and saving factor-related costs at a profit, rather than an economic threat (Bleischwitz 2002). For example, making PET bottles thinner and lighter, smaller household appliances with fewer working parts, and smaller, lighter, fuel-efficient vehicles, all help to reduce material content. For households and individual consumers, reducing consumption, or at least cutting back on environmentally damaging consumption, is the primary goal. While, savings may result, there is considerable concern that money may simply be diverted to consuming more of equally damaging products. The classic example is improved fuel efficiency of vehicles that simply results in increased kilometers driven (Jenkins et al. 2011). Therefore, the eco-efficiency goal must be amended to add that savings should be used for less environmentally damaging goods or services.

Some Typical Technologies

- Nanotechnology
- Organic/green chemistry
- Biotechnology
- Information technology for eco-labeling
- Eco-efficient transport/electric cars
- Car-share technologies
- Mass transit
- Renewable energy
- Household water saving

Nanotechnology and green chemistry offer considerable raw material advantages over current production methods, by either reducing raw material inputs or reducing toxic waste by-products or end of life wastes that are difficult to recycle (Roco et al. 2010).[2] The New Energy and Industrial Technology Development Organization (NEDO) in Japan, for example, is developing nanotechnology based materials in the information and telecommunications sectors, energy, resources and environmental uses, and materials and components areas (NEDO 2011). Some examples include (i) nitride semiconductors to replace silicon and gallium arsenide for order of magnitude reduction in energy consumption; (ii) energy reducing insulation for houses and other buildings using multiceramic layer insulation materials with nano-size multiporous structures; (iii) carbon fiber reinforced polymer materials (one quarter as heavy but ten times as strong as iron) for recyclable materials in cars, railcars and planes; (iv) development of high value-added rare metal substitute materials, for platinum (for exhaust gas purification), iridium, dysprosium, cerium, terbium, europium, and tungsten; (v) reducing weight of vehicles using magnesium alloys manufactured by improved forging technology; (vi) development of metallic glass for next generation recording media, nanomotor parts, and high strength, high conductivity electrical contact parts; and (vii) reduced energy consumption in steel manufacturing (NEDO 2011).

Green chemistry is “an approach to the design, manufacture and use of chemical products to intentionally reduce or eliminate chemical hazards” (Anastas and Warner 1998). The primary areas being addressed by green chemistry in industry are (i) use of alternative feedstocks; (ii) use of innocuous reagents; (iii) employment of natural processes and biomass; (iv) use of alternative solvents; (v) safer chemical design; (vi) development of alternative reaction conditions; and (vii) minimization of energy consumption (Lempert et al. 2003). At the consumer level, some familiar products include tennis balls with clay nanoparticles to slow the escape of air from the ball, stain resistant clothes, self-cleaning glass on high rise buildings, sunscreens, nano-sensors, fleece lining of jackets from PET bottles, paints without volatile organic compounds, plastics made from renewable biomass, and recyclable carpet tile backing (polyolefin resins with low toxicity) (Clean Production Action 2009).

Biotechnology is also learning from nature, particularly from increased knowledge of genomes, and has found multiple applications in pharmaceuticals, food production, energy and manufacturing. Extremophiles (bacteria that live in extreme environments) are being tapped to find genes that will adapt

[2] Like all new technologies, there are cautionary notes from various observers on the uncertain impacts of nanotechnology ranging from environmental concerns to the world being consumed by “gray goo” (Drexler 1986). Similar cautions are also voiced about biotechnology and genetically modified organisms.

commercial plants to saline or toxic soils, while other gene transfers are taking place to enhance desirable features like long storage life or herbicide resistance. The extent to which biotechnology will reduce resource consumption, however, will vary from case to case.

Technologies for reduction of greenhouse gas (GHG) emissions stretch into the hundreds and can be classified under (i) common industrial systems; (ii) sector-specific systems; (iii) transportation systems; (iv) top runner equipment; (v) renewable energy technologies; (vi) green technologies; and (vii) other GHG reduction technology (NEDO 2008). Typical examples include renewable energy, hybrid and electric vehicles, mass transit, energy efficient household appliances, building insulation, and energy conservation, among many others. Investment recovery periods range from a few months to several years.

2.2 Reuse

The spirit of reuse is captured in the Japanese word "mottainai" which loosely translated means "it would be a shame to waste it" if the product still has a potential use. The classic example from Japanese tradition is an expensive kimono which is passed down from generation to generation but eventually can be repaired no longer. Then the remaining cloth can be cut up and used as diapers or cleaning cloths, and ultimately, when only a few threads are left, the used cloth can be added to the compost heap (MOEJ 2008b). In other countries, the market in antiques, Chinese porcelain, and artworks, where the older the more valuable principle often applies, is a further illustration of the contrast with modern mass consumption.

Some Typical Technologies

- Information technology – eBay, PayPal
- Exchangeable/reusable parts
- Multi-purpose design
- Antiques/Thrift Stores
- Containers (e.g. glass bottles)
- Used cars, cell phones etc.
- Used book sales, sharing schemes, leasing

From a technological perspective, it may seem strange to suggest that modern technology may facilitate a new lease of life for this ancient tradition of reuse. Nevertheless, modern information technology is playing an important role in promoting reuse, with online exchange sites like eBay, payment systems like PayPal, and sharing schemes like car share. One particularly interesting example is the use of a special toner in photocopiers and printers that can be erased allowing the sheets of paper to be used 5-10 times (MOEJ 2007).

Other technological advances that promote reuse are design for environment features that allow cost-effective repair when a component breaks, containers that can be refilled, and returnable/reusable containers (such as glass bottles). Biomimicry is an important approach for design for environment. Typical examples of biomimicry include Velcro, passive cooling, gecko tape, whalepower wind turbines, lotus-effect hydrophobia, self-healing plastics, golden streamlining, artificial photosynthesis, bionic cars, morphing aircraft wings, biosilification, friction reducing sharkskin swimsuits, insect inspired robots, and butterfly-inspired displays. Research on extracting order of magnitude higher efficiency from wind power was inspired by the behavior of schooling fish. Finally, new technology, such as 3D printing, can help to design and manufacture collectable products that will become the modern equivalents of antiques.

2.3 Recycle

Of all the 3Rs, recycling has tended to be the focus of most governments, households, and companies. The intermediate steps where potential new recycling technology can be applied include (i) segregation; (ii) collection and transport; (iii) storage; (iv) intermediate treatment (such as incineration, composting, shredding, and compacting); and (v) final disposal (MOEJ 2007). Various attempts at improved technologies for waste collection, such as piped or vacuum systems, have tended not to be viable due to segregation and economic issues (MOEJ 2007). Other improvements have included electronic manifests, GPS and electronic chips to keep track of hazardous wastes, including medical wastes.

Some Typical Technologies

- Composting
- Urban mining
- Recycled building materials
- Waste recycling systems
- Eco-design
- E-waste recycling of rare minerals
- Waste to energy
- Household appliances
- Paper and cardboard recycling

Perhaps the most controversial technology at the intermediate treatment stage is incineration. Incineration reduces the volume of waste (to about 5%), destroys bacteria and most toxic materials, and allows energy to be recaptured. Incineration plants are classified into (i) mechanical stoker types; (ii) fluidized bed incinerators; (iii) fixed floor furnace types; and (iv) rotary furnace types (MOEJ 2007). Combustion gas temperatures are kept over 800^{o}C to break down toxic compounds. Most of the continuous burning incinerators provide stable waste heat recovery and most of the 300 tonne per day or greater facilities have boilers for electricity production. Gasification melting furnace technology has been introduced to neutralize hazardous substances in the waste gas (especially dioxins) and to recover heat (MOEJ 2007).[3]

Current technology that allows material recovery from the waste stream includes (i) mercury from fluorescent light bulbs; (ii) zinc and manganese from domestic batteries; (iii) lead from car batteries; (iv) a wide range of plastics; (v) building materials, including wood; (vi) paper and cardboard; (vii) glass; (viii) aluminum and steel cans, plus other metals (scrap iron, copper, aluminum etc.) and rare metals; (ix) vehicle oil and grease; and (x) cooking oil, among many others. One particularly intriguing example is recycled ring pulls from aluminum cans being recycled into the frames of wheelchairs. Multiple recycling options exist for some products such as used tires, which can be used as a firing fuel in cement production, a material for cement production, a source of thermal energy, safety equipment for children's playgrounds,

[3] From 1997 to 2004, Japan was able to reduce dioxins emitted from waste incineration by 98%, while electricity generated increased by 2.2 times (MOEJ 2007).

or an additive for road surfaces (MOEJ 2007). Multiple technologies, such as composting, fermentation, carbonizing, liquefying, or distilling can take food or wood wastes and recycle them into usable products such as biofuels, charcoal, vinegar, light oil, or livestock feed. Incineration ash is recycled into eco-cement, with some heavy metals recovered in the process (MOEJ 2007). Pyrolysis (or partial combustion) of organic wastes can produce biochar which is an effective soil conditioner as well as a means of carbon sequestration.

Box 1. Composting Organic Waste in Indonesia

Contrasting experience from Indonesia shows the importance of low-tech composting technology and creation of viable markets for the product. In Surabaya, community-based composting was introduced under the Kitakyushu Initiative for Clean Environment, with free compost baskets distributed to 16,000 households. The city recorded a 10% waste reduction, households reduced 16 t/d of organic waste, and 12 composting centers reduced organic waste by 40 t/d. The Surabaya city government provides the market for the compost, using it in city parks. This success was replicated elsewhere in Indonesia and in the Philippines.

Under the World Bank/GEF Western Java Environmental Management Project, a compost subsidy program was initiated in Jakarta, Banten, and Western Java provinces, funding 45 small to large composting plants. The project was successful in producing 218 t/d of compost, but there was insufficient involvement of stakeholders and no clear market for the compost. As the project relied heavily on subsidies, after three years almost half of the composting plants had ceased production.

Source: Sang-Arun, J. (2011) Practical Guide for Improved Organic Waste Management: Climate Benefits through the 3Rs in Developing Asian Countries. Institute for Global Environmental Strategies, Hayama, Japan.

3. Economic and Other Benefits of 3Rs Technologies

The United States Environment Protection Agency (US EPA) has promoted recycling on the basis that it generates significant economic, social and environmental benefits for communities.[4] The Office of the Federal Environmental Executive estimated that recycling and remanufacturing industries alone account for about one million manufacturing jobs and at least $100 billion in revenue in the US. Recycling employs a wide range of skilled and unskilled workers in jobs ranging from materials handling and processing to high-quality product manufacturing. More importantly, the drive for eco-efficiency and use of recycled materials triggers technological innovation, important for long-term economic growth.

Investments in the collection and recycling equipment also have flow through multiplier effects on the economy, employment, environmental protection, and contribute to economic growth. The social and environmental benefits of 3Rs technologies are enormously important. Recycling promotes the sustainable use of non-renewable and renewable natural resources, both domestic and imported. Public participation and community-based recycling activities promote community development and coherence while reducing the need for new landfills, preventing pollution, saving energy, and reducing greenhouse gas (GHG) emissions.

For companies, the benefits of a 3Rs approach are generally reflected in the triple bottom line, with higher resource efficiency generally providing direct financial benefits and adding to profitability. For example,

[4] http://www.epa.gov/osw/conserve/rrr/rmd/econ.htm accessed 25 August 2011.

Japan provides a wide range of economic incentives for companies to develop and adopt 3Rs technologies including (i) low interest loans; (ii) special depreciation and fixed asset taxes for 3R-related equipment; (iii) interest subsidies; (iv) loan guarantees; and (v) other support measures. Firms designing products for reuse and recycling may have a competitive, first mover, advantage and achieve a greater market share from environmentally aware consumers (Guide and Wassenhove 2000). As part of their corporate social responsibility, an improved company reputation may generate increased attention from ethical investors and from highly qualified staff, who want to be associated with an innovative company. Green procurement policies that are increasingly popular with governments in many countries also provide major opportunities for companies focusing on "green" products.

For the individual consumer, considerable social welfare benefits accrue from changes in attitudes and behavior towards the 3Rs. Much of the difficulty in promoting recycling of household waste in the past was due to the extra effort that separating waste, returning bottles, or sending large items to recycling centers entailed (Young et al. 1993, Lave et al. 1999). Over the past decade, curbside recycling and acceptance of mixed recyclables, plus increased environmental awareness, have made enormous inroads in the task of reducing the amount of household wastes going to final disposal (Morris 2004). Lifestyle changes that aim at increased demand for services over ownership of goods, such as car sharing, moving from car to bicycle, and buying only organic food, are becoming mainstream in some countries, although still far from the majority, anywhere (King et al. 2010).

Households have also benefited from the shift away from uncontrolled landfills as the dominant waste disposal technology. For example, evidence suggests that property prices are severely affected by proximity to a landfill site, with the disamenity cost ranging between $3.05 to $4.39 per compacted tonne of garbage (Kinnaman 2006). In general, household willingness to pay for curbside recycling is almost double the average operating costs (Kinnaman op. cit.).

For governments, the 3Rs have highlighted the fundamental changes in industry, commerce, government and household consumption that are needed if progress is to be made towards sustainable development. Through changes in policy to promote the 3Rs, technological innovation and new economic opportunities have been created, although increased attention to the enabling environment is sorely needed (UNIDO 2011a, 2011b). The 3Rs are also an effective policy approach for providing alternative energy sources, reducing GHG emissions (UNEP 2010), reducing damage to roads from transportation of waste, and resulting in considerable trade benefits (Kinnaman 2006). The climate change benefits from improved waste management are due to "avoided landfill emissions, reduced raw material extraction and manufacturing, recovered materials and energy replacing virgin materials and fossil-fuel energy sources, carbon bound in soil through compost application, and carbon storage due to recalcitrant materials in landfills" (UNEP 2010). Governments and private companies may also achieve climate change and economic benefits from the application of the Kyoto Protocol's Joint Implementation and Clean Development Mechanism, which have helped to improve the economic viability of landfill gas capture.

In rural areas, the annual generation of 140 billion tonnes of biomass (equivalent to about 50 billion tonnes of oil) represents a huge, largely neglected, opportunity to recover energy and raw materials from waste (UNEP 2009).[5] Available technologies for conversion of cellulosic biomass wastes to energy can be divided into thermo-chemical conversion (combustion, gasification, pyrolysis liquefaction) and biochemical conversion (fermentation), providing heat, electricity, and bio-fuels as outputs. Technologies for conversion to materials include bio-reduction, bio-refining, decortication, hot melt, hydro-separation, molding, pulping, tuxying, and twining (UNEP 2009). Benefits include reduced economic, social and

[5] "Biomass wastes include agricultural wastes, such as corn stalks, straw, sugarcane leavings, bagasse, nutshells, and manure from cattle, poultry, and hogs; forestry residues, such as wood chips, bark, sawdust, timber slash, and mill scrap; municipal waste, such as waste paper and yard clippings" (UNEP 2009).

environmental benefits (such as reduced GHG emissions, reduced deforestation for firewood, and replacement of extraction of virgin materials). In future, many industrial processes, including nanotechnology and green chemistry will turn to biomass wastes as a raw material source.

4. Learning from Success – Case Studies

4.1 Japan – Sound Material Cycle Society

In many ways, Japan's efforts to establish a sound material cycle (SMC) society domestically and their attempts to internationalize the process, stand as the dominant case study globally, extending from community level SMC blocks to the East Asian region (Bleischwitz 2002, METI 2004, 2010, MOEJ 2008a, MOEJ 2008b). The 3R approach in Japan was designed to tackle two interrelated problems—a mountainous terrain, with little flat land available for landfills and increasing reliance on imported raw materials. Japan uses about 1.82 billion tonnes/year (t/yr) of resources, generates about 470 million t/yr of wastes, and has available final disposal sites of only 15.6 years for general waste and 7.7 years for industrial waste at current waste generation rates (METI 2010). Although the Government built on tentative early efforts dating back to the plague epidemic in 1887 and the subsequent passage of the Unsanitary Substance Cleaning Law in1900, the milestone year for 3Rs was 2000, when the following laws were passed:

(i) Basic Law for Promotion of a Recycling Oriented Society;
(ii) Waste Management Law
(iii) Law for Promotion of Effective Utilization of Resources;
(iv) Food Recycling Law; and
(v) Green Purchasing Law

Additional laws passed in subsequent years include (i) Home Appliance Recycling Law (2001); (ii) End of Life Vehicles Recycling Law (2005); and (iii) Containers and Packaging Recycling Law (amended 2006). Other relevant laws include the Basic Environment Law (1993) and the Energy Saving Law (1999), which introduced the "top runner" approach to improved energy efficiency. In January 2001, the Environment Agency was upgraded to the Ministry of Environment (MOEJ), although responsibility for some of these laws remains with the Ministry of Economy, Trade and Industry (METI) (Bleischwitz 2002).

In 1963, the Government set up the First Five Year Plan for Development of Living Environment Facilities, which marked a transition to incineration of urban waste, with the considerably reduced residues sent to landfills. In 1970, Fukuoka City introduced semi-aerobic landfills, which have significantly reduced emissions of GHGs and accelerated decomposition. In 1976, Hiroshima City introduced waste segregation, sorting wastes into combustible, non-combustible, recyclable, large-sized waste, and hazardous waste (MOEJ 2008a). The Recycling Promotion Association, established in 1991, was renamed as the Reduce, Reuse, Recycle Promotion Association in 2002.

These successful technological and institutional innovations and the ever-increasing waste volumes convinced the Government to introduce the Basic Plan for Establishing a Sound Material-Cycle Society in 2003, to be reviewed every 5 years (METI 2010). The Second Plan (2008) established quantitative targets for 2015 including:

(i) Material productivity from ¥210,000/t in 1990 to ¥420,000 in 2015;
(ii) Usage rate of recycled goods from 8% in 1990 to 14-15% in 2015; and
(iii) Final disposal from 110 million tonnes in 1990 to 23 million tonnes in 2015.

In addition, various indicators have been added to measure the level of effort put into implementation of the 3R initiative (such as reduction of municipal solid waste and industrial waste, change in awareness and behavior, promotion of SMC businesses, and strict enforcement of recycling laws) and to set up the baselines for future policies (e.g. resource productivity of fossil fuels, biomass resource input rate, hidden flows and total material requirements, industry specific resource productivity, and sales of disposable products).

To achieve these targets, a wide range of technologies have been introduced in private companies, households, and the government (Table 1). Future technology development under the 3R Technology Development Program is focused on (i) recovery of rare metals from lithium ion batteries; (ii) accurate separation of plastics by material; and (iii) materials substituting for rare metals (including through nanotechnology) (METI 2010).

Table 1 3R Technologies Utilized in Japan

Application	**Typical technologies**
Container and packaging reduction	Reduce waste through use of thinner PET bottles, development of refillable bottled products, replacement or refills for bottled products (e.g. liquid soap, detergent)
Home appliance reductions	Reduced number of component parts, smaller parts, reduced weight by modularization, extend useful life of products like personal computers
Vehicle-related reductions	Reduced vehicle body weight through increased use of aluminum, extend useful life of engine oil by increasing designated replacement intervals
Reuse of copiers	Reuse exterior components through improved cleaning technologies, as well as reused drive unit and other interior components
Reuse of slot machines	Reduce amount of resources for new slot machines by encouraging reuse of existing machines
Reuse of vehicles	Restore and recondition vehicles by replacing worn or broken components with parts removed from end-of-life vehicles
Eco-designed home appliances	Designs incorporating ease of decomposition, using product assessment projects and washing machines as pilot cases
Eco-designed vehicles	Adoption of recycling conscious resources, such as recycled materials, and the use of the Easy Disassembly Mark labeling system
Recycling of waste containers and packaging	Material recycling and chemical recycling for waste plastic, aluminum cans, and PET bottles
Recycling of end-of-life vehicles	Recycling of aluminum wheels, shredder dust, and waste tires
Recycling end-of-life home appliances	End-of-life home appliance recycling flow and utilization of recycling to provide more added value to the product (closed recycling)
Recycling of construction waste	Technologies to sort mixed construction waste and recycle construction sludge
Recycling of food waste	Technologies to produce compost and eco-feeds and to recycle food waste for other uses, such as bio-fuel (e.g. used cooking oil)
Paper recycling	Technologies to manufacture pulp from used paper to produce recycled paper and cardboard
Recycling technology for non-burnable waste and large discarded articles	Technologies to crush/shred and sort non-burnable waste and large discarded articles in order to recycle valuable materials
Recycling of	Eco-cement manufactured mainly (50%) from wastes such as urban waste

incineration ash	incineration ash and sewage sludge
Waste to power generation	Waste power generation systems utilizing waste heat from incinerators (industrial and municipal solid waste)
Biomass power generation	Power generation systems using biomass such as wood chips, rice hulls, and bagasse (from sugarcane processing)
Refuse derived fuel	Produced by shredding and drying burnable waste and removing any impurities
Refuse derived paper and plastic fuel	Produced mainly from used paper and difficult to recycle waste plastic included in industrial waste
Biodiesel fuel	Used as a substitute for light oil in automotive diesel engines
Bioethanol	Mainly from waste construction wood with other organic wastes like waste paper and food residues
Iron, copper, aluminum recycling	Technologies and material flows to collect and recycle iron, copper, and aluminum scrap
Rare metals, heavy metals	Technologies to recover and recycle rare metals and heavy metals from waste, as an extension of existing smelting technology

Source: Based on MOEJ 2008a

Initial indications are that the 2015 targets are likely to be met. Municipal solid waste peaked in 2000 at 1.2 kg/cap/day and has declined to 1.0 kg/cap/day. The recycling rate increased from 4.5% in 1989 to 20.3% in 2007. Out of 41.97 million tonnes of municipal solid waste treated, 9.78 million tonnes were recycled. For the six major industry sectors that account for 80% of industrial waste (419 million t/yr), 52% is recycled, 43% reduced, and only 5% finally disposed of (METI 2010). METI's Industrial Structure Council provides guidelines and voluntary targets for waste treatment and recycling for 35 product categories and 18 sectors. Industrial Associations have developed their own "design for environment" guidelines to evaluate the safety, resource, and environmental impacts of their products at all stages of the life cycle and to amend the designs and production methods as necessary (METI 2010).

To select only one specific case study from Japan is to do injustice to the multiple excellent efforts in all parts of the country, by local governments, communities, and companies. The case study in Box 2, however, is instructive because the best of intentions and a carefully crafted integrated scheme eventually proved impractical, partly due to a missing element in the technological mix available at the time.

Box 2. Urban-Rural Environmental Connections Plan

In 1980, Toyohashi City started requiring its residents to separate household garbage into five categories to facilitate more effective use of waste. In the same year, five plants were built on a combined site to enable the integrated treatment of waste (i) waste incineration plant; (ii) composting plant, (iii) sorting and crushing plant; (iv) chicken feces drying plant; and (v) sewage disposal plant. The heat generated from incineration of combustible waste and residues from the composting plant was used for heating an adjacent greenhouse complex and for generating electricity. The plan also involved the production of compost from combustible waste and sewage sludge for use by local farmers as fertilizer. However, plastic consumption by local residents increased year after year, eventually making it impossible to produce good quality compost from the combustible waste.

Although Toyohashi City was unable to accomplish its original goals, the attempt to construct an integrated mechanism in which urban waste is used on farms while the food produced is supplied to urban communities, in return, is similar to the current concept of constructing a recycling loop under the Food Waste Recycling Law, and can be regarded as a pioneering attempt in Japan to establish a Sound Material Cycle block. The missing element of technology that would have made the experiment more viable was a cost-effective way of identifying and removing waste plastic from the composting process—a technology that has since been developed (see for example: http://www.airliftseparator.com/website/).

4.2 Green Chemistry

As indicated above, green chemistry involves reducing or eliminating the use of hazardous materials or replacing environmentally damaging chemicals. These technologies offer reductions in resource use, ecosystem damage, ozone depletion, waste disposal, toxic wastes, and greenhouse gas emissions (Lempert et al. 2003). Table 2 shows the results of 25 case studies, where either significant savings have already been demonstrated or the technology shows particular promise. As just one example, new inert anodes for the highly energy intensive aluminum smelting industry have allowed a reduction in the anode-cathode distance of a few centimeters, reducing the energy for smelting by 25%, eliminating carbon and fluorocarbon emissions and reducing cyanide and particulate emissions during anode manufacture and use. Potential annual savings were estimated at approximately $110 million/year (Lempert et al. 2003).

Table 2 Next Generation Environmental Technologies using Green Chemistry

Case Study	Environmental/Energy Benefits	Security/Safety Benefits	Performance/Economic Benefits
Processes using supercritical CO_2 solvent (in cleaning, coffee decaffeination, polymerization solvent)	Elimination of chlorinated solvents; used CO_2 is recycled in closed loop systems	Reduced exposure to solvent vapors	Improves economics and performance
Three steps for ibuprofen (a pharmaceutical)	Elimination of 35 million pounds (lbs) of waste		Reduced investment and operating costs
Converting polymers to monomers for recycle: PET and Nylon 6	Elimination of up to 100 million lbs per year of PET from landfills; 200 million lbs of Nylon 6 diverted from landfills; air emissions reduced by 89%		
47 bio-based processes	Average 20% reduction in waste, elimination of hazardous chemicals in mining, pulp and paper, and speciality chemicals	Reduced exposures, reduced critical metals, reduced storage of chlorine	Implemented where superior economics prevail; provides improved performance and entry to new markets
Dimethyl carbonate manufacture and use	Could eliminate use of phosgene in the manufacture of polycarbonates and polyurethanes		
Direct production of hydrogen peroxide from hydrogen and oxygen (using carbon dioxide as a solvent)	Eliminates waste streams; reduces energy use by eliminating 3 energy-intensive units: oxidation reactors, stripping column, and distillation train	Safety a continuing concern in any manufacturing process for hydrogen peroxide	Cheaper hydrogen peroxide could find greater use in green chemistry
Advanced oil and gas exploration and production	Reduced waste and energy use, no harm to groundwater	Increased worker safety	Lower cost operation
Water purification (chemical, membrane, ultraviolet etc.)	Eliminate use of chlorine	Enhanced security	Lower costs, availability when otherwise not possible
Wood preservation (Replace chromate copper arsenate with alkaline copper quaternary)	Virtually eliminates use of arsenic, use of 64 million lbs of hexavalent chromium and hazardous wastes	Avoids worker exposure in wood treatment	Replacement at increased direct cost
Elimination of ozone depleting chemicals (in printed wire board and electronics)	Completely eliminated the use of CFCs and other ozone depleting substances	Eliminated potential exposure to methyl chloroform	Replacing CFCs with water or no-solvent processes translate to cost savings

Delignification and bleaching of pulp in paper manufacture (use of air in place of sulfur and chlorine)	Eliminates formation of dioxin and other organo-chlorine waste products	Eliminates use of chlorine or chlorine dioxide	
Clean solvent extraction using polyethelene glycol-based aqueous biphasic systems	Technology that would completely eliminate the use of volatile organic compounds		Immediate environmental and economic benefits
Room temperature ionic liquids (used as solvents for catalytic reactions)	Concerns on potential toxicity and environmental impact still need to be studied	Potential to reduce worker exposure to volatile solvents	
Environmentally friendly refrigerants, new refrigeration processes (trifluoro methyl iodide, hydrofluoroethers, and non-chemical cooling)	Carbon dioxide emissions down by 4 million t/yr, particulates down by 12,000 t/yr, NO_x down by 16,000 t/yr, and SO_2 down by 24,000 t/yr.		
Clean diesel breakthrough with compact advanced polymer membrane	Reduces NO_x by 15% and particulates by 60%		
Biodegradable polymers	Eliminates litter; energy savings need to be determined by life cycle analysis		
Capture of nitrous oxide in adipic acid manufacture to use in new phenol process	Can recycle 250 million lbs of nitrous oxides on start up of a full-scale plant		
Advanced oxidation process for the metal casting industry (to avoid volatile organic compounds)	Decreased emissions by 20-75%; diminished by 15-40% the amount of clay, coal, and sand for castings, and reduced casting defects by up to 35%; prevents pollution and reduces wastes to landfills	Worker exposures decreased	Cost savings are claimed for the process
Process for fluorobenzene (copper fluoride catalyst with catalyst regeneration)	Major reduction of waste potential		Potential cost saving
Synthesis of 4-amino-diphenylamine	Elimination of chlorine, major reduction in wastes	Eliminated worker exposure to chlorine	Major cost reduction
Synthesis of glyphosphate (zero waste process)	Eliminated 1 kg of waste for each kg of disodium aminodiacetate; waste contained cyanide and formaldehyde	Eliminated worker exposure to hydrogen cyanide and formaldehyde	Cost reduced by 40% from 1995 to 2002

Source: Based on Lempert et al. (2003)

4.3 Municipal Solid Waste Management Technologies

Until the 1980s, local governments in most countries simply collected mixed waste from households and businesses in urban areas and dumped them in uncontrolled landfills on the outskirts of town, often setting the dumps alight to reduce the volume. Scavengers, rats and livestock picked over the scattered waste to retrieve anything of value. As noted by Barnes (1982) “almost none of the recycled materials tonnage comes from solid waste. Once a product is in the waste can, it is almost certainly destined for disposal.” Gradually, concerns over leachate contamination of groundwater, odor and flies, and fugitive litter, especially where housing crept closer to the landfill sites, plus (a largely unjustified) concern that landfill sites were in short supply, lead to various policy measures that resulted in reduced amounts of solid waste being landfilled, as well as improved technology for controlled landfills, often at larger regional sites (Erikkson et al. 2005, Boyle 2000, Metin et al. 2003, Sundqvist et al. 2002, Palatnik et al. 2004). The increased costs of landfilling occasioned by improved technologies and larger transportation distances also improved the economic viability of recycling, materials recovery, and alternative waste disposal technologies, such as incineration and waste-to-energy facilities (Themelis 2003, Kinnaman and Fullerton 1999, Morris 2004).

Subsequently, as the range of choices expanded, there was considerable uncertainty about the best technological approach to dealing with municipal solid waste, depending on national circumstances. For example, Boyle (2000) noted "the New Zealand waste management and pollution prevention program was found to be vague, lacking in direction and funding, and would not succeed in reducing waste production or effectively managing waste." In 1995, only 8.5% of waste was recycled in New Zealand, despite 80% of households having access to a recycling program (Boyle 2000).

Box 3. Landfill Mining in Belgium

Landfill mining is becoming a new and innovative business model. Near Brussels, a landfill containing 16.5 million tonnes of municipal waste has been bought by a Belgian waste management company that intends to recycle about 45% of the content, with the balance converted to electricity, over a period of 20 years. Partnering with a UK energy-to-waste company, non-recyclable material will be converted into natural gas, generating electricity for 100,000 houses, with the residue converted into a building material. As there are about 3 billion tonnes of trash projected to be disposed in landfills by 2030, rising prices of recycled materials and renewable energy and carbon credits will make this form of business highly profitable, and the sites potentially returned to nature reserves or public parks.

Source: Vijayaraghavan, A. (2011) Belgian Company Leads the Way in Landfill Mining. Triple Pundit, 16 September 2011.

Typical of several countries concerned about the environmental and health consequences of landfilling, Sweden imposed a tax on landfilled waste in 2000, banned landfilling of combustible waste in 2002, and organic waste in 2005 on the grounds that reduced landfilling (in favor of recycling energy and materials) leads to lower environmental impact, reduced energy consumption, and lower economic costs (Eriksson et al. 2005).

By way of contrast, in the United States (US), imposition of the Resource Conservation and Recovery Act (1976) set modern technology standards for landfills, such as thick lining, collecting and treating leachate, monitoring groundwater contamination, and covering waste with soil quickly, which led to many small landfill sites being closed down and larger regional sites opened up. As the economic advantages of landfills over other technologies changed, many local governments began to set up less expensive incineration facilities and passed laws mandating that all local garbage must be brought to the incinerators. The Supreme Court struck down those laws, ostensibly due to restraint of interstate trade, and also ruled that incinerator ash is toxic and must be disposed of in expensive toxic waste landfills, thus pushing more solid waste back into large, regional landfills (Kinnaman and Fullerton 1999). In 1991, the US Environment Protection Agency (EPA) established new federal standards for landfills and modern landfill technology now includes capture and use of flammable gases, like methane (a potent greenhouse gas), 99-100% removal and treatment of leachate, and reclamation for productive uses once the landfill site is full (National Solid Wastes Management Association undated). Sanitary landfill, therefore, remains a preferred technology in many countries with plentiful land area and a widely distributed population.

Incineration has proven to be one of the most controversial technologies for municipal solid waste treatment. As noted by Pickin et al. (2002) incineration is not practiced widely in Australia "because of community fears that incinerator emissions may pose a health risk." In the Philippines, incineration was banned in the nation's Clean Air Act (1999), largely due to nongovernmental organization (NGO) protests over dioxin emissions and likely health impacts.[6] In the US, in the 1980s, waste-to-energy plants

[6] http://www.emb.gov.ph/mmairshed/Policies/ra8749-clean%20air%20act.pdf

were seen as major sources of mercury, dioxin and furan emissions. The Maximum Available Technology regulation in 1995 resulted in $1 billion being spent on retrofitting pollution control systems and now the US EPA claims that the 2,800 MW of electricity generated from waste-to-energy plants results in less environmental impact than almost any other energy source. Dioxin emissions have decreased from 4,260 grams (g) toxic equivalent in 1990 to 12 g in 2000, well below the European Union limit of 0.1nanogram per cubic meter (ng/m^3) (Themelis 2003).[7] In 2000, the European Parliament issued Directive 2000/76/EC on the incineration of waste to protect the public from a potential expansion of the number of incinerators. The Japanese Government in 1999 announced a reduction of dioxin emissions target (for 2002) of about 88% below the 1997 level (6,841-7,092 g toxic equivalent from incineration) and issued the Dioxin Reduction Special Measures Law in 2000. The results indicate a 95% reduction in dioxins emitted between 1997 and 2003 (Yoshida et al. 2009) and 98% by 2008.

Contrary to popular belief, dioxins and furans are reformed downstream of the furnace/combustion chamber, in the heat recovery boiler and during dust removal, during cooling of the flue gas, rather than as a direct result of combustion. In fact, high temperature combustion is one of the few ways to destroy these chemical compounds. Combustion temperatures of at least 1,200 ^oC, with flue gas residence time of at least 2 seconds, and an oxygen content of at least 6% by volume, are needed to destroy these compounds. Well designed and operated waste incinerators are now capable of removing 99.99% of PCDD/PCDF, making them “a rather insignificant source” (Hartenstein and Licata u/d). Typical technologies include adsorbent injection, entrained flow reactor, activated carbon reactor, and tail-end catalytic oxidation, although lower cost alternatives are also being developed.

A (slightly dated) compendium of solid waste management technologies and best practices is maintained by UNEP’s International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management (UNEP 1996) so a full description of alternative technologies is not included in this background paper. Comparison of the various technologies has increasingly relied on life cycle assessment (Eriksson et al. 2005, Sundqvist et al. 2002, Morris 2004, Pickin et al. 2002, Zaman 2010). Some key observations from this body of work are as follows:

(i) The differences between materials recycling, nutrient recycling and incineration are quite small, while landfilling contributes most to global warming potential and is the most expensive treatment (Eriksson et al. 2005);
(ii) Recycling of plastics is the most expensive recycling option but results in the lowest environmental impacts (Eriksson et al. 2005);
(iii) Mass burning to recover energy from waste is the best practice environmental option (for a typical English county) closely followed by fluidized bed energy from waste (Sunqvist et al. 2002);
(iv) “Recycling of newspaper, cardboard, mixed paper, glass bottles and jars, aluminum cans, tin-plated steel cans, plastic bottles, and other conventionally recoverable materials found in household and business municipal solid waste consumes less energy and imposes lower environmental burden than disposal of solid wastes via landfilling or incineration, even after accounting for energy that may be recovered” (Morris 2004);
(v) Energy conservation and pollution prevention from recycling is much greater than the added energy for collecting, processing, and transporting to end users (Morris 2004);
(vi) For the proportion of paper wastes not recyclable in Australia, waste-to-energy is the most effective option (Pickin et al. 2002); and

[7] Since polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) comprise 75 and 135 cogeners respectively, with varying levels of toxicity, the dioxin/furans group is referred to in terms of toxic equivalents, normally measured in ng/m^3 (Hartenstein and Licata u/d).

(vii) Comparing sanitary landfill, incineration, and gasification-pyrolysis in Sweden, landfill with energy recovery facilities is environmentally positive and gasification-pyrolysis is more environmentally favorable than incineration, mainly due to the higher energy recovery efficiency (Zaman 2010).

This brief review of technologies for municipal solid waste illustrates the importance of waste management policy in driving technological innovation and continuous improvement in environmental, social, and economic impacts. The crucial role of 3R policy is outlined in Section 5.

4.4 Information Technologies for 3Rs

Most people are familiar with the remarkable success story of mobile phones leapfrogging over the old fixed telephone lines, with their heavy material and land requirements. For example, Vietnam's population of just over 90 million is served by less than 18 million fixed lines, but more than 98 million mobile phones[8] and Cambodia's 14.8 million people have only 54,200 fixed lines but 5.6 million mobile phones[9]. The first telephone lines, over 100 years ago, were made from iron and steel, until 1884, when an experimental copper line was strung between Boston and New York, a technology that remained until the 1980s, when fiber optic cables came into use. Submarine cables now link all continents except Antarctica. As the cost of copper has risen in recent years, theft of telephone cables has become a frequently observed crime in some countries.[10] Of course, mobile phones also contain copper (about 9 gm each) but there are considerable material savings compared to fixed lines, which may weigh about one tonne per kilometer. As there are now about 4.6 billion mobile phone users globally, the copper content would be equivalent to 300,000-400,000 km of fixed lines.

Less well known is the role of modern information and communication technology in facilitating the global expansion of 3Rs. For example, many people are prepared to use mass transit systems for their daily commute to work, but really need a car for a vacation overseas or for a short trip to a destination not well served by public transport. Car share is a possible solution. Companies like ZipCar use modern information technology to make car sharing convenient and foolproof.[11] Applications, reservations, and account management are all conducted online. Registered users are provided with an embedded electronic chip card, using radio frequency identification, which allows the user to unlock and lock the reserved car, while the keys remain inside. The car is returned to the reserved parking location, often given priority by local governments, and the details of the trip are added to the user's account. Using software applications on a mobile phone or iPod, the registered user can search for the nearest car, reserve it, and even extend the use by simply sending a text message.

If this is not sufficiently environmentally sound, another alternative is online car- or lift- sharing, which is the modern equivalent of hitching a ride.[12] Drivers can offer spare seats in the car to other passengers or potential passengers can find out if someone is driving in the direction they want to go. The supply and demand are matched online and cars may have 5 or 6 occupants than the commonly observed single driver. For those simply opposed to travelling in a car and prefer bicycles, then bicycle sharing is the next best alternative. In the city of Hangzhou, China, 50,000 bikes in 2,050 bike share stations are available for sharing through Hangzhou Public Bike, resulting in 240,000 trips per day. The company plans on increasing the bicycle sharing system to 175,000 bikes by 2020.[13]

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[8] http://www.economywatch.com/economic-statistics/Vietnam/Telephone_Statistics/, accessed 25 August 2011.
[9] http://www.economywatch.com/economic-statistics/Cambodia/Telephone_Statistics/, accessed 25 August 2011.
[10] http://lirneasia.net/2007/06/vietnams-submarine-cable-lost-and-found/ accessed 25 August 2011.
[11] http://www.zipcar.com/how/technology, accessed 25 August 2011.
[12] https://carshare.liftshare.com/default.asp, accessed 25 August 2011.
[13] http://www.shareable.net/blog/chinas-monster-50000-bike-bikesharing-system, accessed 25 August 2011.

Modern information and communication technology is also shifting to the supermarket to facilitate sound environmental choices by consumers. Product bar codes contain information about the life cycle assessment of products and details on the country of manufacture or even the individual producer. All the consumer needs to do is scan the barcode on a mobile phone and download all the information that is relevant to a purchasing decision. As noted by King et al. (2010) "social networking sites, SMS and Twitter, YouTube, etc., will allow information to spread virally, especially among the young. As a modern supermarket has over 15,000 product lines, generating useful information and conveying this information in simple terms is a major undertaking. Groups like GoodGuide[14] rate over 70,000 [*now over 100,000*] products on health, environment and social grounds, on a scale of 1 to 10, but how effective such ratings will be remains unknown".

Information and communication technology, especially through internet, has also triggered development of numerous green procurement networks, such as the International Green Purchasing Network based in Japan (www.igpn.org), Green Purchasing Network Malaysia (www.gpnm.org/e/), Thai Green Purchasing Network (www.thaigpn.org), Australian Green Procurement (www.greenprocurement.org), and Green Purchasing Network of India (http://gpnindia.org/), among others. These networks serve to match buyers and sellers of green products, as well as identify opportunities for new markets and/or new products.

The massive expansion in information and communication technologies has given rise to increasing concern over e-waste and recycling the rare earth materials embedded in small quantities in personal computers and mobile phones, as well as disposing of the residues from current battery technology. Some recent developments in capturing the energy from walking (kinetic charging) and portable solar systems (for example, thin sheet solar panels on backpacks) may reduce the need for batteries in future. The power generated by walking is already captured in two Tokyo railway stations, where thousands of commuters' feet generate electricity from power generating mats which operate the stations' automatic doors. Another intriguing example is the demonstration of the power of linking information from smart phones to record traffic flows and send advice to drivers on the optimal speed to cut fuel use by up to 20% (MIT 2011).

5. Best Practice Policy to Promote 3Rs Technology Transfer, Adaptation and Diffusion

The Organization for Economic Cooperation and Development (OECD) outlined some important principles that should guide policy development on 3Rs in the *OECD Environmental Strategy for the First Decade of the Twenty-first Century*, as follows:

- "Regeneration: Renewable resources shall be used efficiently and their use shall not be permitted to exceed their long-term rates of natural regeneration."

- "Substitutability: Non-renewable resources shall be used efficiently and their use limited to levels which can be offset by substitution by renewable resources or other forms of capital."

- "Assimilation: Releases of hazardous or polluting substances to the environment shall not exceed its assimilative capacity; concentrations shall be kept below established critical levels necessary for the protection of human health and the environment."

- "Avoiding Irreversibility: Irreversible adverse effects of human activities on ecosystems and on biogeochemical and hydrological cycles shall be avoided" (OECD 2001).

[14] http://www.goodguide.com/, accessed 25 August 2011.

In general policy design for 3Rs should cover resource extraction, manufacturing and the product cycle, consumption, recycling resources and energy, and waste disposal (Bringezu 2002). The main policy instruments that have been applied include taxes, subsidies, process standards, product standards, consumer information, eco-labels, green procurement, and research and development promotion, etc. (Lorek and Lucas 2003).

Taxes and charges – China has imposed pollution fees since the 1990s and fees for sewage and garbage disposal have been in place for the past decade, although these have often been set too low (or not collected) to influence industry behavior (UNEP 2011). Since 2006, taxes have also been levied or increased on mineral resources, fuel consumption, large engine vehicles, disposable chopsticks, and timber floor boards, among others (UNEP 2011).

Sweden introduced a tax on natural gravel in 1996, designed to achieve a 70/30 ratio between crushed rock from quarries and natural gravel, as well as setting a volumetric target (12 million t/yr) and requiring at least 15% from recycled materials. Similarly, Denmark introduced taxes on waste and raw materials under the Raw Materials Act 1997, while the United Kingdom introduced an aggregates levy in 2002 to address the environmental impacts of quarrying, to reduce demand, and to encourage recycling (Bringezu 2002). Landfill taxes have been implemented in the US, France, UK, Sweden, and the Netherlands since the early 1990s (Kinnaman 2006).

Subsidies and tariffs – Since 2007, China has imposed higher export tariffs on 142 energy-intensive and polluting products, while reducing export rebates (a form of subsidy) from 553 energy-intensive and polluting products. Export of these products was reduced by 40% by 2007 as a result (UNEP 2011).

Standards and target setting – Most countries in Asia-Pacific have begun to set national targets in 3R related laws and regulations. China introduced its Solid Waste Environmental Pollution Prevention Act in 1995, a Cleaner Production Act in 2003, and Law on Circular Economy Promotion in 2008. China's 11^{th} Five Year Plan for Economic and Social Development (2006-2010) established eight mandatory targets, of which five relate to environment and resource use. The targets include a 20% decrease of GDP energy intensity, 10% decrease in SO_2 and COD emissions by 2010, to be implemented through an Action Plan for Energy Conservation and Pollution Reduction (UNEP 2011). This Action Plan set targets for phasing out obsolete production capacity in 12 energy-intensive and polluting sectors. China has also set a target of reducing GHG emissions by 40-45% per unit of GDP by 2020 (against a 2005 benchmark). The Republic of Korea issued its Resource Economization and Recycling Promotion Act in 1992 (revised in 2002). Taiwan Province of China introduced a Resource Collection and Reuse Act in 2002. Malaysia has targeted its recycling rate to reach 22% by 2020 (METI 2004).

Japan's Top Runner program uses standards in a unique manner. Instead of mandating a minimum energy efficiency standard for household and commercial electrical appliances and transportation equipment, the Top Runner program searches for the most efficient product on the market and makes this top runner model the standard for that class of appliances. Other manufacturers are required to meet this standard within a set period of years (UNEP 2011). Initial expectations for products like air conditioners, vending machines, computers, fluorescent lights, and refrigerators have already been exceeded. Japan's principal targets for 2015 include a 60% resource productivity improvement over the year 2000, a 40-50% improvement in the cyclical use rate, and a 60% reduction in the final disposal amount. Voluntary targets have been set by various industrial associations. Progress towards these targets appears to be assured (UNEP 2011).

Vietnam's 2025 targets cover (i) waste separation at source (80% of cities); (ii) collection (100%) and recycling (90%) of solid wastes from urban households; (iii) collection (90%) and recycling or reuse (60%) of construction site wastes; (iv) collection and treatment of sludge from grade 2 cities and above

(100%); (v) reduction in plastic bags from commercial outlets (85% from 2010); (vi) collection and treatment of industrial waste (100%); and (vii) collection and treatment of solid wastes from rural areas (90%) and craft villages (100%).[15]

Information-based policies – Both voluntary and mandatory efforts to implement the 3Rs approach are facilitated by the provision of reliable and accurate information. Information-based policies include independent certification, eco-labeling, product content and production information, independent testing and verification, producer and consumer education, and social marketing (King et al. 2010). Eco-labeling (such as the Energy Stars system for household appliance energy efficiency) not only identifies the manufacturing company as a trustworthy provider of equipment, goods and services, but also allows the informed consumer to preferentially choose environmentally sound products, in turn triggering improved design and production processes (IGES 2010).

Technology research and development – UNIDO in association with UNEP have established National Cleaner Production Centers in 47 countries. Recently both organizations have established a joint program on resource efficient and cleaner production to scale up these initiatives (UNIDO/UNEP/SECO 2010). Since 1994, the Danish Technological Institute has developed a Technology Partnership which now comprises a global network of 22,000 technology experts dedicated to finding the ideal solution any technological challenge.[16] Some 3R-related solutions include an alternative to lead for roofing applications and non-toxic lamp oil, among many others. The Blue Economy is another useful database of innovative technologies dedicated to "using the resources available in cascading systems, where the waste of one product becomes the input to create a new cash flow.[17] Some interesting examples include growing mushrooms on waste coffee grinds, using silkworms to make fiber as strong as titanium, using food wastes to make bio-plastics, and using silica beads in paint to create an effective insulator, among more than 60 case studies.

Box 4 – Resource Efficiency and Cleaner Production in Sri Lanka

A desiccated coconut factory in the Northwestern Province, assisted by a UNIDO-supported Cleaner Production Center, has been able to reduce raw material use by 390 tonnes per year and water use by 5,400 kl per year, as well as introducing energy efficiency measures and using the waste coconut shells as an energy source. Relatively simple improvements included (i) reduction of coconut kernel lost during peeling; (ii) reduction of water consumption through improved processes and cleaning; (iii) recovery of oil from wastewater pits; and (iv) switching from fossil fuel to coconut shells. For an investment of $5,000, the company saved more than $200,000 and is now used as a model for other millers.

Source: UNIDO (2010) Enterprise Benefits from Resource Efficient and Cleaner Production: Successes from Sri Lanka.

Japan has established a 3R Technology Development Program that is focused on downstream measures including (i) recovery of rare metals from lithium-ion batteries; (ii) accurate separation of plastics by material category; and (iii) development of materials that could substitute for rare metals (currently in short supply globally). Since 1975, Japan has also issued awards for resource recycling technologies, as well as providing interest subsidies, research grants, low interest loans, and tax incentives for technology development (METI 2010). The medium- to long-term vision is to accelerate 3R aspects throughout

[15] http://www.uncrd.or.jp/env/spc/docs/PM_NSISWM_Eng.pdf accessed 31 August 2011.
[16] http://www.technology-partnership.com/ accessed on 17 September 2011.
[17] http://www.blueeconomy.de/ accessed on 17 September 2011.

product lifecycles and across supply chains. Priorities include (i) prolonged life of buildings and consumer products; (ii) reduced by-products in manufacturing; (iii) increased reuse and recycling of products; (iv) energy and materials recovery; (v) responsible disposal of waste; (vi) selection of materials to reduce the ultimate environmental load; (vii) coordinated design and manufacture of design-for-environment products; (viii) improved technology for reuse and recycling processes; (ix) quality control technology; (x) thermal and power recovery from waste disposal; (xi) cyclical use of harmful products that are difficult to replace; and (xii) advanced technologies for renewable biomass materials (MOEJ 2008b).

Policy transfer and adaptation – As a major importer of raw materials and exporter of manufactured products, Japan has realized the importance of transferring its good policy experience on resource efficiency, recycling, and waste disposal to its trading partners in Asia-Pacific. Under the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal (1992), Japan exports thousands of tonnes per year of batteries and scrap lead, while importing silver and copper laden sludge, lead, and electronic parts containing rare metals among other components. Under non-controlled imports and exports of recyclable materials, Japan imports scrap iron and paper while exporting plastics, scrap iron, copper, aluminum, and paper in large volumes (METI 2004). Japan first proposed the 3R Initiative at the G8 Summit in June 2004 and has progressively worked towards promoting a sustainable Asia based on the 3Rs (METI 2004). The G8 Environment Ministers' Meeting in Kobe, Japan, 24-26 May 2008 adopted the Kobe 3R Action Plan and Japan announced its Global Zero Waste Society Action Plan (MOEJ 2008b).

The Kobe 3R Action Plan has 3 main goals (i) prioritize 3Rs policies and improve resource productivity; (ii) establish an international sound material cycle society; and (iii) collaborate for 3Rs capacity development in developing countries. Proposed technology related actions include (i) promote science and technology and create a market for 3R related products; and (ii) promote technology transfer, information sharing and environmental education (MOEJ 2008b). The Global Zero Waste Society plan includes inter-city cooperation, development of equipment and facilities, promotion of green productivity, sharing information on best practices, and promotion of mutual understanding (MOEJ 2008b).

UNIDO's Green Industry Policy Paper outlines a "green industry initiative" to encourage industries, especially in developing countries, to achieve equitable and environmentally sound economic growth, by taking extended responsibility for their operations and products, cutting pollution, and creating decent, "green" jobs (UNIDO 2011a, UNIDO 2011b). Green industry is expected to drive technology development and innovation, as well as creating entrepreneurial new business ventures. In addition to changes in consumer behavior, choices and lifestyles, sustainable consumption and production is only possible if industries minimize their resource use, contain pollutants throughout product life cycles, and design products for the environment. The green industry initiative will (i) incorporate sustainable production in industry policies; (ii) make more advisory services available; (iii) support national learning and innovation hubs; (iv) provide replicable models of sustainable production; and (v) encourage absolute resource reduction in developed countries and relative decoupling in developing countries (UNIDO 2011b).

6. Conclusions and Recommendations

6.1 Conclusions

Reduce, reuse, recycle sounds like a very simplistic policy formulation, but in fact it has been enormously influential in creating the enabling framework for change, changing consumer attitudes, and triggering technological innovations. A crucial question, however, is whether the 3Rs will be sufficient to lead countries across the globe (especially those just beginning to enter a mass consumption mode) towards the ultimate goal of sustainable development.

Some observers take the view that the 3Rs and eco-efficiency are laudable steps needed to buy time for more fundamental changes in society (McDonough and Braungart 1998). The perceived challenges are that (i) too much recycling is actually down-cycling, as the quality of material reduces over time; (ii) few products were designed to be recycled from the outset; (iii) small amounts of endocrine disruptors and nano-scale particulates are being released into the environment; and (iv) reduce and reuse are constantly undermined by social pressures, including advertising. These challenges, however, can be overcome by a redesign of industrial structure that would ensure that "waste is food" and product design that takes a "cradle-to-cradle" approach rather than "cradle-to-grave" (McDonough and Braungart 1998). As in nature, there would be zero waste, as any waste product soon falls into a niche that is exploited by various species. Technical nutrients would be circulated in closed loop industrial systems and would not be allowed to contaminate natural metabolic systems.

The technological innovations related to 3Rs described above, responding to thoughtful and far-reaching policies, show considerable potential for contributing to sustainable development. Developing countries have the potential to leapfrog over old, outdated technologies and adopt innovative technologies based around the 3Rs. Industrial revolutions do not take place in a few short years and there is emerging evidence that human ingenuity will continue to provide technological advances that will make the world of tomorrow very different from the single throughput mass consumption economy spawned by the Industrial Revolution. Progress is sure to be patchy but the potentials for technological leapfrogging in the Information Age are enormous. Continued monitoring and dissemination of the best practice technologies to implement the 3Rs approach will help to ensure that the 3Rs will take their rightful place in the next industrial revolution.

6.2 Recommendations

In accordance with the final Tokyo 3R Statement that established the 3R Forum in 2009, developing countries wishing to avoid the trap of locking into outdated technologies that lead to inefficient resource use and environmental degradation are advised to recognize the benefits of the 3R approach and develop the necessary human resources to implement appropriate national policies and programs. Specific recommendations based on the Tokyo Statement in the context of technology for the 3Rs include the following.

Recommendation 1 – The 3Rs should be mainstreamed into the national development agenda, including environmental, social, and economic plans, policies, strategies and programs;

Recommendation 2 – Developing countries should mobilize additional financial resources in cooperation with bilateral and multilateral donors for the implementation of 3R activities, including the transfer of modern technologies and associated capacity strengthening;

Recommendation 3 – Build adequate technical and human resource capacity for collection and safe treatment of toxic and hazardous wastes, including household waste, medical waste, and e-waste;

Recommendation 4 – Consider development of eco-industrial zones and clusters to strengthen industrial capacity for recycling, where waste from one enterprise becomes a resource for another; and

Recommendation 5 – Develop and transfer environmentally sound technologies for waste management and the 3Rs, from wherever they are developed, and use these technologies to create new, entrepreneurial businesses that can compete on the global stage.

In 2006, the Asian Development Bank established the 3R Knowledge Hub with the Asian Institute of Technology, United Nations Environment Programme (UNEP), and United Nations Economic and Social Commission for Asia and the Pacific, *inter alia*, to "mainstream new concepts in innovation, science, technology, management development and related fields for the region."[18] The United Nations Centre for Regional Development (UNCRD)[19] and UNEP International Technology Centre (IETC)[20] also maintain data and compendia on relevant 3Rs best practices and technologies.

Recommendation 6: The various 3R knowledge portals in Asia-Pacific should cater to the needs of developing countries for 3R related technologies, along with links to relevant websites in other regions like the Canadian Recycling Website[21] and the Grassroots Recycling Network[22].

Several advanced countries in the Asia-Pacific region have not only demonstrated technological superiority in relation to the 3Rs but also have expressed willingness to transfer this knowledge through international cooperation with developing countries. However, the real challenge is getting a consistent timely linkage between the transfer of technologies and the financing to implement projects that would benefit from the use of that technology.

Recommendation 7: The Asian Development Bank (in conjunction with the World Bank and Japan International Cooperation Agency) should create a regional, multi-donor 3R Fund similar to the Climate Investment Funds[23], specifically for preparation and implementation of national 3R action plans.

At the Copenhagen climate change conference of the parties in December 2009, developing nations proposed that green technology should be subject to "compulsory licensing" similar to emergency use of patent protected pharmaceuticals for HIV/AIDS patients. Developed countries, particularly in the European Union and US are opposed to this idea as they think it would stifle technological innovation and green jobs.

Recommendation 8: Consideration should be given to use of the proposed 3R Fund, or some other financial mechanism, to compensate the holders of intellectual property rights of crucial 3R-related technologies for foregone revenues, voluntarily waived, to facilitate acceleration adoption of the 3Rs in developing countries. In addition to technology transfer, however, capacity development must be provided at the same time (Hall and Helmers 2010).

In the hierarchy of the 3Rs, prevention of waste generation through reduced consumption has the greatest impact, but it is constantly frustrated by government efforts to boost consumption, especially as economic growth slows or a recession is on the horizon. The consistent barrage of advertising and peer pressure to consume more is difficult enough to resist without the added incentive of government handouts or other blandishments designed to boost a slowing economy.

Recommendation 9: Governments, of both developing and developed countries, should refrain from fiscal stimulus packages that promote unrestrained consumption, by earmarking most of the stimulus funding for environmental technologies and infrastructure, including at the household level (such as insulation of houses, rooftop solar panels, or recycling of solid wastes), or for public facilities that minimize

[18] http://3rkh.net/3rkh/ accessed 31 August 2011.
[19] http://www.uncrd.or.jp/env/spc/ accessed on 31 August 2011.
[20] http://www.unep.or.jp/ accessed on 31 August 2011.
[21] http://www.nrcan.gc.ca/mms-smm/busi-indu/rec-rec-eng.htm accessed 31 August 2011.
[22] http://www.grrn.org/zerowaste/kwmn.html accessed 31 August 2011.
[23] http://www.climateinvestmentfunds.org/cif/ accessed 31 August 2011.

consumption (such as libraries, free bicycle schemes, converting roads into pedestrian malls, and car free days).

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