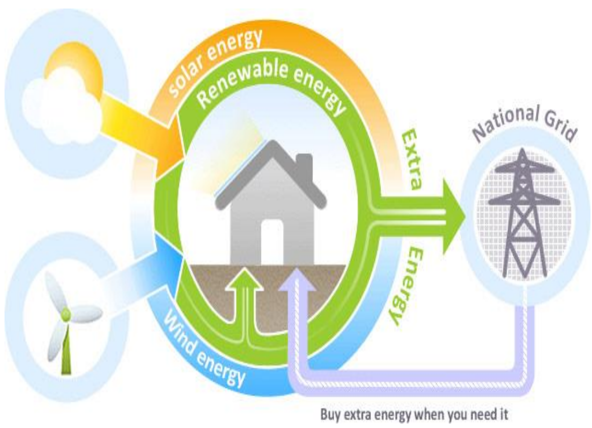
Doubling Energy & Resource Productivity by 2030

Unlocking a $25-30 Trillion Cumulative Increase to Global GDP
+ Transitioning to a Low Carbon Future through Sustainable Energy and Resource Management



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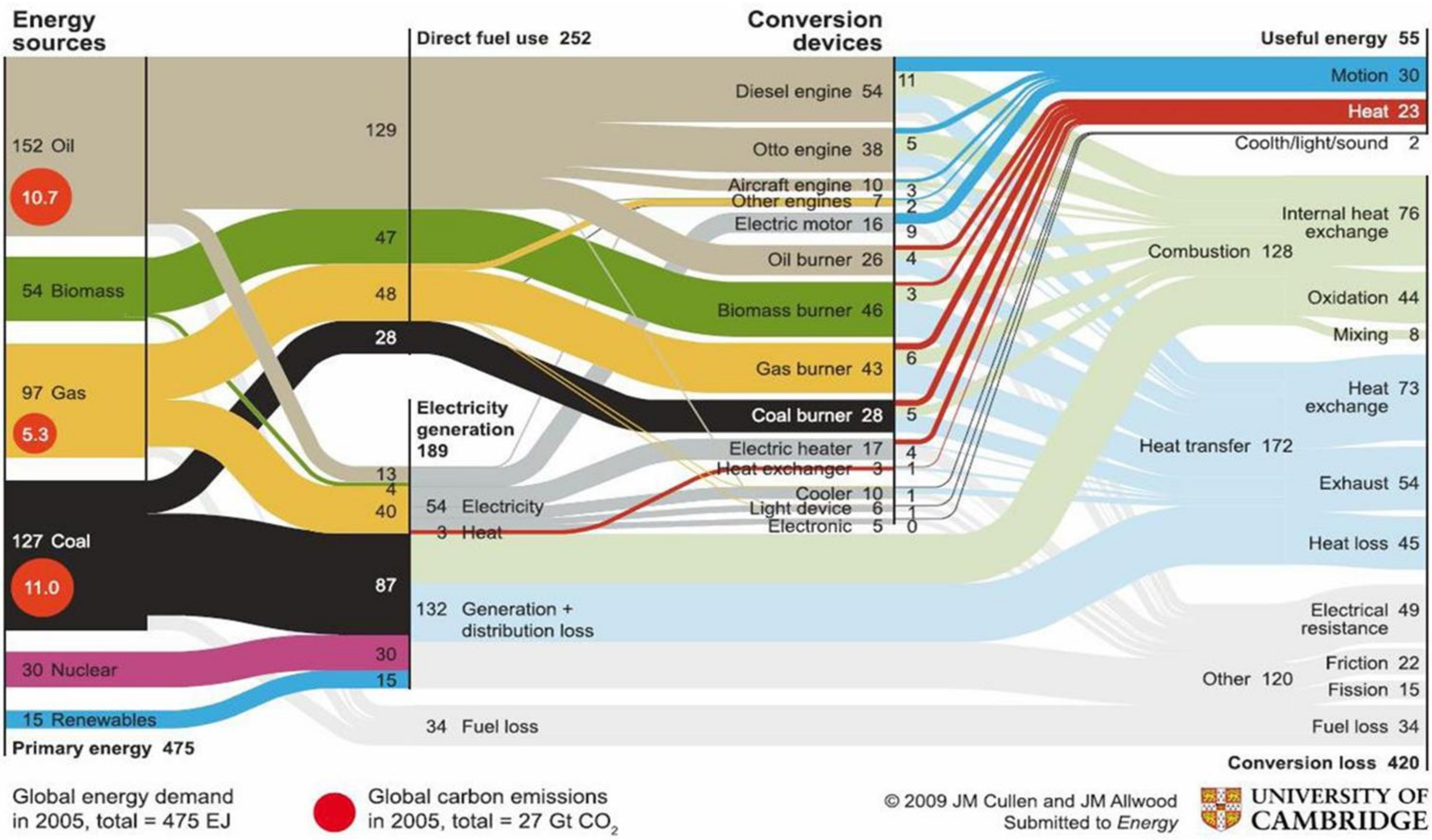
By Dr Michael H Smith (ANU)



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Executive Summary

In 2014, and again in 2015, the OECD, IMF, and World Bank have published warnings that a slowdown in global economic productivity is threatening to usher in a new low-growth era. OECD countries, including the USA and Australia, have been experiencing relatively poor labour and multi-factor productivity rates in most years since 2000 (See Figure 1 below)[1]. **Hence many decision makers are currently focused on how to find new sources of productivity growth?** Through these recent efforts a range of new reports are showing that a focus on energy and resource productivity is a way to significantly boost overall national economic growth [See BOX 1 below]. This report (and its Appendix) is novel because it goes a step further and shows, in detail, how energy and resource productivity improvements together can enable simultaneous improvements in labour, capital and multi-factor productivity – the traditional measures of national productivity and economic growth. This report and its Appendix 1 shows how, sector by sector, doubling energy and resource productivity simultaneously unlocks new sources of labour, capital and multi-factor productivity through - improved rates of production, greater labour participation, quicker returns on capital expenditure, avoided capital misallocation as well as reduced energy and resource input costs.[2] Thus overall total productivity benefits are up to 2.5 times greater than the simple productivity benefits from reduced energy and water input costs from energy/resource productivity investments.[3]-[4] With this understanding, this **report shows, for the first time, how a global focus on doubling energy and resource productivity by 2030 could simultaneously unlock new sources of labour, capital and multi-factor productivity to boost cumulative global GDP >US$25-30 Trillion by 2030** compared to business as usual (BAU).[5]

The Energy Productivity Opportunity

Energy Productivity – Potential to Boost GDP, Jobs and other Co-Benefits –Simply focusing on improving "Energy Productivity", by investing in energy efficiency opportunities by 2030, could alone boost global GDP by over $15 Trillion above BAU**.** This is the conclusion of respected studies by the International Energy Agency (IEA), as well as a range of other studies [See BOX 1 below]. Also, investments in energy efficient transport systems and encouraging people to use more active forms of transport (public transport, cycling, walking) have additional productivity benefits through reduced air-pollution, urban congestion and health costs from diseases of physical inactivity. These respectively globally cost >US$3.5[6], US$2-4.3[7], and >$US3 Trillion[8] per annum. Hence reducing these costs will result in significant health and productivity co-benefits.

USA Commits to a National Energy Productivity Target: President Obama has already recognised this and convened a national taskforce on this topic. Based on their work he has adopted a commitment to double US energy productivity by 2030[9]. The "*US Energy Productivity Roadmap*" study shows that a doubling of energy productivity by 2030 would boost US GDP growth by 2% above business as usual, achieving per annum savings of US$327 billion per year, reducing oil imports as well as achieving significant greenhouse gas reductions. A focus on improving energy productivity, including the USA transport sector, could also enable further productivity co-benefits through reduced USA congestion costs, air pollution costs, and costs of diseases of physical inactivity. These respectively cost >US$50-120 billion, US$75-280 billion[10], and >US$60 billion per annum.

Australian Government Commits to Developing a National Energy Productivity Roadmap with Targets: The Commonwealth Government of Australia, in the new 2015 *Energy White Paper* has also recognised the significant benefits of energy productivity, committing to developing a national energy productivity roadmap. Studies show that Australia could double energy productivity by 2030 adding ~AUD$35-50 billion respectively to the GDP above BAU[11]. The Alliance to Save Energy in partnership with partners such as UTS ISF and ANU Energy Change Institute has been developing a national energy productivity roadmap for Australia in partnership with government and business to help realise this opportunity. Many other nations in the Asia Pacific, such as, China have also committed to purposeful energy productivity targets to reduce rising energy demand and air pollution and improve energy security. It is possible therefore to build on these precedents in the energy productivity space, to more easily convince decision makers to now make similar commitments to doubling resource productivity by 2030 and developing national resource productivity roadmaps.

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The Resource Productivity Opportunity

Resource Productivity Targets can Help Achieve Energy Productivity Targets and Vica Versa: Resource productivity strategies – such as reducing waste, resource efficiency, product stewardship and recycling – often yield energy productivity co-benefits and vice versa. The availability of these strong "win-win" synergies means that nations and businesses, which commit to both energy and resource productivity targets will find a focus on resource productivity gives nations and businesses additional cost effective ways to improve energy productivity. This will make it easier and more cost effective for nations and business to achieve their energy productivity targets whilst also achieving a larger overall boost to national GDP, jobs growth and business profits. Hence there is an opportunity here for both the USA and Australia governments to adopt resource productivity targets to help them i) achieve their existing energy productivity targets, (ii) reduce vulnerability to resource price shocks and (iii) risks of resource scarcity for rare earth metals and other critical commodities.

Resource Productivity Through Transitioning to the Circular Economy – Potential to Boost Global GDP and other Co-Benefits: Resource productivity strategies, such as resource efficiency, remanufacturing and recycling, result in lifecycle energy and water savings thus also improving energy and water productivity. This makes it easier for nations to achieve their energy productivity targets. Improving resource productivity could add around US$1 Trillion per annum (or cumulatively at least >US$5 Trillion) to global GDP by 2025[12].

Natural Resource Productivity - Potential to Boost Global GDP and other Co-Benefits To feed the world, by 2050, food production will need to increase 70%. Yet, due to land degradation, already 30% of arable farmland[13] globally is unproductive[14]. The global annual economic costs of food waste, deforestation/land degradation, invasive species and unsustainable management of wild fisheries are respectively ~US$1 Trillion[15], EU$400 Billion-650 Billion,[16] US$1.4 Trillion[17] and US$50 Billion per annum[18]. Their costs to specific nations can be significant. For instance, they cost the US economy >US$350 Billion per annum. Pro-actively addressing these issues could add > US$2-3 trillion cumulatively to the global GDP by 2030 whilst enhancing food security.

Water Resource Productivity – Potential to Boost GDP, Jobs and other Co-Benefits– As this report shows, smart water productivity investments through reducing water leakage rates, improving water efficiency and low carbon sustainable water management practices could cumulatively boost global GDP by ~US$1-2 Trillion by 2030 whilst achieving significant energy productivity co-benefits as well. Many of the best ways to save water, save energy and vice versa.

Implications for Climate Change – Action on Climate Change Could Boost Economic Growth - International Energy Agency and Global McKinsey Institute reports show that a focus on improving energy and resource productivity will cut >70% the required greenhouse emissions by 2030 to keep global warming under 2 degrees. **This means that a focus on improving energy and resource productivity could enable nations to mitigate greenhouse gas emissions in ways that boost economic growth.** A recent ClimateWorks Australia study into *Australia's Energy Productivity Potential*[19] showed that if Australia doubles its energy productivity by 2030, this will ensure Australia is on track to achieve deep cuts to emissions by 2050**.** Climate mitigation, plus adaptation, also is "productivity enhancing" because it significantly reduces the costs of climate change estimated to be ~$1.2 Trillion in 2013 and which, without mitigation, could cost >10% of global GDP by 2100.[20]

Energy and Resource Productivity Enabling Technologies: A New Wave of Innovation: Finally, this report, and the reports which compliment it, show that there is potential for a new wave of innovation made possible by advances in energy and resource productive enabling technologies. These technologies, can help nations and business to unlock new sources of labour, capital and multi-factor productivity - through improved rates of production, greater labour participation, quicker returns on capital expenditure, avoided capital misallocation as well as reduced energy and resource input costs.[21] **Hence, the report shows the value to governments and businesses of adding a focus of energy and resource productivity to their productivity agenda's**. **To help governments and business do that, this report is complimented by**

- **Report #2 – *A Guide for Policy Decision Makers*** - which evidences the value of adopting national targets to double energy and resource productivity by 2030, and policy options to achieve such goals.

- **Report #3 – *A Guide for Business Leaders* -** which shows, business sector by sector, how doubling energy and resource productivity by 2030 is key to improving business competitiveness and productivity.

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BOX 1 – Recent Economic Studies Empirically Evidencing The Energy and Resource Productivity Opportunity

A range of studies listed below, evidence that a focus on both energy and resource productivity (including natural resource productivity) could achieve significant annual increases in energy and resource productivity of US1-3 Trillion above business as usual. Cumulatively this could achieve at least >US$25-30 trillion boost to global GDP by 2030. These studies include the following;

- The International Energy Agency 2012 *World Energy Outlook* reports "Energy Efficient World" scenario showed that a focus on energy efficiency could boost global GDP growth cumulatively by US$18 Trillion by 2035 above BAU, reduce the need for new energy supply capital and fuel costs by US$7 Trillion each[22].
- International Energy Agency 2014 study *Capturing the multiple benefits of energy efficiency* shows that the overall productivity benefits of investment in energy efficiency can be as much as 2.5 times that of simply the direct productivity benefits from energy cost savings.[23]
- UNEP International Resource Panel's *Decoupling 2: Technologies, Opportunities and Policy* report found that a focus on energy and resource productivity could add US$1-3 Trillion per annum by 2025-2030.
- McKinsey Global Institute *Energy Productivity*[24] studies show that global energy demand growth could be cut by at least half while generating average internal rates of return of 17% through a focus on energy efficiency. This work shows that $900 billion per annum savings could be achieved as soon as 2020.
- The World Bank and ClimateWorks (USA)'s "*Climate-Smart Development"* report shows that improving global energy efficiency performance could boost global GDP by US$1.6-2.6 Trillion per annum by 2030[25].
- Vivid Economics' *"Energy Productivity*" study found that global GDP growth could increase by ~ US$600 Billion per annum by 2030 per 1% increase in the rate of energy efficiency improvement above BAU[26].
- A2SE, UTS and ANU's 2014 report on *Australia's energy productivity opportunity*, evidences the potential for improving energy productivity in many countries and the broader productivity benefits of doing so[27].
- McKinsey Global Institute's 2011 *Resource Revolution* study shows that a focus on energy and resource productivity improvement could increase global GDP US$2.9 trillion per annum by 2030 above BAU[28].
- The World Economic Forum's *Circular Economy Program's* Report cites modelling which shows that improving resource productivity could add an additional US$1 Trillion per annum to global GDP by 2025[29].
- Veolia Water and International Food Policy Research Institute (IFPRI) *Finding the Blue Path for A Sustainable Economy* study found that BAU water management could result in approximately US$63 Trillion, or almost half the global economy being exposed to risks of water scarcity by 2050[30].
- The United Nations (UN) and European Union (EU) study entitled *The Economics of Ecosystems and Biodiversity* showed that the costs of inaction on preservation and restoration of natural resources would cost the global GDP as much as $7 Trillion per annum by 2050.
- Food & Agriculture Organisation's – *Food Waste Global Footprint*[31] study shows that food waste is already costing the global economy US$1 Trillion per annum and that there is significant potential to reduce this.
- The World Bank's *Sunken Billions*[32] study showed that annual productivity losses through over-fishing has been around US$50 billion per annum for 30 years, or around US$2 Trillion over the last three decades.

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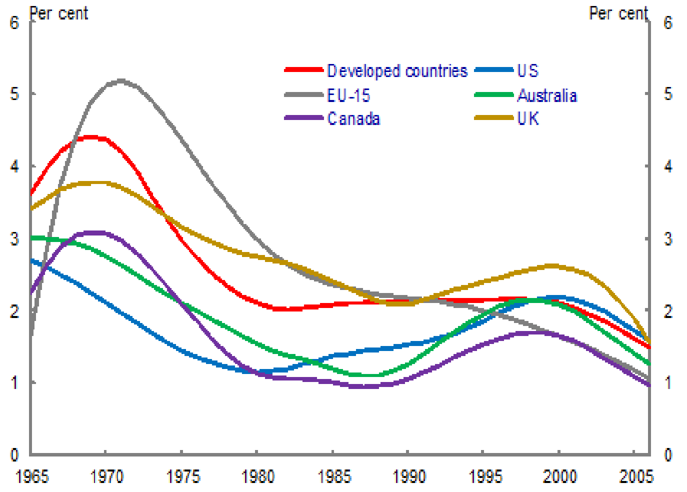
Doubling Energy & Resource Productivity by 2030 – Unlocking a $25-30 Trillion Boost to Global GDP Whilst Transitioning to a Low Carbon Future

1.1 The Challenge – Declining Labour and Multi-Factor Productivity

Numerous developed countries have been struggling since the global financial crisis to return to historic productivity and economic growth levels. This is partly because there has been, since 2000, a decline in the rates of labour and multi-factor productivity growth in many developed countries, including the USA and Australia[33].



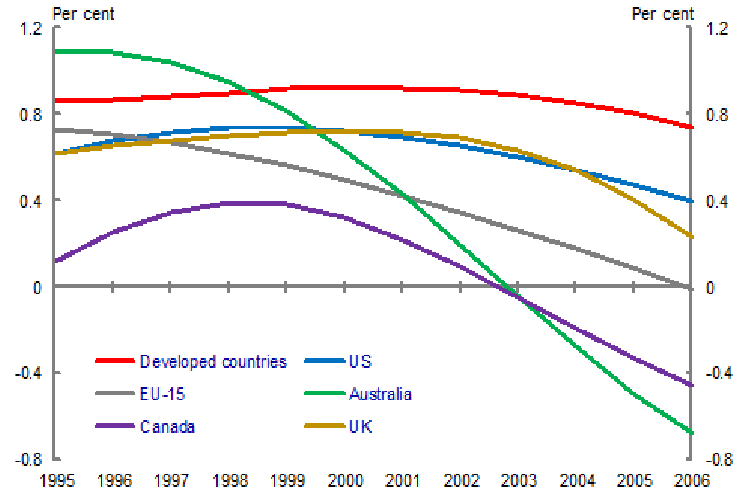


Figure 1a OECD Labour Productivity (1965-2005) **Figure 1b** OECD Multi-Factor Productivity Growth (1965-2005). (Source: Commonwealth Treasury Department of Australia, 2013[34])

Even relatively successful economies, since the global financial crisis, such as the Australian economy have had poor underlying labour and MFP productivity growth rates since 2000. Since 2005, Australia's labour productivity has barely grown 8%, whilst capital and multi-factor productivity growth rates have been negative in some years[35]. As Productivity Commission staff in Australia have commented,

> *"the debate about Australia's productivity slump seems to have overlooked the significance of the depth to which the rate of productivity growth has fallen. Multifactor productivity (MFP) growth over the most recent productivity cycle was at an unprecedented low. More than that, it was zero (or even negative!)."[36]*

This productivity decline over the last decade did not initially result in poor economic growth in Australia because of a commodity minerals boom. With the construction component of that boom now over, many experts are warning that Australia must address its "productivity problem"[37]. Improving productivity rates is thus a high priority for policy makers in all developed countries because higher productivity improves business competitiveness and makes it easier for governments to balance budgets and to afford the rising costs of an aging population, the need to improve education and health services and investments in infrastructure**.** Many leading economists have been investigating new ways to boost national and firm level productivity. Some of their work, summarised and listed in BOX 1 above at the end of the executive summary, provides a rationale for, and

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highlights the benefits of, adding a focus on improving energy and resource productivity to national and firm-level productivity agendas.

1.2 The Energy and Resource Productivity Opportunity

As explained in the Executive Summary, a focus on doubling energy and resource productivity by 2030 from 2010 levels could **cumulatively boost global GDP by >US$30-35 Trillion by 2030 compared to BAU** [For further details see BOX 1, BOX 3 and Appendix 1 in this report for more detail] based on the following facts. **A focus on energy and resource productivity can:**

(i) **Directly boost global productivity by US$2-3 Trillion per annum by 2030, or cumulatively by >=US$25 Trillion by 2030**. This very conservative estimate is based on the studies listed in BOX 1 in the executive summary above. The International Energy Agency finds that investing in economically viable energy efficiency opportunities alone would boost global GDP by US$18 Trillion by 2035.

(ii) Simultaneously unlock new sources of labour, capital and multi-factor productivity growth worth as much as 2.5 times the original simple productivity gain from reduced energy and resource input costs. (See BOX 3 below and Appendix 1 below for More Explanation)

(iii) Drive a new wave of innovation to boost productivity through increasing the diffusion and uptake of enabling technologies which enhance energy and resource productivity. In bestselling books such as “Factor Four”, Factor Five”, “Natural Capitalism”, and “The Natural Advantage of Nations” the authors have shown that business can improve their competitive advantage by cutting operational energy and resource costs whilst improving product differentiation through a focus on energy and resource productivity. The International Energy Agency and others are showing that markets for energy and resource productive enabling technologies - for green buildings, eco-efficient appliances, technologies, industrial/mining processes and equipment, transport vehicles - are already a significant fast growing market. Major multi-national corporations are already reaping the financial benefits of strategically positioning for these rapidly growing markets. Technical analysis prepared by The Carbon Trust, has assessed the potential market for 15 emerging clean technology sectors in the developing world. Together, investments in these sectors are estimated to reach up to US$6.4 trillion over the coming decade (2014-2023). As a result of this, the authors of *The Natural Advantage of Nations* showed, with appropriate government policies, that energy and resource productivity enabling technologies could create a new 6th wave of innovation to improve national productivity.

(iv) Reduce greenhouse gas emissions compared to BAU thereby helping to reduce risks of productivity losses from damage to capital assets and operational disruption from more intense extreme weather events this century. Economic and productivity losses from extreme weather events have risen exponentially over the last 40 years. Andrew Dlugolecki, the director of general insurance development at CGNU, has argued that “*Global economic losses from natural disasters have risen at an annual rate of ten per cent over the last four decades, reaching US$100 billion in 1999. Extrapolated, the cost of damage would exceed global GDP by 2065*”.[38] In the USA, in 2012, climate-related droughts, super storms, hurricanes, blizzards, heat waves, and wildfires caused $139 billion in costs and damages. A recent study found that, *“As the frequency and severity of extreme weather events intensify with the effects of climate change, USA federal and state disaster relief and insurance programs will become increasingly unsustainable as losses from such events increase. The net present value of the USA federal government’s liability for unfunded disaster assistance over the next 75 years could be greater than the net present value of the unfunded liability for Social Security.”*[39]This is a factor not only reducing business productivity but also the productivity of the insurance sector and increasing government national debt in some countries.

(v) Achieve additional co-benefits from a focus on energy productivity that help to reduce risks of potential future drags on economic growth compared to business as usual.

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- **Reducing urban congestion costs through encouragement of active sustainable transport, modal shifts and urban planning.** According to the Asian Development Bank, road congestion costs economies 2%–5% of gross domestic product every year due to lost time and higher transport and related costs. This amounts to US$2-4.3[40] Trillion globally.
- **Increasing population health and reducing obesity by active transport**. Global health costs from diseases of physical inactivity cost well over >$US3 Trillion[41] per annum. *The likelihood of becoming obese increases by 6 per cent for each hour spent in a car each day.*[42] *Conversely, it is possible to reduce these odds by 5 per cent simply by walking an additional kilometre each day.*[43] Active energy efficient transport options therefore encourages better physical fitness and can reduce health costs associated with obesity whilst also improving energy productivity.
- **Reducing air pollution related health costs which globally cost >US$3.5[44] Trillion.** Energy productivity strategies such as energy efficiency, co-generation, renewable energy, low carbon transport technologies can have near-term health co-benefits from reduced air pollution, which offset a substantial fraction of the upfront investment costs[45]. The literature in this area, as shown most recently in a 2014 Nature Climate Change journal paper, shows that "*Because human activities emit greenhouse gases (GHGs) and conventional air pollutants from common sources, policy designed to reduce GHGs can have co-benefits for air quality that may offset some or all of the near-term costs of GHG mitigation.*"[46].

(vi) Make it easier for governments to balance their budgets. For instance, the International Energy Agency finds that a focus on energy efficiency in buildings in Europe would increase government budgets by US$41 billion to US$55 billion. Adding potential additional tax revenues from improved growth and reduced unemployment payments from energy efficiency related job creation increased the value to US$91 billion to US$175 billion.[47]

1.3 Doubling Energy Productivity (EP) by 2030 (See Reports #2 and #3 for More Detail + Policy Options)

Internationally there is growing recognition of the value of prioritising energy productivity is a strategy to improve national productivity (Table 1).

Table 1: Sample of National Energy Productivity-Related Targets

Nation	Target	Baseline	Target Year
USA	Double energy productivity by 2030	2010	2030
Australia	At least 40% energy productivity improvement by 2030	????	2030
China	15% energy intensity reduction	2010	2015
Germany	2.1% average annual energy productivity improvement	2008	2020
Indonesia	1% energy intensity reduction per year	2005	2025
Singapore	Aims to achieve a 35% improvement	2005	2030
Japan	30% energy efficiency improvement	2003	2030
South Korea	46% energy intensity reduction	2007	2030
EU	Energy efficiency to save 27% of EU energy consumption	2012	2030

Over 80 developing nations have signed up to the UN's "*Sustainable Energy for All*" Initiative which includes as one of its goals, "*Doubling the global rate of improvement in energy efficiency.*"[48]

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Many studies suggest that all countries still have significant potential to significantly improve their energy productivity through improving end use energy efficiency, energy supply conversion efficiency, and greater electrification of industry, mining and transport systems to name a few. And technology innovation increases the potential for future additional benefits, even after today's potential is captured. Significant potential exists to improve energy productivity of national economies because currently, globally only 11% of primary energy is converted actual useful physical work that contributes to economic growth. The correct engineering way to describe this is that the global economy's exergetic efficiency is around 11%. 89% of primary energy is currently lost as energy conversion and delivery losses as shown in Figure 2 below. Numerous studies evidence the potential to still achieve significant improvements in energy efficiency. For instance,

- New buildings can be designed to achieve 50-90% energy efficiency whilst existing buildings can be retrofitted to be at least 20% more efficient.[49]
- Potential exists with LED lighting, which uses up to 80% less electricity than incandescent lighting to cut electricity demand globally by close to 10% whilst providing the same or better service.
- According to the IEA, "The energy intensity of most industrial processes is at least 50% higher than the theoretical minimum determined by the laws of thermodynamics."[50]
- According to the IEA, potential exists to improve the energy efficiency of motor driven systems by 30-50% enabling over time a reduction in global electricity demand of 10%."[51] (See BOX 3 for more detail)

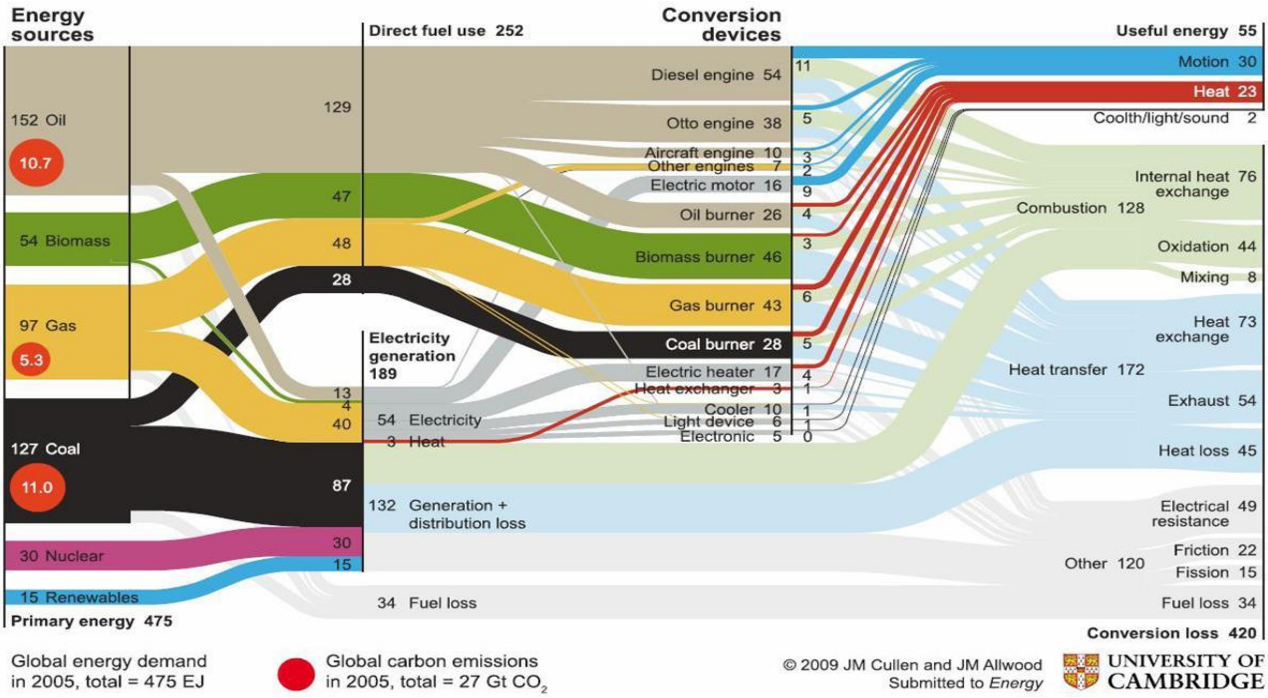

Figure 2: Global energy conversion losses result in 89% of all primary energy being lost (Source: Cullen and Alwood, 2009)

Energy productivity can also be improved by improving energy conversion efficiency of energy supply systems by

- Improving power plant energy efficiency. Most power plants have around a 30-35% energy conversion rate, but it is technically possible to achieve 50-60% energy conversion rates at power stations.
- Investment in combined heat and power could meet 10% of future global electricity demand at significantly higher energy conversation efficiencies than current power stations.

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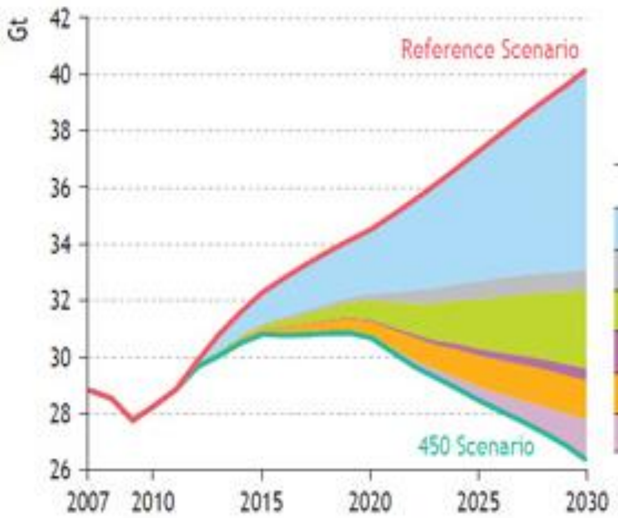
- Utilising hydropower which has energy conversion rates of around 70-80%.
- Investing in onsite renewable systems (solar thermal, solar PV powered heat pumps, renewably powered co-generation) to meet onsite electricity and heating and cooling demand. This has significantly higher energy conversion efficiencies and reduces transmission losses compared to using electricity from fossil fuel based power stations.
- Shift from internal combustion engine to hybrid or electric battery powered transportation vehicles.

A focus on improving both end use energy efficiency and energy conversion efficiency to boost energy productivity can also contribute the majority of the required global greenhouse gas emission mitigation in the energy sector by 2030. (Figure 3)



	Abatement (Mt CO_2) 2020	Abatement (Mt CO_2) 2030	Investment ($2008 billion) 2010-2020	Investment ($2008 billion) 2021-2030
Efficiency	2 517	7 880	1 999	5 586
End-use	2 284	7 145	1 933	5 551
Power plants	233	735	66	35
Renewables	680	2 741	527	2 260
Biofuels	57	429	27	378
Nuclear	493	1 380	125	491
CCS	102	1 410	56	646

Figure 3 International Energy Agency – World energy sector related CO2 emissions abatement options. (Source: IEA, 2009)

Nations and regions of the world, like California, which have focused on improving energy efficiency have already close to double the energy productivity rate of a country like Australia or most of the rest of the USA. The fact that California, and other leading nations already have energy productivity rates for their electricity sector close to double that of Australia, highlights that doubling energy productivity is a very feasible target.

1.4 Doubling Resource Productivity (RP) by 2030 (See Reports #2 and #3 for More Detail + Policy Options)

In addition many opportunities exist to improve resource productivity by 2030 and that these strategies can be designed to further simultaneously enhance energy productivity.

Doubling Water Productivity by 2030 – There is significant potential to improve freshwater productivity through reducing water leakage rates, improving water efficiency and better harvesting and use of treated rain and stormwater, which currently simply flows out to sea in most cities of the world. Singapore has shown that it is possible to increase water productivity 10 fold between 1977-2013 to $1048 GDP/ per cubic meter of total freshwater withdrawal. This water productivity rate is over 10 times that of the vast majority of countries. Achieving such ambitious water productivity improvements has created the environment within which Singapore businesses have become world leading innovators and exporters of "sustainable water technologies and services." Other top 15 performers like Isreal have shown that it is possible to improve agricultural production 9 fold whilst using less freshwater over the last few decades through improved water efficiency, water treatment and recycling. This has also helped Israeli businesses become world leaders in water efficient agricultural irrigation technologies and services. This report shows that reducing urban water leakage and improving water efficiency globally could add US$165 Billion and ~US$120 Billion to GDP per annum by 2030[52] and potentially more if energy savings co-benefits are included. Australia and the USA could gain from such a focus, as they are currently rank 51st and 63rd respectively in the world on water productivity performance. In the USA, a US$10 billion investment in water efficiency programs would boost GDP by US$13-$15 billion above BAU creating 150,000 jobs[53] saving 35 trillion litres.[5455]

Significant water productivity gains can also be made by cleaning currently polluted water and ensuring greater access to clean and safe water. Investments to clean water generally can boost country national GDP[56]. Such investments have economic multipliers of 4:1 to 14:1[57]. These are some of the motivations for why the draft UN Sustainable Development Goals (SDG #6) recommends nations improve water productivity "*by 2030, substantially increasing water-use efficiency across all sectors and ensuring sustainable withdrawals and supply of freshwater to address water scarcity, and substantially reduce the number of people suffering from water scarcity."* [58]

Double Non-Renewable Resource Productivity by 2030 - Increasingly experts are calling for nations to commit to a doubling of resource productivity by 2030. For instance, the European Resource Efficiency Platform (EREP) in 2014 called upon the EU Commission to set a target to double – at least – resource productivity by 2030 in order to boost competitiveness and improve the quality of life of our citizens.[59] Other studies show that doubling resource productivity globally by 2030 through a transition to the circular economy, could add as much as USD 1 trillion per annum to the global economy by 2025[60]. Improving resource productivity through material efficiency, diversifying supply chains, product stewardship and onsite recycling can help business reduce both resource input costs and waste disposal costs. It is in business's interests to minimise these costs, and hence the amount of raw materials and other inputs they need to create their product or provide their service. Improving resource productivity through a transition to a circular economy could add US$1 Trillion per annum to global GDP by 2030[61]. Cumulatively this could increase global GDP US$5-10 Trillion by 2030.

The report shows that there is significant potential to improve resource productivity in the USA to boost growth, create new business opportunities and jobs through recycling and remanufacturing adding >USD$250 billion per annum to the US GDP by 2030.

Australia has also much to gain here given Australia ranks #3rd worst on resource productivity in the OECD. A focus on resource productivity would also reduce the ~AUD$26 Billion per annum Australian business spends on resource input costs. Resource productivity strategies, such as recycling, result in lifecycle energy and water savings thus also improving energy and water productivity.

Increase Natural Resource Productivity – By Restoring Natural Capital and Ecosystem Services - Natural resource productivity is falling. Due to land degradation, 30% of arable farmland[62] globally and in the USA[63] is now unproductive[64] and most soils are degraded. The EU/UNEP 2010 study on *The Economics of Ecosystems and Biodiversity* (TEEB)[65] showed that the economic benefits of this are considerable because cumulative costs from the loss of ecosystems services under BAU, would cost around 7% of global GDP per annum by 2050– equivalent, by 2050, of around US$11.2 trillion per annum[66]. In addition, other specific studies show that the economic costs of food waste, land degradation, and unsustainable management of wild fisheries are respectively around US$1 Trillion[67], EU$1.4-3.4 Trillion,[68] US$1.4 Trillion[69] and US$50 Billion per annum[70]. By comparison, the costs of a global habitat protection and ecosystem restoration plan to preserve and restore the earth's ecosystems remaining habitats, fisheries, fertile lands and soils is around an additional US$110–130 billion per annum, or approximately ~0.2 per cent of current global GDP.[71] Making this investment in natural capital would not only help restore ecosystem services but also, if done well, could improve the long term productivity of agricultural, forestry and fishery systems as well. This is known as ecological intensification.

As the ecological health of soils, landscapes and fisheries are restored, they can become more productive and can produce more food, timber of fish than if they were left to continue to degrade. Ecological intensification

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could conservatively add US$500 billion - $1 trillion dollars per annum to global GDP (or cumulatively <US$7 trillion extra to global GDP by 2030) whilst improving food security, and providing other energy and water productivity benefits. This is why the UN draft Sustainable Development Goals[72] calls on nations to, by 2030, *achieve the sustainable management and efficient use of natural resources"* (SDG #12) , "*Conserve and sustainably use the oceans, seas and marine resources for sustainable development." (SDG #14)* and "*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*. (SDG #15).

1.5 Unlocking New Sources Of Labour, Capital and Multi-Factor Productivity (See Appendix 1 for more Explanation and Business Sector Examples)

Most importantly, (and to date largely unappreciated[73]) investing in energy and resource productivity improves labour, capital and multi-factor productivity growth through improved rates of production, quicker returns on capital expenditure, avoided capital misallocation as well as reduced intermediate energy, water and resource input costs.[74] It also helps labour productivity by creating jobs and improving participation rates. For instance, the IEA has found that these overall total productivity co-benefits from improving energy productivity are between 50% to 2.5 times higher than the simple energy cost input savings[75]. Hence, the cumulative boost to global GDP above BAU from a focus on energy and resource productivity, once the labour, capital and multi-factor productivity co-benefits are included could be ~US35-$50 Trillion by 2030 above BAU. (BOX 1 and 3)

BOX 3 Investing in energy and resource productivity unlocks new sources of labour, capital and multi-factor productivity in many ways, such as;

<u>Labour Productivity</u> – Newer, more energy and resource efficient equipment often provide labour productivity co-benefits**.** Newer, more efficient equipment can either enable the same task to be done faster or to be done with fewer people to operate and maintain the equipment. This can boost labour productivity across many industries and service sectors as shown, in Appendix 1 of this report. For instance, investing in energy and resource efficient "green buildings", which have better quality lighting, air and reduced indoor air pollution increases staff labour productivity and reduces absenteeism.[76] In many cities, citizens are spending 1-3 hours per day commuting to and from work. Reducing this through telework, tele-conferencing, as well as improved energy efficient sustainable public transport options to reduce congestion also enhances labour productivity.

<u>Improve Labour Productivity through Greater Participation Levels</u> - Improving energy and resource productivity can also lead to jobs growth because focusing on labour intensive energy, water and resource efficiency opportunities creates significantly more jobs than capital intensive "supply side" investment in new power stations, dams or desalination plants. Skill diversity and broader geographical distribution also are benefits. UNEP finds that up to an additional 60 million new "green jobs" globally will be created by 2035 from this focus[77]. This would help to achieve UN draft SDG #8 "*Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all."* [78]

<u>Capital Productivity</u> – Investment in energy and resource productivity improves capital productivity by providing a quicker return on investment (through the operational energy cost savings), improving capital asset values and thus the contribution of capital assets to the value of the business. They also improve capital productivity by reducing unnecessary capital investment. For instance, the IEA finds that by 2035, investment in energy productivity could cut the amount of new energy capital infrastructure needed globally by US$7 Trillion[79].

<u>Multi-Factor Productivity (MFP)</u> – MFP is defined as the residual contribution to economic growth not accounted for by measures of labour and capital productivity. It effectively measures the contribution of technical innovation which improves efficiency and thereby reduces energy and resource intermediate input costs for business and households compared to BAU. Hence improving energy and resource productivity directly correlates with improving MFP. This is shown by studies across a range of nations showing that MFP

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growth rates correlate very closely to energy productivity growth rates over the last 200 years. Their analysis has also identified mechanisms which explain how improving energy productivity improves MFP.

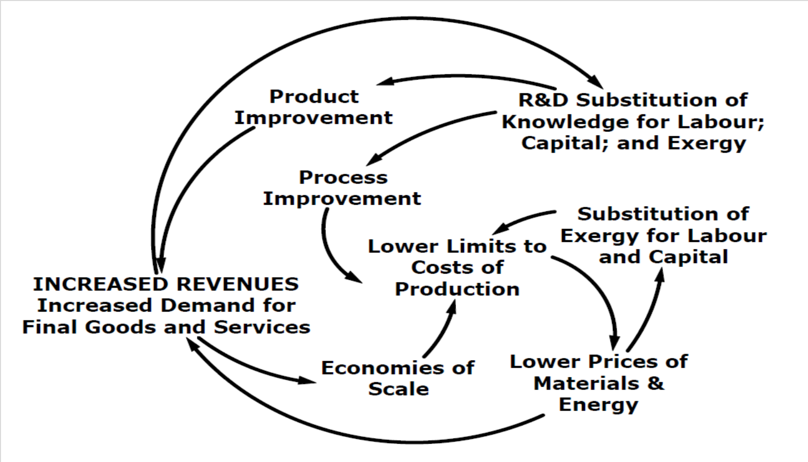

Figure 4: Virtuous cycle driving economic growth from technical innovation to improve energy productivity (exergetic energy efficiency). (Ayres et al, 2006)

Namely (1) R&D technical Innovation – product or process improvement - enables a step change in the exergetic efficiency, ie: the amount of useful work produced per unit of energy input. (2) Lower operating energy costs of a product or process improvement make it more competitive than less energy efficient models. Lower operational energy costs increase customer demand for the product. This enables markets to grow for these new innovations in energy efficient products and services. Economies of scale further reduce costs and increase demand. This virtuous cycle illustrates how technical innovation to improve efficiency has contributed to economic growth since the start of the industrial revolution. For more explanation see Appendix 1 of this report.

Finally, the economic literature also evidences that investments in energy productivity have good economic multipliers. Reviews of the effects of national post GFC stimulus packages, have found that investing in energy efficient buildings, vehicles and transport modes as well as smart grids and renewable energy had good economic multipliers. (Table 2)

Table 2. Effectiveness of green stimulus: analysis of benefits to economy and jobs

Effectiveness of Green Stimulus – based on 17 countries (1 = worst, 3 = best)							
Green Stimulus Areas	***Investment Approach***	***Stimulus Fund (USDbn)***	***Time-liness (Shovel – ready)***	***Long Term Social Return***	***Positive Lock-in Effects***	***Domestic Multiplier/Job Multiplier***	***Rank***
Buildings Efficiency	Public/Private	66.8	3	3	2	3	1
Renewables	Private with incentives/rebate	38.0	2	3	2	2	2
Low-carbon vehicles	Private with Incentives	15.9	2	3	3	2	3
Rail	Public/Private	121.8	1	3	3	2	4

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Grid/Smart metering	Public	91.7	2	3	3	2	5

(*Source*: HSBC[80])

Hence, increasingly nations and businesses are adopting energy and resource productivity targets and governments are implementing smart policy reforms to underpin such efforts. The second report in this series of reports provides options for policy makers on how to do this.

1.6 Implications for Climate Change Economics – Could Action on Climate Change Achieve Higher Economic Growth than Business As Usual?

Most economic modelling to date has failed to include or quantify productivity co-benefits from action on climate change. As Professor Teng and Associate Professor Frank Jotzo have explained, the reasons why climate change mitigation economic modelling overestimates the costs of climate change mitigation is that *"**Positive effects of emissions reductions policies on productivity are typically not fully captured in conventional economic modelling studies. Partial equilibrium modelling of climate change mitigation, usually by way of marginal abatement cost curves, does not take changes in productivity into account**. Unless combined with specific estimates of beneficial impacts from mitigation, these analyses by their very nature present only costs not benefits. Computable general equilibrium (CGE) models, the mainstay of economic analysis for mitigation policy assessment, do represent productivity, but they lack detailed information about differential productivity between sectors or activities, and typically assume that in the baseline economies follow an efficient pattern of investment and structural change. Thus, **by default, a deviation from a model's base case (the hypothetical future scenario against which scenarios with emissions reductions are compared) will show up as a reduction in productivity and economic growth.**"*[81]

This failure to be able to accurately include productivity co-benefits is significant because most of the significant smart climate change mitigation strategies are productivity enhancing. (See Table 4 below in BOX 4)

BOX 4 –Is it Possible to Design a Portfolio of Climate Change Mitigation Strategies which are Overall Productivity Enhancing?

A very effective way to consider and discuss how best to design global and national portfolios of climate strategies comes from using the climate "stabilisation wedges" approach outlined first in 2004 by Princeton scientists Pascala and Socolow in their highly cited Science journal paper.[82] This approach also helps to succinctly communicate the potential to mitigate climate change succinctly to busy decision makers. Pascala and Socolow's paper recommended that humanity choose a portfolio of potential climate change mitigation "stabilisation wedges", where each wedge represented 1 gigatonne of carbon dioxide equivalent reductions by 2050 to stabilise the earth's climate.

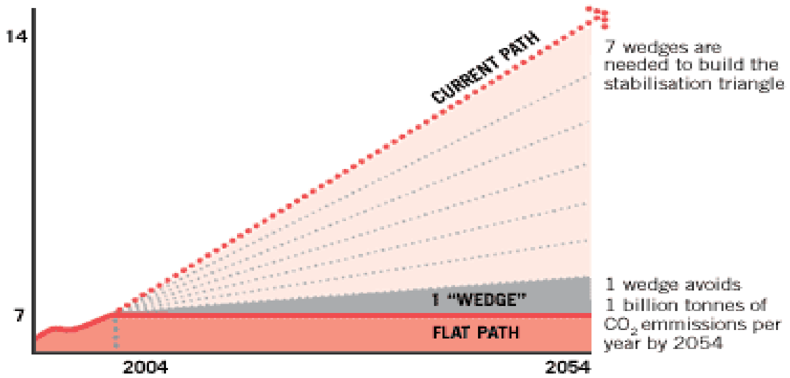

Figure 5: The Stabilisation Triangle, measured in increments of one billion tonnes (or 1 Gigatonne) of carbon per annum globally (Source: Pascala and Socolow, 2004)[83]

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Put together, they argued that the stabilisation wedges, listed in Table 3, demonstrated that it was possible, using existing technologies, to stabilise CO_2 emissions rapidly and keep them stable over the next 50 years.

Table 3. Pascala and Socolow's 15 Stabilisation Wedges	
(1) Double Vehicle Fuel Efficiency	(10) Wind – 2 million MW (50 times current)
(2) Reduced Use of Vehicles – By Half	(11) PV – 2000 GW (700 times current)
(3) Efficient Buildings and Appliances – Cut GHGs by ¼	(12) Wind generated hydrogen – to power hydrogen fuel cell cars.
(4) Efficient Base-load Coal Plants – Double Conversion Efficiency to 60%	(13) Biomass for fuel – 100 times current Brazil and US cropland – 1/6th of world's crops.
(5) Replace 1400 GW 50%-efficient coal plants with gas plants (four times the current production of gas-based power)	(14) Reduced deforestation, plus reforestation, afforestation, and new plantations
(6-8) Carbon Capture and Storage (3 wedges) (6) Capture CO2 at baseload power plan. (7) Capture CO2 at H2 plants. (8) Capture CO2 at coal-to-synfuels plant	(15) Conservation Tillage in agriculture
(9) Nuclear Power – Double Current Global Output	

However, Pascala and Socolow's recommended wedges included several "stabilization wedges" that could have significant negative impacts on energy/water productivity and/or food security such as

- Stabilisation Wedge #13 - Adding 100 times the current Brazil or U.S. ethanol production to use a sixth of the world's crop production,
- Stabilisation Wedge #5 - Increasing four fold natural gas production globally,
- Stabilisation Wedge #14 - Expansion of plantation forests and finally,
- Stabilisation Wedges #6,#7 and #8 - Large scale roll out of carbon capture and storage which increases by 80% water consumption at coal fired electricity power stations. For instance, by 2030, the addition of carbon-capture technology would boost water consumption in the U.S. electricity sector by 80 percent, or about 7500 mega-liters per day.

Also, some of the strategies outlined in Table 3 are not yet commercially viable. This raises the question, is it possible to devise a new portfolio approach to climate change mitigation that does not have these trade-offs and which is largely productivity enhancing? **Through a comprehensive focus on energy and resource productivity (including natural resource productivity), it is possible to identify many additional climate change mitigation stabilisation wedges, in addition to those identified by Socolow and Pascala. (See Table 4) This, recent literature shows that it is possible to achieve significant levels of climate change mitigation in ways that are productivity enhancing whilst maximising social and environmental co-benefits**. The below Table 4 builds on and updates the Pascala and Socolow stabilization wedges approach, including more climate change mitigation opportunities, many of which have positive productivity co-benefits. At least 14 stabilisation wedges are now needed to stabilise the global climate at 450 ppm CO2 equipment by 2050. The below Table lists 20 climate change mitigation strategies that collectively achieve at least 14 stabilisation wedges. The table below integrates literature over the last decade that has identified and quantified additional climate change mitigation strategies showing them to also be able to contribute additional stabilisation wedges.

Table 4 20 mitigation strategies using existing technologies that could together prevent 18.5 GtC emissions by 2050.[84]		
Climate Change Mitigation Strategy	**Existing Enabling Technologies and Design Strategies**	**No. of Stabilisation Wedges**
Energy and Resource Productivity Enhancing Climate Change Mitigation Strategies		

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Buildings – 50% Improvement in Energy Efficiency	Daylighting, efficient lighting (ie LEDs), double and triple glazed windows, low-emissivity windows, insulation; passivhaus design for heating and cooling[85];	~ 1.25
Appliances, office, cooking and industrial equipment - 50% in energy efficiency	The IPCC 5th Assessment buildings chapter shows that the most efficient appliances require a factor of two to five less energy than the least efficient appliances available today.[86]	~1/2
ICT and datacentres – 50% improvement in energy efficiency	Computers: Laptop computers and LCD/LED monitors.[87] Datacentres and Servers: Over fifty technical or design strategies exist to achieve 70% energy efficiency improvements including 'virtualisation'.[88]	~1/8
Increasing urban albedo	Thermoplastic white vinyl, coated roofs, white winyl membrane, [89] (more technologies to be added)	~1
Low carbon building and construction materials	Low embodied energy materials for buildings and construction – bamboo, wood products and engineered timbers[90] from sustainably managed plantations, as well as low carbon cement and bricks.	~1/2
Street and Neon Lighting – 50% improvement in energy efficiency + Solar	Light emitting diodes, metal halide, and solar powered street lighting.[91]	~1/4
Cars – doubling of fuel efficiency to 60mpg	Hybrid, electric or fuel cell engines, lightweight materials (aluminium and composite plastics), regenerative breaking, improved aerodynamics.[92]	~1[93]
Cars – decreasing BAU miles travelled by half.[94]	Public Transport (rail, light rail, bus, tram) and non-motorised transport (cycling, walking), urban and land planning.	~1[95]
Non-car transport vehicle – doubling fuel efficiency	Non-car vehicle transport system (buses, trucking, rail, air-transport[96] and shipping) fuel efficiency	~1/4
Air travel – decreasing BAU miles travelled by half	Video-conferencing, high speed internet, very fast trains.	~1/8
Industry – 30-50% improvement in energy efficiency of motor driven systems	Upgrade and optimise efficiency of industrial and commercial technologies, eg, whole of system energy efficiency improvement of electric motor driven systems such as pumps and fans and compressed air could cut global electricity usage by 10% (IEA, 2011[97])	~1/2
Industry – 30-50% improvement in industrial process energy efficiency	A step change in energy efficiency of industrial processes. The energy intensity > 50% higher than the theoretical minimum determined by the laws of thermodynamics (IEA, 2006[98])	~1
Smart Grid Integration	Smart Grid Technologies [99]- Monitoring devices, ICT integration, distributed generation integration, trans-mission enhancement applications, distribution grid management, metering infrastructure.[100]	
Renewable Energy	Concentrated solar thermal (aka solar baseload)– ~ 1000 peak GW by 2050.[101]	1/2
	Increasing wind electricity capacity to 2100 GW peak by 2050.[102]	1
	Geothermal energy[103] plus tidal, wave, ocean thermal to 50 GW peak by 2050	1/8
	Producing current coal-based electricity with twice today's efficiency.[104]	1/2

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	Solar PV electricity powering residential, commercial buildings and factories.[105]	3
	Solar hot water systems/heat pumps – 80% saturation of residential sector.	¼
	Renewably powered co-generation and tri-generation could meet up to 10% of forecast increases in electricity demand by 2040/50[106].	1/2
Cars –powered by low carbon renewable energy.	Plug in hybrid or fully electric drivetrains, lithium rechargeable batteries[107], light-weight materials, vehicle to grid software.[108]	Using the renewable energy listed above
Public Transport – powered by renewable energy.	Rail, light rail, buses and trams powered by renewables – additional renewable energy capacity.[109]	Using the renewable energy listed above
Product Stewardship, Recycling, and Integrated Waste Management	Materials efficiency and waste minimization; designing products for reuse and recycling; recycling; landfill methane recovery; composting of organic waste; anerobic digestors; methane recovery from waste water treatment plants.[110]	1[111]
Eliminating Black Carbon	<u>Household:</u> (i) use clean burning stoves using biomass or gaseous fossil fuels or LPG stoves to replace household coal use, (iii) solar cookers. <u>Transport</u>: (i) convert heavy-duty vehicles to natural gas fuel, (ii) retrofit them with after-treatment devices (particulate traps) (iii) retrofit "super-emitting" vehicles.[112]	1[113]
Reducing non-CO2 Emissions	Reducing greenhouse gas emissions from CH_4, NOx, HFCs, PFCs, SF_6 - NB Some strategies to reduce non-CO_2 emissions are energy productivity enhancing by enabling synergistic improvements in energy efficiency. However, some mitigation strategies to reduce non-CO2 emissions are "end of pipe" solutions that do involve costs with little productivity gain.	1-2
Conserving forests - halt deforestation plus doubling the rate of re-afforestation.	Reduced deforestation, reforestation; forest management – whether this has productivity gains depends on economic incentives related to a price on carbon.	1[114]
Agriculture – Cropping and Grazing	Improved cropland and grazing systems management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; agroforestry techniques; improved rice cultivation techniques	1[115]
	Total	17.5-19.5 GtC

(Compiled by Smith, M, updating Pascala and Socolow, 2004[116])

Also many adaptation no-regrets measures exist which also are productivity enhancing by improving water productivity, crop production productivity or reducing productivity losses from damages and loss of operations from extreme weather events.

Currently, a significant percentage of climate change economic modelling does not include these latest insights from the climate change related productivity literature (See BOX 1 in the Executive Summary).

Given the rapid reductions in prices for renewable energy mean that for many countries investing in renewable energy will be more cost effective over the coming decades. Even in Nigeria, an oil and gas rich country, IEA and World Bank figures highlight the economic value of pursuing renewable energy rather than more coal based electricity generation. The World Bank study showed that already low carbon energy options are cost competitive today in many cases and by 2025 they will be cheaper (World Bank 2013[117]). (Figure 6)

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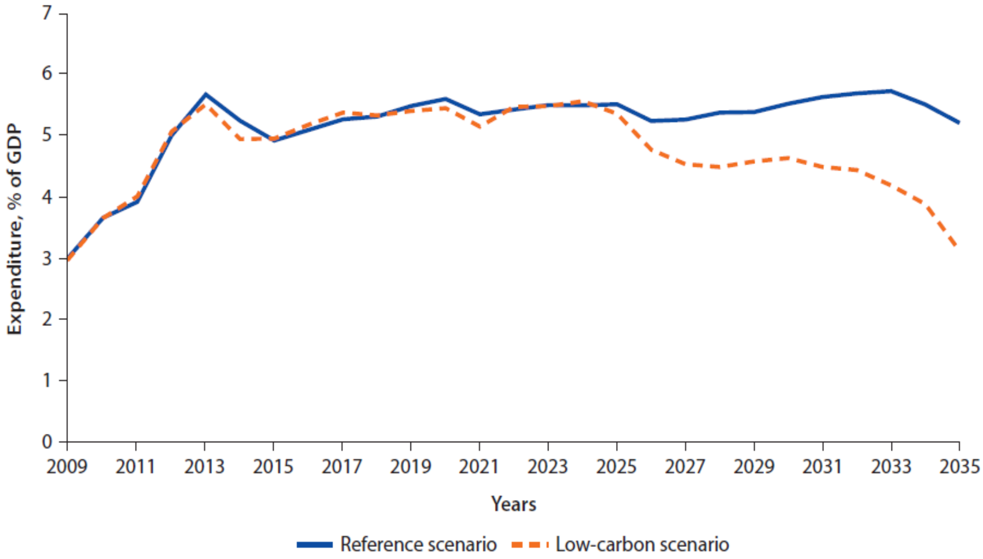

Figure 6 Total General Expenditure (% of National GDP) for Business as Usual Reference Scenario compared to the Low Carbon Resilient Pathway Scenario (Source: World Bank, 2013[118])

The World Bank explains that their result here is very robust and, if anything, quite conservative in the assumptions it had made on comparative costs of renewables versus fossil fuels;

> *"This study modelled several low carbon scenarios' considering different "lowest cost of energy" mixes by technology, using recent projections adapted from a variety of credible international sources, including IEA. A sensitivity analysis explored a "delayed low-carbon scenario" in which adoption of renewables is delayed by 5–10 years due to lower fuel prices and/or slower learning curves for renewables. This delayed low carbon scenario reduces cumulative emissions through 2035 by 40 percent relative to the reference scenario, compared to a 43 percent reduction due to the original low-carbon scenario. It costs about the same as the original low-carbon scenario, assuming costs favour fossil (low fossil prices and slow renewable learning). Both the original and delayed low-carbon scenarios cost less than the reference business as usual fossil fuel scenario for all three cost cases, implying that the conclusions are qualitatively robust to these uncertainties."* [119]

Assuming the relative costs to economies out to 2050 of investing in renewable energy versus fossil fuel supply will either be similar or better for renewable energy technologies, the opportunity exists to also reduce greenhouse gas emissions in ways that will significant add to global GDP above BAU, such as investments

- In energy/fuel efficiency, water efficiency and resource efficiency improvements
- In a transition to the circular economy
- In ecological intensification of agricultural systems including improving soil carbon uptake
- Reducing food waste

As outlined in the Executive Summary, based on studies by the IEA and others (listed in BOX 1) these strategies could cumulatively boost productivity and global GDP by $25-30 Trillion globally by 2030 whilst also reducing productivity losses from extreme weather events. In addition the peer reviewed literature finds that social, environmental and health co-benefits of climate change mitigation measures to be significant. The air-pollution reduction co-benefits alone are found to offset anywhere from a quarter to over 100% of the "costs of climate change mitigation" to 2050.

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1.7 Implications for Green Growth - A focus on energy and resource productivity could enable "green growth" to achieve higher economic growth than BAU

It is important to note that increasing the rate of energy and resource productivity is fundamental to decoupling economic growth from energy and resource consumption and associated environmental pressures to achieve "Green Growth." (Figure 7). Decoupling GDP from resource consumption and environmental pressures lies at the heart of what the OECD refers to as "Green Growth", is achieved by strategies which enhance and increase the rate of both economic growth and reductions in environmental pressures like energy and resource productivity. (Figure 4) Hence this report and the following subsequent reports are designed to help nations better understand how *Green Growth* can genuinely help them to achieve higher economic growth than business as usual whilst also reducing environmental pressures and enhancing natural capital. Proponents of "Green Growth" have argued that it can enhance economic growth above BAU but have never suggested "by how much". This is the first report to show how a focus on "Green Growth" could enhance global GDP by as much as US$25-30 Trillion above BAU by 2030. US$25-30 Trillion may initially appear to some as unrealistic, but as explained, the IEA finds that investing in economically viable energy efficiency opportunities alone would boost global GDP by US$18 Trillion by 2035. A still greater boost to global GDP is achieved if, in addition to energy productivity targets, nations also adopt resource productivity (including natural resource productivity) targets.

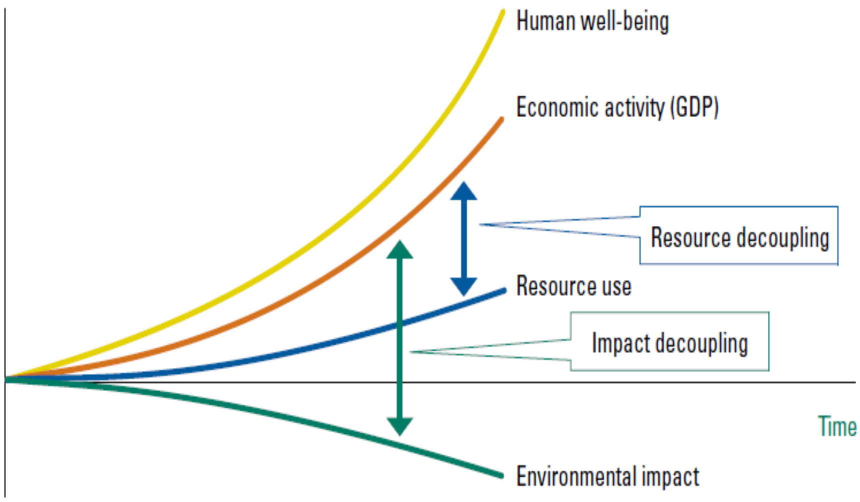

Figure 7: Decoupling Well Being/GDP from Resource Use and Environmental Impact. (Source: UNEP, 2011)

Also, the results of this report have significant implications for discussions about the costs of action on climate change. To date, most economic modelling of the costs of action on climate change has been done with general equilibrium models which ignore the productivity co-benefits of action on climate change[120]. This report suggests that the productivity co-benefit from action on climate change is >US$25 Trillion by 2030 because most of the energy and resource productivity opportunities outlined in this report – energy and resource efficiency, co-generation, renewables, reducing methane leakage, energy efficiency sustainable transport, reducing waste and achieving a transition to a circular economy, reducing deforestation and land degradation and instead restoring soils and biodiversity to boost stored carbon - also are the key ways to reduce greenhouse gas emissions. Hence, if climate change economic modelling includes the costs of inaction on climate change[121] as well as productivity and other co-benefits of action on climate change, studies show that action on climate change can boost economic growth[122]. To help further evidence the value of this approach, the next sub-section shows how a focus on energy and resource productivity specifically could help USA and Australia is considered.

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1.8 Energy and Resource Productivity Potential and Benefits - USA and Australian Case Studies

1.8.1 USA Case Study – Doubling Energy and Resource Productivity by 2030 - Boosting US GDP ~US$3 Trillion by 2030 above BAU

Based on the below studies, by 2030 an integrated approach to increasing energy and resource productivity could boost the USA economy GDP by up to US$600 billion per annum by 2030. This could result in a cumulative increase to US GDP above BAU conservatively ~US$3 Trillion between now and 2030.

Energy Productivity Potential: USA's exergetic efficiency is only around 14%, which means that only 14% of primary energy is transformed into useful work to contribute to economic growth whilst some 86% of potential work from primary energy is lost currently as waste. The US currently lags many major competitors who have 20% levels of exergetic efficiency. This is recognised by President Obama whose administration has formally adopted a commitment to double US energy productivity by 2030. The "US Energy Productivity Roadmap" study shows that a doubling of energy productivity by 2030 would boost US GDP growth by 2% above business as usual, achieving per annum savings of US$327 billion per year, reducing oil imports as well as significant greenhouse gas reductions. The American Council for the Encouragement of Energy Efficiency (ACEEE) have shown that this estimate of the benefit is conservative. ACEEE modelling suggests that 40 to 60 percent reductions in energy demand can be achieved through highly cost-effective efficiency investments to generate up to 2 million jobs while saving all residential and business consumers a net US$400 billion per year, or the equivalent of about US$2,600 per household annually[123]. A focus on improving energy productivity, especially in the transport sector, could also reduce congestion costs, air pollution costs, and costs of diseases of physical inactivity in the USA which respectively cost, over US$50-120 billion, US$75-280 billion[124], and over US$60 billion per annum.

Water Productivity Potential:_The USA has made progress on improving water productivity. The USA has improved water efficiency to such an extent that it has decoupled GDP from freshwater consumption since the 1980s. (Figure 5). If the USA invested US$10 billion in water efficiency programs it could boost GDP by US$13-$15 billion per annum above BAU creating 150-200,000 jobs[125] saving 35 trillion litres of water[126].

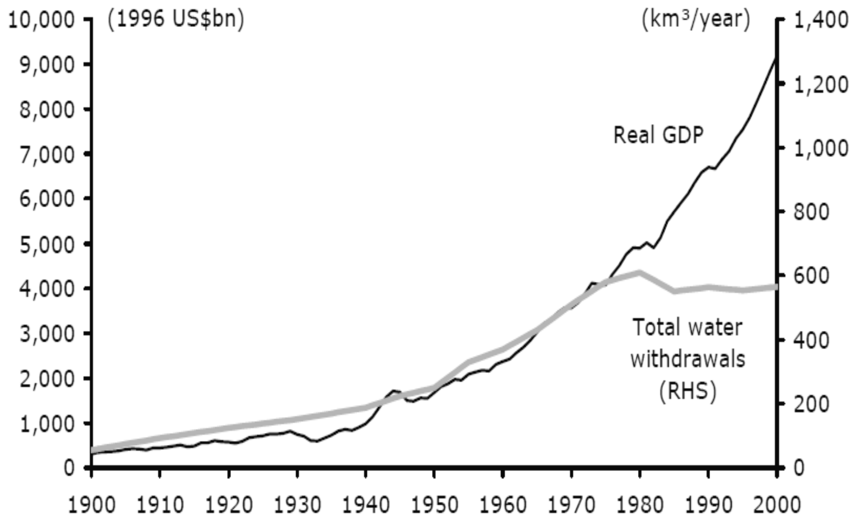

Figure 5 US GNP and total freshwater withdrawals (km^3/annum). (Source, Gleick, P, 2002[127])

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Resource Productivity Potential There is significant potential to improve resource productivity in the USA to boost growth, create new business opportunities and jobs through recycling and remanufacturing. The below data and studies suggest potential to double the levels of recycling and remanufacturing in the USA by 2030 with the right policies and incentives, adding >USD$250 billion per annum to the US GDP by 2030.

Recycling: The US EPA studied[128] the recycling and reuse industry which consists of approximately 56,000 establishments that employ over 1.1 million people, generate an annual payroll of nearly $37 billion, and gross over $236 billion in annual revenues. This represents a significant force in the U.S. economy and makes a vital contribution to job creation across a range of skills and economic development. In addition to the economic activity of the recycling and reuse industry itself, other economic activity is supported because the industry purchases goods and services from other types of establishments (such as office supply companies, accounting firms, legal firms, building and landscape maintenance firms, etc.). Economic modelling estimated that nearly 1.4 million jobs are maintained in support businesses because of the recycling and reuse industry. These jobs have a payroll of $52 billion and produce $173 billion in receipts. There is significant potential to improve recycling rates in the USA, because 75% of USA waste is recyclable, but only about 30% of it is recycled. For instance,

- The USA has the lowest rates of glass recycling in the OECD at 20%, whilst Switzerland has achieved over 80%.
- Of the 243 billion beverage bottles and cans sold in the U.S. in 2010—153 billion were either landfilled, littered or incinerated. Hence less than 40% were recycled.[129]

Yet at the same time, The USA produces the most municipal solid waste per capita in the world.

Remanufacturing: There are over 70,000 firms in the USA employing over 400,000 people contributing US$53 billion in sales per annum through manufacturing. Remanufactured products sell for 50-80% less than the original product, providing cost savings to customers. There is significant potential for this to increase, as it currently represents a very small percentage of US manufacturing. Studies show that if a range of barriers were addressed, including improving design of original manufacturing products for remanufacturing, the contribution of remanufacturing to improving resource productivity could increase significantly.[130]

Natural Resource Productivity Potential: Natural resource productivity is falling in the USA. Due to land degradation, land productivity has fallen and 30% of arable farmland[131] in the USA[132] is now unproductive[133]. The annual economic costs of food waste, deforestation and land degradation, invasive species and unsustainable management of wild fisheries in the USA are estimated at respectively US$165 billion, US$100, US$120[134] and US$2 billion per annum. So addressing these issues could realistically add US$150-$387 billion per annum to the national USA GDP. There are additional multiple benefits and cost savings in addressing these issues.

Consider food waste. In the USA, food production involves 10 percent of the total U.S. energy budget, uses 50 percent of U.S. land, and consumes 80 percent of freshwater. Yet, 40 percent of food in the USA goes uneaten, resulting in losses of all embedded inputs and large volumes of fertilizers and pesticides with their embodied energy. Losses in the USA are often caused by factors such as retailers' rejection of produce due to poor appearance. Food waste currently costs the US economy US$165 Billion per annum. (more than $40 billion from households) including US$750 million per year just to dispose of the wasted food into landfill whilst contiributing 33 million tons of landfill waste (leading to greenhouse gas emissions).[135]A focus on energy and resource productivity can also help the USA boost productivity by simultaneously unlocking new sources of labour and capital as well as multi-factor productivity growth (See BOX 3 and Part 3 below for more details).

Productivity Co-benefits - **Reducing greenhouse gas emissions to reduce risks of negative economic impacts from unmitigated climate change.** As mentioned in the report precis and opening to this report, a

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focus on energy and resource productivity also will reduce greenhouse gas emissions and play a part in reducing risks of more intense extreme weather events. In the USA, in 2012, climate-related droughts, super storms, hurricanes, blizzards, heat waves, and wildfires caused $139 billion in costs and damages. A recent study found that, *"As the frequency and severity of extreme weather events intensify with the effects of climate change, USA federal and state disaster relief and insurance programs will become increasingly unsustainable as losses from such events increase. The net present value of the USA federal government's liability for unfunded disaster assistance over the next 75 years could be greater than the net present value of the unfunded liability for Social Security."*[136] ***Thus, adding up the economic benefits of improving energy, water, resource productivity and climate change mitigation could cumulatively boost the USA economy by at least US$3 trillion above BAU by 2030.*** Adopting a focus on energy and resource productivity is particularly relevant and helpful for nations to help address a problem of significant poor productivity performance in certain sectors. Australia is one such example. The following shows that a focus on energy and resource productivity (ie water productivity) can help address the poor productivity performance of 4 key sectors, which collectively are responsible for 80% of the decline in Australia's multi-factor productivity performance.

1.8.2 Australia – Doubling Energy and Resource Productivity by 2030 - Boosting GDP > cumulative $AUD50-100 Billion by 2030 above BAU

It is widely acknowledged by many reports that it is critically important for Australia to improve productivity growth. This is because the previously high terms of trade effectively hid the fact that, since 2000, Australia's productivity performance has been relatively poor. (Figure 6)

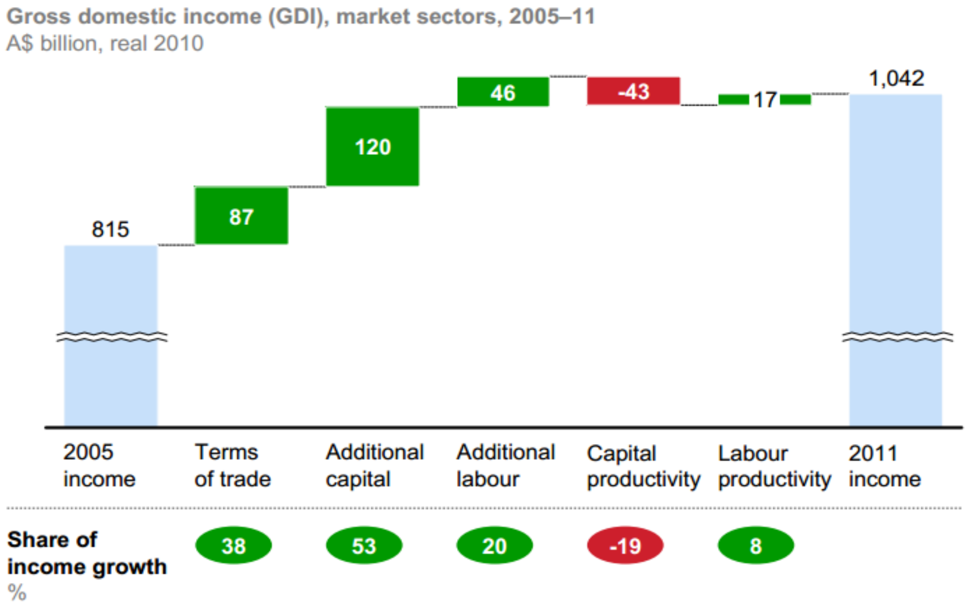

Figure 6: New Capital and Terms of Trade have Driven Income Growth Since 2005 in Australia (Source: McKinsey Consulting, 2012[137]).

Some argue for greater infrastructure and capital spending to boost productivity. But, not all infrastructure and capital spending improves productivity. According to the Productivity Commission (of Australia) sub-optimal decision making and planning in major infrastructure and capital investment in four sectors is negatively impacting on Australia's productivity growth namely, the utilities (electricity, water), mining and agricultural sectors. The Productivity Commission estimates these sectors in Australia account for almost 80% of the decline in multi-factor productivity growth between the growth cycles of 1998-1999 to 2003-2004, and 2003-2004 to 2007-2008, a conclusion endorsed (at least initially) by the Australian Treasury. Multi factor productivity (MFP) is

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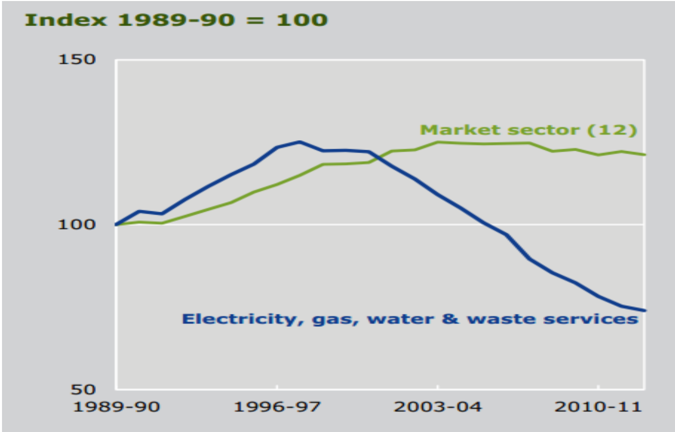
important because it can account for up to 60% of economic growth within modern economies.[138] Key factors identified as contributing to the decline in MFP in Australia in these sectors include;

- (1) Electricity Utilities - significant investment in poles and wires to meet increasingly peaky summer electricity peak demand, rather than energy efficiency and peak demand management, has resulted in declining capital productivity (See Pictured Right). Now over 15% of Australia's electricity grid is only being utilised for less than 1% of the year to meet summer peak electricity demand. This has been a major factor in driving up Australia's electricity costs further negatively impacting on productivity in other sectors.



- (2) Water utilities - investment in desalination plants which are under-utilised currently instead of more investment in urban water efficiency, contributing to a decline in productivity in the water services sector (See Pictured Right). In addition,

(3) Agriculture sector - Failure to invest adequately pre-2000 in water efficient irrigation infrastructure in Australia for irrigated agriculture and more resilient grazing pasture systems resulted in Australia's agricultural sector productivity being very vulnerable to, and significantly harmed by the millennium drought with production being significantly reduced in 2002-3 and 2006-7 especially. (Gray et al 2014[139]).

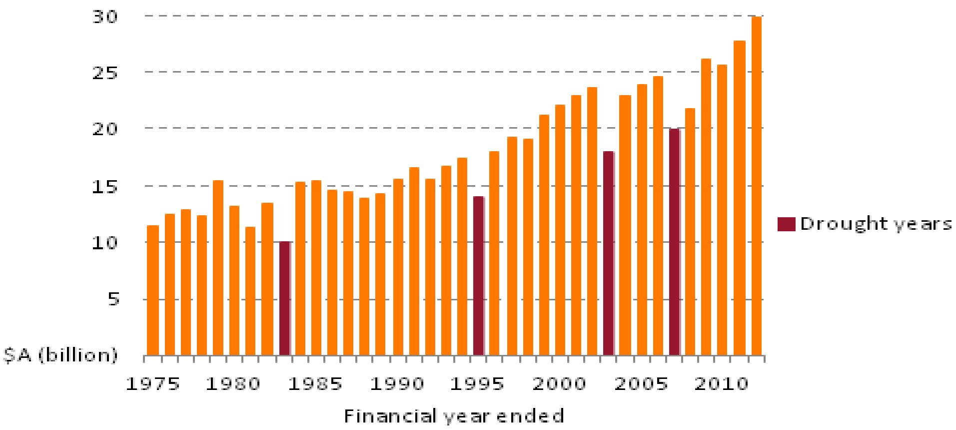


Figure 8 Impact of drought on the gross value of agricultural production (Source: ABARE, 2014[140])

(4) Mining - a failure to sufficiently invest upfront in equipment which improves the energy efficiency with which mineral ores are mined and processed. This is a key and under-appreciated factor in declining multi-factor productivity in the Australian mining sector.

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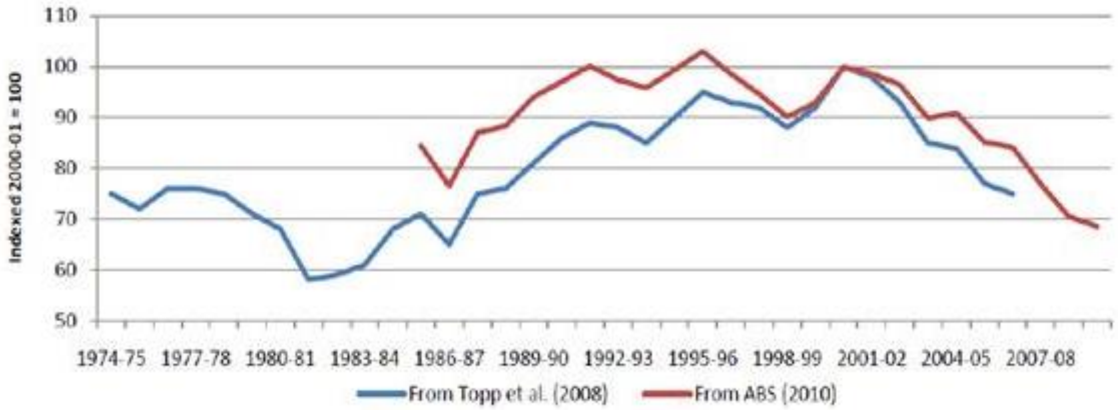

Figure 9: Multi-Factor Productivity in the Australian Mining Industry from 1974-2008. (Sources: Topp et al[141] and ABS)

The common explanation proffered for the declining multi-factor productivity in the Australian mining sector is that there has been a lot of capital investment in the mining sector which is yet to result in productive output. That is certainly part of the explanation, but, as the Australian Productivity Commission has shown, the other main factor is rising energy input costs due to the higher energy and resource intensity required to mine and process declining mineral ore concentrations.[142] (Figure 10) Once ore grade concentrations reach below 1%[143] the amount of energy, water and material flows required to extract each unit of valuable mineral rises exponentially.[144] Over the last 30 years, the average grade of mined Australian ore bodies has halved[145]. This has already led to a 70% increase in energy consumption per tonne of minerals produced in Australia and contributed to declining multi-factor productivity in the mining sector. As the Productivity Commission shows, when this is taken into account, productivity in the sector has not fallen over the last decade (Figure 10). So, if the metal ore mining sector had invested more upfront in cutting edge energy and resource efficient approaches to mining (See 3rd report in this series) to pro-actively address the risk of rising energy costs from declining ore grades, productivity could have been improved. Improving energy-efficiency of new resource developments can reduce their operational costs (Opex) enabling companies to pay off their capital investment costs (Capex) and more quickly boost profits and the capital productivity of such investments. For instance, recent analysis of large resource developments in Australia have found that, if profit margins on a long-term asset are 5% and energy is 20% of operational costs, a 25% improvement in energy efficiency will double the profit of the life of that project.

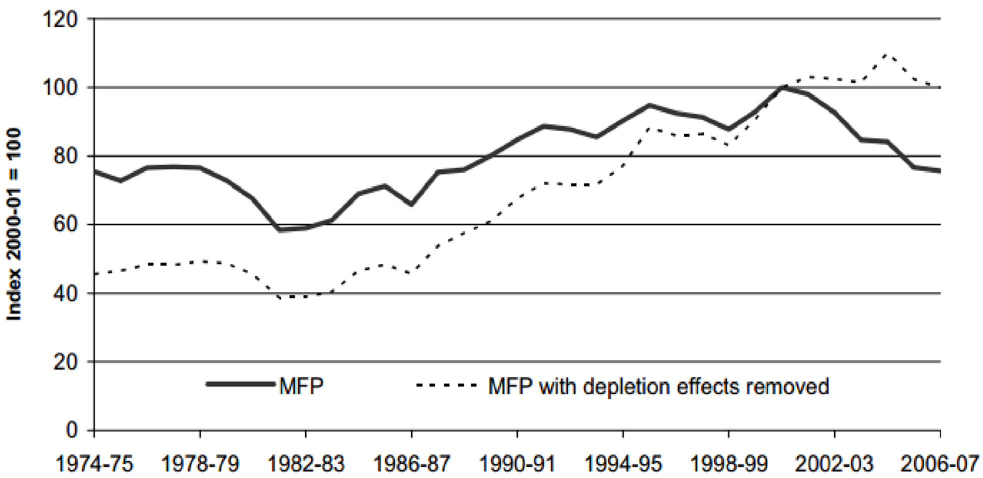

Figure 10 – Mining Multi-factor Productivity and Mining Multifactor Productivity with mineral ore depletion effect removed. (Source: Topp et al, 2008[146])

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In all four sectors, if decision makers and policy makers had focused first on incentives and investment in energy or water efficiency and smart technologies to better manage energy and water demand and supply constraints, the productivity in all these sectors over the last decade could have been significantly enhanced compared to BAU. For instance, studies show that energy efficiency and demand management are effective means of reducing peak electricity demand to improve energy productivity and capital productivity. Also, investment sin water efficiency and demand management would prevented the need for desalination plants in some of Australia's cities (with the exception of Perth and Adelaide) to improve capital productivity in the water sector. The failure historically to prioritise energy efficiency in Australia is well illustrated by the fact that the energy productivity of Australia's electricity grid is close to half that of California's as shown in BOX 4.

BOX 4 – Australia versus California on Energy Productivity of Electricity Infrastructure –. California is the 10th biggest economy in the world, with roughly 40 million people and a GDP 50% bigger than the Australian economy. Yet to meet the demands of this economy and population, California generates 292 TWh of electricity where Australia requires almost as much (261 TWh) for a population of 60% that of California.[147]. This highlights the potential improvement available for Australia between 2015 and 2030 by learning from examples such as that of California. California's energy productivity rate is almost double that of Australia's. Since 1978, California's energy-efficient appliance standards, combined with their energy-efficient building standards, (mentioned above) have saved more than US$56 billion in electricity and natural gas costs, *w*hilst creating nearly 1.5 million jobs from 1977 to 2007[148]. Whilst this has meant reduced jobs growth in the fossil fuel sector, for every 1 job lost in this sector, 50 have been created in the energy efficiency sector. A focus on improving energy productivity in California has also created a regulatory environment which has helped Californian business become leaders in the cleantech industry**.**

The Australian economy would particularly benefit from a focus on energy productivity because Australia has both the fastest rising energy costs in the OECD and one of the worst energy productivity rates in the OECD (Figure 11). This means Australian business and households are currently exposed to rising energy costs. For instance,

- Australian retail electricity prices rose roughly 100 per cent from 2005 levels by 2015[149] due mainly to AUD$45 Billion investment in "poles and wires" electricity infrastructure over the last five years[150].
- Wholesale natural gas prices have increased from $2.50 to around $8.00 per gigajoule (GJ), with some contracts reported to be up to $12/GJ in Western Australia. In eastern Australia, the wholesale price has increased from about $3.50 to $6/GJ in the last few years, with an expectation of further rises as high as $9.00/GJ[151]

Improving Energy Productivity: In recognition of these facts the latest Energy White Paper by the Australian Government[152] has made improving energy productivity a major priority and committed to developing a national energy productivity roadmap plan and target. ClimateWorks' detailed bottom up 2015 modelling study on the Energy Productivity Potential for Australia shows that "*the (technical) potential exists to nearly double the energy productivity of the Australian economy by 2030 by investing in the modernisation of our energy system and taking advantage of recent technological developments. This would mean almost double the economic output (in terms of GDP) for every unit of energy consumed in 2030. Their report shows that around 64 per cent of the potential improvements can be achieved by improving the way energy is used in the economy, through:*

-Energy efficiency: Adoption of more efficient technologies and processes.

-Electrification: A shift to electricity for certain activities, such as electric vehicles, and conveyor belts rather than trucks on mining sites.

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-Optimisation and structural change: Optimisation of systems and continued structural shifts in the economy towards less energy intensive activities.

The remaining 36 per cent of the opportunity is in improving the way energy is supplied, through:

-Energy conversion: Switch to more efficient forms of energy generation.

- Energy distribution: Reduction in losses from distribution of energy to end users." (CWA, 2015[153])

The ClimateWorks Australia report also shows that "The good news that can be drawn from this analysis is that improving energy productivity and achieving the required level of emissions reductions are complementary and mutually supportive." It shows that doubling energy productivity by 2030 ensures that Australia is on track to play its part in helping keep global warming below 2 degrees.[154]

The economic, social and environmental benefits of pursuing such an increase in energy efficiency are likely to be significant. In Australia, the direct economic benefits of a doubling of energy productivity by 2030 include the following;

- Increasing Australia's GDP by at least AUD$30 Billion by 2030 above business as usual[155].
- Reducing peak electricity demand and better managing it could reduce forecast Australian electricity energy price rises significantly by cutting peak electricity demand consumer costs by AUD$3-12 billion per annum[156] and delaying the need for costly electricity grid infrastructure investment.
- Cutting Australian business energy input costs by 10-20%, or just over AUD$10-20 Billion per annum by 2030 compared to BAU.[157] This estimate may seem optimistic, but, the Australian Minimum Energy Performance Standards for appliances, office equipment and motor systems alone, over the period 2000-2020 are forecast to achieve cost savings to the Australian economy in total of AUD$22.5 billion, including saving households AUD$5.2 billion.
- Improving the bottom line of Australian commercial transport companies by approximately AUD$763 million per annum (CWA, 2013)[158]**.** Fuel costs amount to as much as 30% of total business costs for commercial transport companies so even small savings in consumption will have significant financial benefits.. So, when major trucking company Linfox, achieved 30% fuel efficiency savings it cut its fuel costs by millions per annum. Improving the energy productivity of passenger transport systems (including improving active and public transport options) is essential to improve productivity, public health, fuel security, as well as social equity[159]
- Cutting household electricity costs by AUD$5.2 Billion (more efficient appliances) by 2024, and AUD$7.9 Billion (more efficient cars) from fuel cost savings by 2024. (CWA, 2014) This can significantly contribute to reducing cost of living, as transport makes up around 16% of the average Australian household budget[160]. According to the ABS, transport fuels represent 45% of total energy usage of households. Other economic benefits of shifting to energy efficient and energy productive transport systems– include reducing congestion, air pollution and obesity related costs, which cost Australia respectively AUD$10 billion,[161] AUD$3.3 billion[162] and AUD$58 billion per annum*."*[163]

Water Productivity: Doubling water productivity by 2030, could add ~AUD $1 billion to national GDP per annum by 2030, or cumulatively add >AUD$5 billion to national GDP by 2030 through water cost savings. Billions more could be saved through avoided unnecessary or inappropriate water supply infrastructure investment. There is significant potential to increase water productivity in Australia, as Australia is ranked #55th for water productivity performance in the world. Australia rates in the middle of OECD countries in terms of water productivity performance further evidencing the potential for still greater improvement. (Figure 20). For instance,

- **In agriculture,** there is still significant potential to improve water productivity through greater investment in water efficient irrigation infrastructure, greater usage of irrigation scheduling and smart deficit irrigation

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techniques. Time controlled grazing systems, where applied successfully, suggest that they can thrive on less freshwater inputs, as they store and reduce runoff and evaporation of water that falls as rain on these properties.

- In many capital cities in Australia, where annual rainfall is greater than 800mm, the volume of urban storm-water runoff into the ocean is larger than the volume of water supplied by mains water for consumption.[164] Greater amounts of this stormwater could be harvested and used as is being done in Orange County, California, USA..

- **In the residential sector,** most Australian cities' per capita water usage is still behind best practice for this sector as demonstrated by cities like Singapore. New residential developments could be made to be largely self-sufficient in freshwater through use of rainwater tanks and dual reticulation systems which enable new developments to use recycled water for toilets and gardening.

- **In the commercial property sector**, significant water efficiency opportunities exist. For instance, Melbourne University's new Faculty of Economics and Commerce building shows it is possible to achieve 90% reductions in mains freshwater.[165]

- **In the industrial/manufacturing sector,** water use rose during the 2001-2009 drought, yet some manufacturers have achieved up to 70% freshwater savings compared to past average industry performance. (See Report #2 in this series for more details) For instance, Ingham's Enterprises, Australia's largest poultry processing company, has reduced mains freshwater usage by 72% in their major Brisbane poultry processing plant through water efficiency, water treatment and recycling onsite.

- Mining companies, until recently, did not have an agreed water accounting framework to help them understand, measure and manage the myriad of aspects of water usage in mining. Using this new framework, researchers at University of Queensland's Centre for Water in Mining have shown that significant freshwater savings are possible in Australian mining.

- **In the energy sector**, for Australia, improvements in energy efficiency and demand management to reduce use of electricity from fossil fuel thermal power plants, could result in significant freshwater reductions. Wind power and solar PV, for instance, consume significantly less water per unit of energy produced than traditional fossil fuel based power stations.

- **In the water sector,** significant reductions in water losses are possible through reducing evaporation loses from dam water and from reducing water leakage rates.

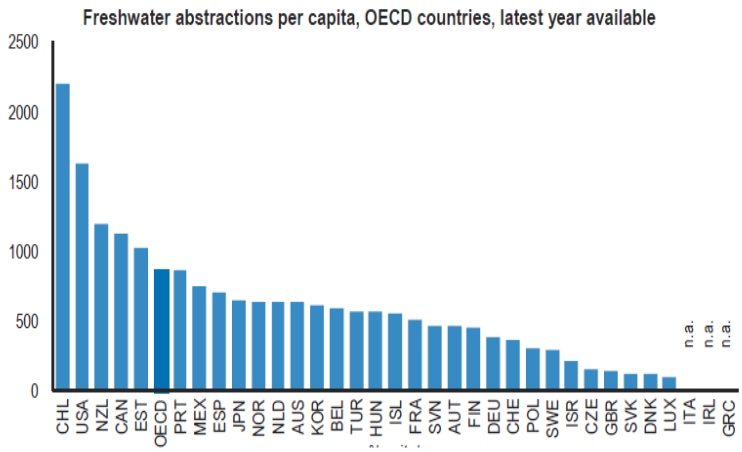

Figure 12: Freshwater abstractions per capita, OECD countries, (Source, OECD, 2011[166])

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Resource Productivity Potential: There is significant potential to improve resource productivity in Australia through

- **Improving material efficiency:** Australian business spends ~AUD$26 billion on resource input costs. Improving material efficiency by 10% would cut Australian business costs by ~AUD$2.6 billion per annum.
- **Expanding remanufacturing:** Australian firms have engaged in remanufacturing for more than a decade in the automotive, printer consumables, servo motors and compressors for air-conditioners and refrigerators sectors. This has potential to be expanded.[167]
- **Improving recycling rates.** Most states and territories have recycling targets of 70% or over by 2020 or 2030 but currently are achieving well below this[168]. (Figure 21) Further evidence for the potential to increase recycling is shown by the fact that both the ACT and South Australia has achieved >70% of waste diverted from landfill, roughly 30% above other states. There are significant cost benefits of recycling metals, many plastics, organics and paper. In some regions and countries, around the world, where they incentivise the recycling of these materials, the percentage going to landfill has been reduced to 2-20% (See Figure 22 below)

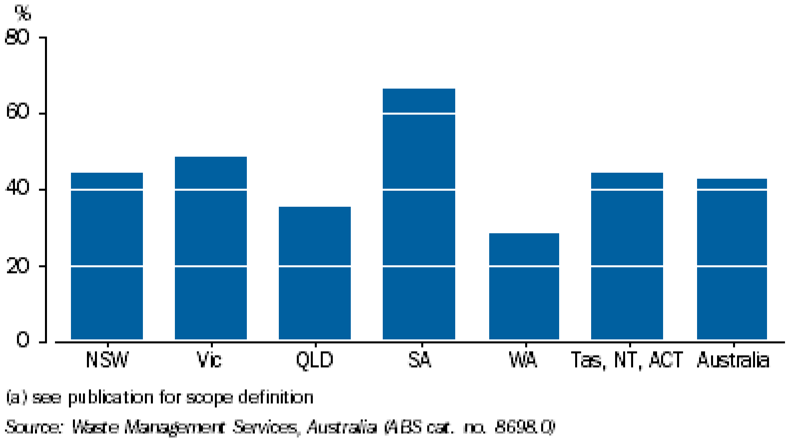

Figure 13: Percentage of Waste Diverted from Landfill. Australia, States and Territories - 2009-10 (Source, ABS, 2009-2010)

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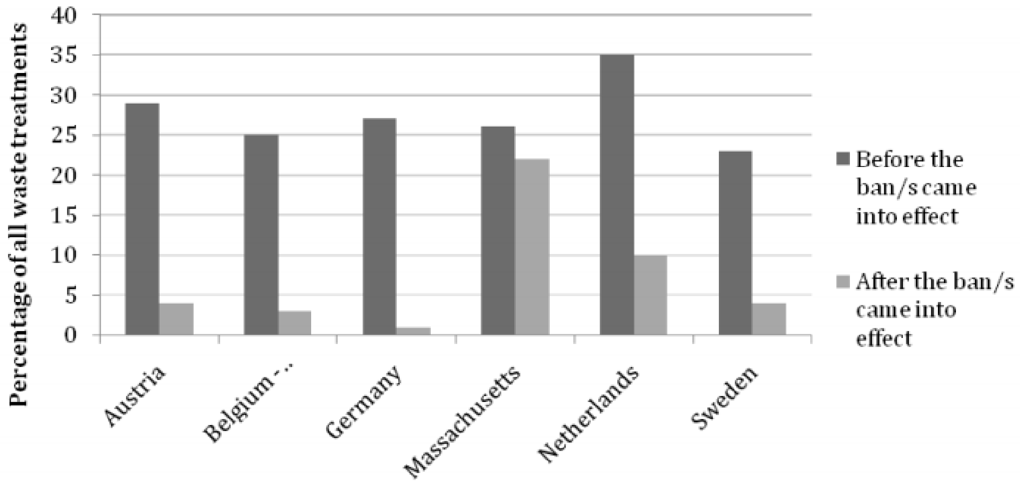

Figure 14: Percentage of Waste Going to Landfill Before and After Bans on Particular Waste Streams. (Source: WRAP, 2012[169])

Natural Resource Productivity Potential - Australia's natural capital and the ecosystem services that it provides has been valued at around AUD$1 Trillion per annum[170]**.** Australia's natural resource productivity is declining. The economic costs of food waste, lost agricultural production due to land degradation, invasive species, weeds is respectively AUD$5 billion[171], AUD$1.4 billion, AUD$720 million[172], AUD$3.4 Billion[173]. Australian fisheries production of a number of species has been declining since the late 1980s[174]. Hence, greater efforts to reduce food waste and restore soil health and land productivity could conservatively help add > AUD$1 billion per annum to GDP or >AUD10 billion cumulatively by 2030.

Using conservative estimates, the potential cumulative boost to GDP from energy productivity (>AUD$30 billion), water productivity (>AUD5 billion), resource productivity (>AUD$10 billion), natural resource productivity (>AUD$10 billion) totals > an $AUD55 billion boost to GDP above BAU by 2030. If we assume, based on IEA studies, that the overall net productivity increase from these energy and resource productivity improvements is roughly two times the simple productivity benefits from energy and resource cost savings, it is possible that the overall productivity boost to Australia could result in a boost of AUD$100 billion by 2030.

Including other co-benefits from the reduction of air pollution, congestion and diseases of inactivity from greater encouragement of active transport, could further add to this figure. This focus could also help Australian business cut energy input costs of AUD$113 billion, water input and trade-waste costs of around AUD$10 billion per annum, and resource input costs of around ~AUD$26 billion per annum. Even just a 10% improvement in energy, water and resource efficiency could achieve a cut in business costs of around ~AUD$13 billion per annum.

Given the evidence presented thus far, clearly it is possible for nations to boost GDP and jobs through a renewed focus on improving energy and resource productivity using the latest insights into how to do this. The next report – Report #2 in this series – firstly brings together the latest studies for a number of nations and regions of the world are evidencing that best practice approaches to improving energy and resource productivity can achieve a doubling of energy and resource productivity by 2030. The 2nd report,

- recommends nations adopt targets to double energy and resource productivity by 2030
- brings together evidence from respected sources of how to achieve such targets
- and provides policy options to underpin their achievement.

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Appendix 1 - A Deeper Understanding on The Economic Case for Energy and Resource Productivity - Unlocking New Sources of Labour, Capital and Multi-Factor Productivity

"The Australian economy will need to become more energy, resource and environmentally efficient. In fact, going forward, energy, resource and environmental efficiency will be key drivers of productivity."

[175] Dr Martin Parkinson. Former Treasury Secretary, Commonwealth Government of Australia

2.1 The Productivity Challenge and Opportunity

As the Executive summary pointed out, a new body of studies and literature shows that by 2030, a focus on energy and resource productivity could add around US$2-3 Trillion per annum to global GDP [See BOX 1 above]. The Executive Summary shows that this cumulatively could amount to at least a US$25 Trillion increase to global GDP by 2030. Despite this, still the belief is common that focusing on increasing energy and resource productivity will not result in significant increases to national or global GDP. This is an incorrect assumption for the following four key reasons, namely:

Firstly, a 0.5-1% increase annually to GDP from either energy productivity or resource productivity or both becomes significant rapidly overtime. For instance, in the 2014 IEA Multiple Benefits of Energy Efficiency report, the IEA writes that investing in energy efficiency could boost global GDP by a cumulative US$18 Trillion by 2035[176]. As the IEA states in 2014, this is bigger than the current USA economy! But this fact was not appreciated in the IEA's previous 2012 report on the multiple benefits of energy efficiency. In 2012, in the IEA 2012 report on the *Spreading the Net*: *Multiple Benefits of Energy Efficiency*[177], in its discussion of macro-economic effects of energy efficiency, the IEA wrote they were "relatively small." Specifically the IEA stated that,

> *"Improvements in energy efficiency can produce significant positive macroeconomic impacts such as increases in GDP, trade balance, economy restructuring, employment, and national competitiveness to name but a few. The few studies examining the macroeconomic effects of improved energy efficiency (where energy demand is reduced by 8 to 15%) suggest significant potential impacts including increases in GDP ranging from 0.8% to 1.26%. In summary, it appears that the case for energy efficiency from a macroeconomic growth perspective is good. Although the effects are estimated to be relatively small, they remain positive[178].*

Between this 2012 version of the IEA *Spreading the Net: Multiple Benefits of Energy Efficiency*[179] and the IEA's 2014 *Multiple Benefits of Energy Efficiency* report, the IEA has simply put the potential of improving GDP by 1.26% pa in a more accurate perspective. The IEA has simply recognised that a 1.26% increase annually to GDP in a US$85-90 Trillion global economy is equivalent to a boost to GDP of US$1.25 Trillion per annum. And, as explained in the executive summary and precis to this report, this annual boost will be cumulative over time. This is because once investments in energy efficiency are made, a) they tend have a return on investment of 1-4 years in most cases and b) after that, the cost savings continue every year to the business or household for the design life of the energy efficient design or equipment. Hence a potential US$1.25 Trillion boost to annual global GDP over 15 years, results in around an US$18 trillion boost to global GDP.

Secondly, the above paragraph from the IEA report highlights the simple fact that most studies either look at the macro-economic effects of energy productivity or resource productivity but rarely both as shown by the list of reports in BOX 1 in the Executive Summary. This report is the first to bring these studies together to highlight that the potential for investments in energy productivity to have resource productivity co-benefits and vice versa. This energy-resource productivity nexus increases the potential for energy productivity to boost national and global GDP.

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Third, studies assessing the potential macro-economic GDP benefits from a focus on energy efficiency or water and resource efficiency tend to ignore the potential for eliminating or delaying the need for new costly energy, water or resource supply infrastructure. When this is considered the impact is considerable. For instance, the IEA has calculated that investing in all economically viable energy efficiency opportunities would cut the need for US$7 Trillion worth of new energy supply infrastructure by 2035.

Fourth, economic studies assessing the potential macro-economic from a focus on energy and resource productivity usually fail to consider the full range of potential simultaneous labour, capital and multi-factor productivity co-benefits. In developed countries, where energy and resource input costs can make up a relatively small percentage of the overall economy, it is these labour and capital productivity co-benefits of energy and resource productivity which can make a relatively large contribution to boosting national productivity. Most studies into energy and resource productivity, with a few notable exceptions, have not properly or comprehensively considered these labour, capital or multi-factor productivity co-benefits. This report submits that it is only by considering the labour, capital and multi-factor productivity co-benefits of a focus on energy and resource productivity that its true economic benefits of pursuing these strategies can be appreciated. Hence this Appendix next focuses on showing in detail

- How a focus on energy and resource productivity can help boost labour, capital and multi-factor productivity in detail. Through this discussion this Part 3 report evidences that a focus on energy and resource productivity can enable a new wave of technical innovation to unlock new sources of labour, capital and multi-factor productivity.
- Having shown that, Part 4 then looks at how to maximise improvements to energy and resource productivity and policy options to help enable this.

2.2 Doubling Energy and Resource Productivity (EP and RP) by 2030 – Unlocking New Sources of Labour, Capital and Multi-Factor

As explained in the Australian Energy Productivity Roadmap *"Driving energy productivity improvement is not an alternative to pursuing labour, capital or broad-based multi-factor productivity strategies. As an integral part of the way we live and do business, the mechanisms through which productive energy use translates into additional economic value directly touch all three elements of the productivity equation and also have a multiplier effect."*[180]

Most studies into the macro-economic effects of improving energy and resource productivity have not ever modelled this comprehensively. Hence most studies to date under-estimate the potential of a focus on energy and resource productivity to enhance economic growth.[181]

Energy and Resource Productivity – Unlocking New Sources of Labour, Capital and Multi-Factor Productivity

The following examples evidence how new opportunities for technical innovation or improved design still exist in developed economies, like the USA and Australia, which can simultaneously increase not just energy and resource productivity – but also labour, capital and multi-factor productivity. For instance:

Property, Commercial Buildings and Services Sectors

Investing in energy and resource efficient "green buildings" has been shown to increase labour productivity, capital productivity, and multi-factor productivity.[182]

<u>Labour productivity:</u> In the operation of green buildings, there can be up to 11 per cent gains in labour productivity from improved ventilation[183], and up to 23 per cent gains[184] in labour productivity from improved lighting design. Even small staff health and labour productivity gains can dramatically improve organisational

profitability (Figure 3). This is because, in the services sectors, labour costs (staff salaries and expenditures) make up over 85% of total workplace costs, compared to less than 10% on rent and less than 1% on energy.

So, most of the cost benefit for business, from investing in energy and resource efficient green buildings, arises from the resulting improved labour productivity benefits from their staff.**[185]** For instance, at the City of Melbourne's CH2, Australia's first 6 Star Green Star - Office Design rated building, productivity has risen by an impressive 10.9% since staff moved in, with an estimated productivity benefit of $2 million per annum.[186]

This matters when trying to quantify the potential of energy productivity to help boost national productivity growth because commercial building based services sectors constitute over 60-80% of OECD country GDP. So, even just small improvements in labour productivity in these sectors, can significantly boost OECD economies' overall productivity like that of Australia and the USA.

Capital productivity: In a number of studies that compared certified green buildings to non-certified buildings in the same sub-market, price premiums were found to be up to 30% better. These studies find that green buildings improve capital productivity by enhancing asset value,[187] achieving higher asset values through securing premium tenants (e.g. government departments), higher rents[188], lower tenant turnover[189], lower lease-up costs, higher occupancy levels, and lower operating costs.[190]

Multi-factor productivity**:** Studies report that green buildings on average use 25-50% less energy and 30-70% less water, thus reducing operational intermediate energy and water input costs.

Other productivity benefits: Other studies have found that well designed energy efficient green buildings assist productivity by

- Improving indoor air quality through energy efficiency measures, in a high energy efficiency scenario, could save the European Union's economy as much as USD 259 billion (EUR 190 billion) annually[191].
- Reducing length of hospital stays by 8.5% as well as enabling faster recovery rates in rooms with windows views of nature[192].
- Reducing patients'/ need for pain medication by 22% in rooms with natural daylighting and bright sunlight.[193]

and increasing

- sales per square foot in Walmart[194] a 15 - 20% increase in sales at Target[195] and a 73-store retail chain in California with a 40% increase in sales due to daylighting[196] and
- attendance by three days per year, a 5 - 14% improvement in test scores[197] and 20 - 26% faster learning rates in schools with optimal daylight.[198] (See Figure 5)

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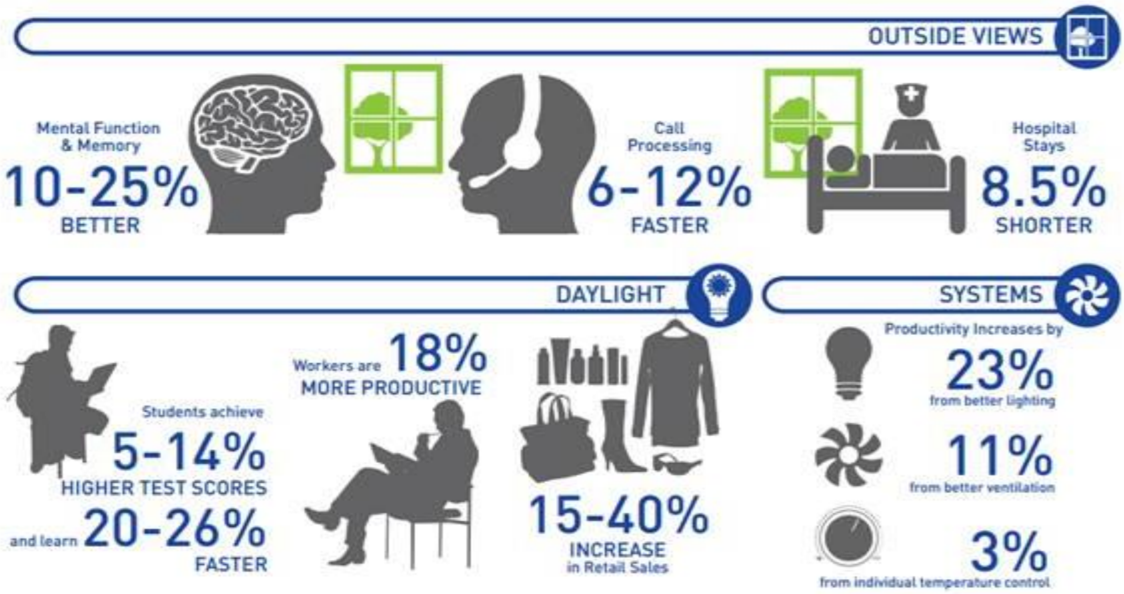

Figure 15 Net present value analysis of the operational cost, productivity and health benefits of energy and resource efficient "green" LEED certified buildings (Source: World Green Building Council, 2013[199])

BOX 5: The labour "productivity" benefits of investing in the energy and resource efficient green buildings has been demonstrated since the mid-1990s.

Greening the Building and the Bottom Line: Increasing Productivity Through Energy-Efficient Design by William Browning and Joseph Romm[200] demonstrated very attractive economic returns, not only through savings in electricity and other energy sources, but also far more significantly through sustained savings in employee-related costs, such as improved productivity, improved work quality and reduced absenteeism. The large savings in employee-related costs are due to these costs being about 6 times higher than gross office rent and about 70 times higher than energy costs (see Figure 8.3), so it only took a very small improvement in labour productivity or small reduction absenteeism or reductions in product defects to accumulate a large financial saving.

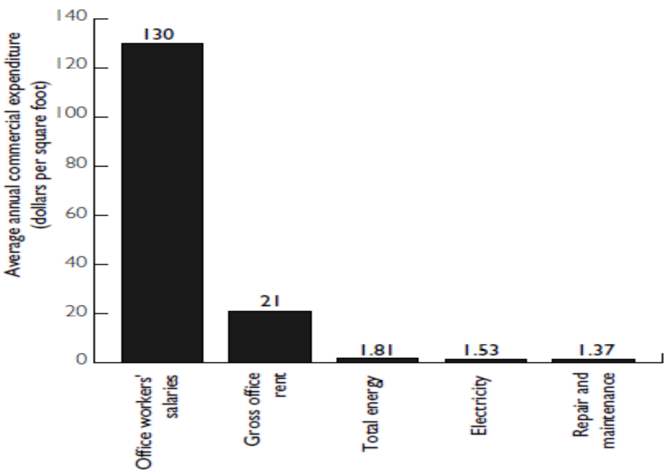

Figure 16 Comparison of average annual expenditure of various costs for commercial buildings.

Source: Building Owners and Managers Association (1991) and *Statistical Abstract of the United States* (1991) cited in Romm and Browning (1998)[201]

Browning and Romm concluded that these savings arise in buildings where the quality of employee workspaces are improved through improved visual acuity and thermal comfort, and that such improvements can be achieved concurrently with large energy savings. This paper featured numerous case studies showing this for retrofit and new buildings such as :

- Reno Post Office (retrofit): a lighting retrofit and new ceiling at a cost of $300,000 resulted in annual savings of $22,400 in energy costs and up to $500,000 through a 6 percent increase in processing rate.
- Boeing (retrofit): a lighting retrofit resulted in a 2 year payback through 90 percent savings in lighting electricity and even greater financial savings through a reduction in defects.
- Hyde Tools (retrofit): a lighting retrofit at a cost of $98,000 resulted in annual savings of $48,000 in energy costs and $25,000 through an increase in product quality.
- Pennsylvania Power & Light's (retrofit): a lighting retrofit at a cost of $8,362 resulted in annual savings of $2,035 in energy costs through 69 percent savings in lighting electricity, $42,240 through a 13 percent increase in product quality, at least $50,000 through a reduced error rate and a 25 percent reduction in absenteeism.
- Lockheed Building 157 (new): daylighting and energy efficiency measures at a cost of $2 million resulted in annual savings of $500,000 in energy costs, a one year payback of all addition costs through a 15 percent reduction in absenteeism and a 25 percent improvement in productivity.
- West Bend Mutual Insurance (new): energy efficient lighting, HVAC, controls and other measures resulted in annual savings of $126,000 in energy costs through a 40 percent reduction in total energy consumption, $364,000 through a 2.8 percent increase in productivity and a 16 percent increase in claims processed.
- Wal-Mart (new): daylighting and energy efficient HVAC resulted in an increase in sales compared to the non-daylit area.
- ING Bank (new): daylighting and energy efficient HVAC and building design at a cost of $700,000 resulted in annual savings of $2.6 million in energy costs through a 90 percent reduction in total energy consumption, a 15 percent reduction in absenteeism and a 16 and a positive new image.

In the services sectors there are also sub-sector specific opportunities to boost energy and labour productivity such as

- ***Service Sectors - Food retail – Restaurants/Bakeries*:** Better insulated and more energy efficient ovens, catering/cooking equipment in general, and induction stoves cook food faster improving labour productivity and improving service to customers. Reducing heat losses from ovens in bakeries also helps productivity by ensuring work areas are not extremely hot in summer.
- ***Service Sectors – Supermarkets and online delivery***. Online orders and delivery of food to customers has been shown to cut life cycle analysis energy costs significantly with labour productivity and congestion reduction co-benefits. This is achieved through
    a) one van delivering food to multiple customers rather than multiple customers driving to and from supermarkets
    b) the food being able to be stored and refrigerated in a warehouse. Actual supermarkets are very energy intensive buildings because, to keep customers warm, supermarkets use energy to heat the aisles next to refrigerated cabinets. This results in the heating of the store and refrigeration of food competing with each other resulting in significant inefficiencies. Ordering food online enables food to be delivered from warehouses instead, where the food is efficiently refrigerated in cool rooms, saving energy overall.

- ***Service Sectors* - *Dry Cleaning (Hotels, Aged Care, and Laundromats)*** - Even in dry cleaning, newer more energy efficient technologies boost labour productivity. For instance, advanced ozone technology washing machines boost labour productivity in dry cleaning because they wash clothes more effectively and faster than traditional systems. For instance, Oak Towers Aged Care Facility in Melbourne have invested in ozone washing machines and reduced energy usage by 490 GJ of gas per year, whilst lifting labour productivity by 12%. This investment paid itself back in 18 months. This technology allows hotels, aged care facilities, as well as dry cleaners to improve labour productivity.

Industry Sectors - Newer, more energy and resource efficient technologies and equipment can simultaneously boost labour, capital and multi-factor productivity. This is because more eco-efficient equipment or technologies often either enables the same task to be done faster or to be done with fewer people. This can boost labour productivity across many industries and service sectors. For instance, innovations to improve industrial/manufacturing processes to utilise recycled materials as source materials can reduce the size of the manufacturing plant and the number of steps required in a manufacturing process yielding labour, capital, energy and resource productivity co-benefits.

- ***Steel Manufacturing*****:** For instance, electric arc steel making furnaces (EAF) have been replacing blast furnaces for steel making plants, after world war two because of
    - Improved Labour Productivity – EAF plants that utilise recycled materials cut out a number of steps (raw material mining and extraction and processing) and have quicker processes because of the lower melt temperatures required to reprocess scrap steel into new products. EAF mini-mills have adopted *"New innovations in iron and steelmaking technology e.g. new productive and energy efficient technologies in scrap melting (DC-furnace, utilization of post combustion, off-gas and fossil energy), thin slab casting, direct reduction of iron ore as well as new smelting reduction techniques for ironmaking without sintering and cokemaking."*[202]
    - Improved Capital Productivity - The low capital cost for an electric arc furnace mini-mill—around US$140–200 per ton of annual installed capacity, compared with US$1,000 per ton of annual installed capacity for an integrated steel mill.
    - Improved Multi-Factor Productivity: EAF mini mills have far lower energy, water and resource input costs compared to blast furnace operations.
    - Improved Energy and Resource Productivity – Electric arc furnaces use 30-50% less energy per tonne of steel partly because they can use 100% recycled steel as inputs. Energy savings are also possible through the fact that
        - EAF mills have greater flexibility and can be shut down depending on supply and demand. By contrast, blast furnaces cannot vary their production by much.
        - EAF mills, being smaller, can be built closer to local markets reducing transport energy consumption to deliver product to market and allowing production to be matched more closely to demand, reducing inventories.

  As a result, recent literature shows that EAF plants using scrap, from an economic and environmental perspective, are always cheaper and better than mining virgin ore and moving it through the process of making new steel[203].

- ***Metal Manufacturing*** - A similar trend can be seen in other industries which produce metal products. Many researchers in the past have shown that a similar trend applies to the shift to plants that focus on metals recycling and metal scrap utilisation[204]-[205]. As lower grades of ore increase energy input costs for production from virgin materials, this trend is likely to increase labour, capital, energy and resource productivity improvements relative to producing metals from extracting raw mineral ores.

- ***Material Manufacturing*****:** A similar trend can be seen in other materials manufacturing sectors using recycled materials such as the trend of smaller paper recycling mills increasingly replacing large Kraft paper manufacturing plants. The smaller paper recycling mills have improved capital, energy and resource productivity for similar reasons to EAF steel plants[206]. Using recycled paper over the life cycle saves 30–50%[207] compared with virgin fiber production. A range of reports show that better insulated and more energy efficient furnaces[208], kilns[209], and ovens[210] tend to melt metals, glass and ceramics more quickly improving labour productivity and energy productivity.

- ***Paper Manufacturing: Office printers now allow you to recycle and reuse your own paper in your office up to 5 times*****:** This has effectively moved paper recycling and manufacturing from the paper mill into the office achieving significant energy, resource, labour and capital productivity gains and efficiencies. (Pictured right). Over the lifecycle the energy savings are >60%.
- ***Cement Manufacturing*****:** Cement manufacturing has not changed much in over 200 years since the invention of Portland cement. Australian cement company Zeobond Pty Ltd is the first company to commercialise a low carbon, low embodied energy cement material based on industrial waste streams through innovations in geopolymer cement technology. This new cement technology has 80% less embodied energy and greenhouse gas emissions. Produced at scale it is also cost competitive with Portland cement. It can be made in existing Portland cement plants, meaning there is no significant capital cost to change over to making low carbon cements. The Green Building industry globally is increasingly demanding low embodied energy building materials such as this.

Mining and Resources Sector

In the capital intensive mining and resources sector improving energy-efficiency of new resource developments can reduce their operational costs (Opex) enabling companies to pay off their capital investment costs (Capex) quicker, thus boosting profits and thus the capital productivity of such investments. For instance, recent analysis of large scale resource developments in Australia have found that, if profit margins on a long-term asset are 5% and energy is 20% of operational costs, a 25% improvement in energy efficiency will double the profit of the life of that asset and project. Some of these more energy productive mining technologies also offer significant labour productivity savings such as

- <u>In underground mining</u>, significant energy efficiency savings, labour productivity and safety improvements can be achieved by investing in automated electric powered underground drilling, scooping and materials movement machines.[211] These electric powered underground equipment can now replace diesel powered underground mining machines and thereby eliminate diesel fumes reducing the amount of ventilation energy demand in underground mining by up to 90%.[212]
- <u>In open cut mining</u> – most mines have haul trucks to move ore out of the mine to be processed. In-pit crushers and conveyors (IPCC) can now often be used instead yielding significant energy, water and labour productivity gains. BHP Billiton informed UK investors of their decision to move towards truckless mines through investing in IPCC systems in 2012. BHP executive Marcus Randolph stated, *"'When you run a truck, it takes 10 to 11 employees for every truck. It takes 4½ to five to run it, all the crews that do the maintenance on it, all the camp people that do the camp cleaning and cooking and everything else. If you go truckless (and use input crushers and conveyors) you do not need any of these staff. You do this at a time when you see increasing diesel prices, carbon taxes, a number of reasons why getting rid of trucks or using fewer trucks*

is desirable." Mr Randolph said "the technology was already viable in mines with soft ground that did not require blasting but he said it could be adapted to also work in mines that did require blasting."[213]

- US mining giant Vale is also replacing trucks at some of its mines with in-pit crushers and conveyors. In its largest Brazilian iron ore mines, Vale SA (VALE5) is replacing trucks with 23 miles of conveyor belts and a new railway line to cut materials movement related energy costs by 77%.[214] As Vale states, "*This measure will cut fuel consumption by 77%. Compared with conventional methods, the truckless system and ore processing using natural moisture will together cut S11D's annual greenhouse gas emissions by 50%, or 130,000 metric tons of CO2 equivalent. In addition, the main equipment used at the project will be powered by electricity. Only crawler dozers, motor graders and other auxiliary equipment will run on diesel."*[215]

Figure 17 Mobile crushing plant, mobile transfer conveyor & bench conveyor.

Farming and Agricultural Sectors:

FAO (2011)[216] along with numerous recent reviews[217] have highlighted that it is both possible and highly advantageous to address future food needs by transitioning to systems of food production that are based on "ecological intensification"—using land, water, biodiversity and nutrients efficiently and in ways that are regenerative, minimizing negative environmental impacts."[218] This can boost productivity and profits by (i) increasing yields compared to BAU, ii) gaining premium organic prices, (iii) reducing input costs (ie artificial fertilisers and pesticides), (iv) reducing overall energy consumption (ie reducing high embodied energy fertiliser inputs) v) increasing resilience of landscapes, soils, grasslands to drought (vi) and improving capital productivity by increasing the asset value of the property. For instance, in Australia, holistic grazing practices which restore natural capital to grazing farms have been shown to increase carrying capacity and stock rates, reduce farming input costs, improve the health and value of farm assets and thereby increase farm productivity in grazing systems in the majority of the literature since 1996. Earl and Jones, 1996[219], McCosker, T. 2000[220]; McArthur 1998[221]; Gatenby 1999[222]; Joyce 2000[223]; Sparke 2000[224], Ampt & Doombos, 2011[225] Walsh, D. 2009[226], Teague et al, 2011[227], Sanjari et al, 2008.[228]

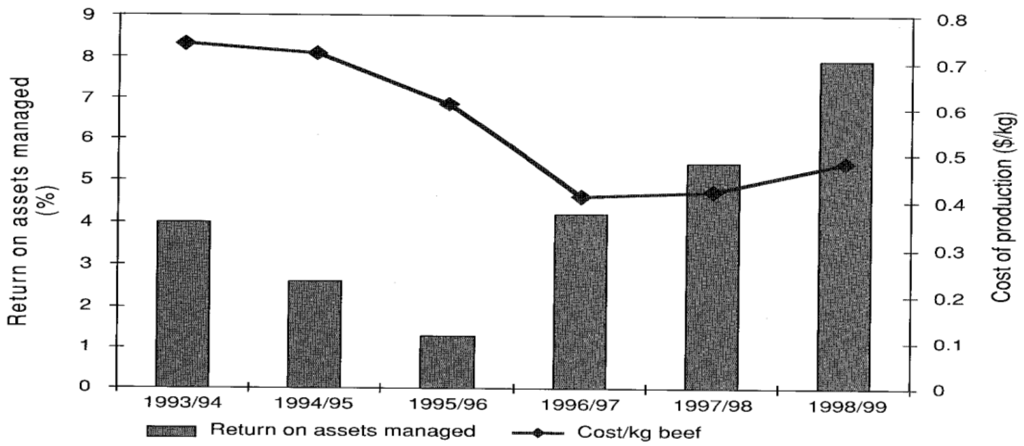

Figure 18: Trends in return on assets managed and cost of production from a case study group of grazing farms in central Queensland who have implemented time controlled holistic grazing. (McCosker, T. 2000[229].)

As the figure above shows, implementation of time controlled grazing in central Queensland, Australia led to almost a halving of farm input costs of production and a significant increase in return on assets managed[230]. The *Soils for Life* initiative in Australia also features actual grazing farms (http://www.soilsforlife.org.au/case-studies.html) evidencing that holistic grazing practices have also improved labour productivity too. The restoration of the natural capital of the farm also increases the value of the asset increasing capital productivity. It is also important to note the farming sector can also improve productivity by diversifying to gain additional revenue for land sector businesses (ie farms, forest projects), through for instance, carbon farming and selling energy to the grid from wind farms, in ways that do not compromise agricultural production, and help to insulate farmers from loss of revenue due to extreme drought.

Forestry and Forest Products Sectors

There is great potential to re-invent the forestry and forest products sector by moving away from low value products (ie woodchips) to higher value products and new revenue streams through, for instance, expanding production and markets of high strength engineered timber, such as cross laminated timber,[231] products that can replace high embodied energy steel and cement in building construction. Using engineered timbers instead of steel has been shown to enable low carbon embodied buildings to be constructed faster increasing labour productivity and reducing construction costs. Engineered timbers can be made from plantation forestry stocks that are only 10-15 years old, thus increasing also the return on capital investment (ie improving capital productivity) with which the forestry sector can produce high value products. Lendlease Australia has built the first high rise apartment building in Melbourne in 2012 using engineered timbers reducing embodied energy and CO2 equivalent emissions by more than 1,400 tonnes when compared to concrete and steel[232].

Additional Capital Productivity Co-Benefits from Energy and Resource Productivity

Increasing energy and resource productivity can further boost national productivity by reducing capital misallocation and significantly helping to improve capital productivity in numerous ways;

- First, the IEA argues that a focus on energy efficiency can reduce forecast capital energy supply expenditure by $7 Trillion by 2035[233]. McKinsey Global Institute has shown there is potential to improve energy productivity significantly globally in developing countries that could cut global energy demand growth by at least half while generating average internal rates of return of 17%.[234] Energy efficiency also helps to reduce unnecessary capital expenditure in OECD countries. Where nations, like the EU, USA and Australia have many old power stations, which will need to be replaced over the next two decades, improving energy efficiency to cut electricity demand growth significantly will reduce the amount of new capital investment in replacement electricity power supply systems.

- Secondly, a focus on energy productivity can reduce forecast peak electricity demand. Currently significant amounts of capital investment goes into energy supply infrastructure ensuring that cities and nations can meet peak electricity demand. But this tends to be relatively inefficient capital investment with low capital productivity. Take Australia as an example. Currently close to 15% of the Australian electricity supply sector and infrastructure has been built to meet just 1% of annual electricity peak electricity demand on hot summer days. This is a highly inefficient way to meet peak electricity demand and is a significant reason why the capital productivity of the energy services sector has declined so much the past decade in Australia. It is also a key factor in causing significant electricity price rises in Australia since 2007. A focus on energy productivity to reduce peak electricity demand and better manage it would reduce forecast Australian electricity energy price rises significantly by cutting peak electricity demand costs by AUD$3-12 billion per annum[235] and delaying the need for costly electricity grid infrastructure investment. For instance, The Australian Productivity Commission has evidenced that there are better ways to address national peak electricity demand through (i) more effective price signals and (ii) national electricity market reforms that would encourage greater levels of energy efficiency and demand management to reduce capital misallocation and boost energy and capital productivity by billions of dollars by 2030.[236]
- Third, a focus on water productivity would also save trillions in reduced water supply infrastructure costs thus improving capital productivity through avoiding capital misallocation. This is because, as reported in Science, *"The annual (investment) cost of ensuring all globally has access to clean water through investing in more large-scale centralized dams and treatment plants would cost around US$180 billion per annum to at least 2025. This figure can be reduced to US$10–25 billion, if the emphasis is on investing in (water productivity) – namely water efficiency, demand management, rain and stormwater harvesting and water recycling*."[237]
- Fourth, improving capital productivity through energy efficient forms of public transport capital infrastructure. As stated in Chapter 1 of The Natural Advantage of Nations,

  > *"It has long been believed that (capital infrastructure investment in) building roads is good for the economy of cities while public transport is a financial drain. But, as Professor Peter Newman explains 'cities that emphasize walking, cycling and public transport are healthier financially and spend less of their wealth on transport costs. The six cities that came out the best were cities like Zurich, Copenhagen, Stockholm – very wealthy cities now, which spend only 4 or 5 per cent of their wealth on transport, and yet they are the cities that are putting their money into public transport. And the cities still pouring money into freeways use up to 17 per cent of their wealth. Australian and US cities like Perth and Phoenix are wasting far more of their valuable wealth on just getting around. Our data would really question that freeway building has any economic rationale; unless you are building up the rail system (as in Perth) you are not going to help it economically. As soon as you put in big roads, you create a market for city sprawl and this is very expensive. If you build railways, particularly light rail, it concentrates a city as developers like building around it, thus helping to stop the sprawl. Then you get a whole lot of flow ons.' The study also found that the mechanisms driving this additional cost include the following:*
  >
  > > • *The land required to build the infrastructure and its subsequent requirements for parking; a single lane of railway can carry up to 50,000*

persons per hour, a bus way can carry 7000 persons per hour and a highway lane just 2500 persons per hour.

• The direct cost to households of owning a car are considerable, especially if it is a second or third car. A study in Australia showed that a household could save AU$750,000 over a lifetime if a second car could be avoided.

• The opportunity cost of such capital and land can be considerable if seen on a whole city basis. The difference between the most competitive cities, in terms of their transportation costs as a proportion of city wealth, and the least competitive (5–8 per cent compared to 12–18 per cent) can be equivalent to an extra day a week of work in car dependent cities."

2.3 National Energy Productivity Correlates with Multi-Factor Productivity Performance

National productivity is measured as the sum of labour, capital and multi-factor productivity (MFP) (See Appendix 1 for formal definitions). Multi-factor productivity is thus defined as the residual growth, i.e. the part of GDP growth that cannot be explained by growth in labour or capital productivity changes[238]. The US Government defines MFP as follows, "*MFP measures reflect output per unit of a set of combined inputs. A change in MFP reflects the change in output that cannot be accounted for by the change in combined inputs. As a result, MFP measures reflect the joint effects of many factors including research and development (R&D), new technologies, economies of scale, managerial skill, and changes in the organization of production."* Hence, multi factor productivity, many argue, is a critical driver of long term growth within an economy. Multi factor productivity can account for up to 60% of economic growth within modern economies.[239]

Recent techno-economic research by Stern and Ayres et al[240] shows that multi-factor productivity, correlates very closely with the relative energy efficiency of nations. Ayres et al work shows that multi-factor productivity correlates closely to how technical innovation improves the exergetic efficiency with which primary energy is turned into useful work which contributes to economic growth. As Aryes et al explain, "Exergy services can be equated to exergy inputs multiplied by an overall conversion efficiency which, of course, corresponds to cumulative technological improvements over time." Aryes et al show that it is possible to explain economic growth rates over the last 200 years for the USA, UK and other economies as a function of rates of labour and capital productivity improvement plus improvements in exergetic efficiency. Laitner (2012), more recently has shown that the rate of increase in exergetic efficiency correlates closely with overall USA productivity growth rates over the last 60 years. (See BOX 6 below)

BOX 6 - USA – Evidence Rates of Economic Growth Correlates Closely with Exergetic Efficiency (and thus Energy Productivity)

Studies show that US economic productivity rates correlate very closely to energy productivity and exergy – namely the level of efficiency with which potential work is converted into actual work to generate growth. USA's rates of exergetic efficiency improvement has fallen significantly since 1980 suggesting that this has contributed to USA's decline in productivity post 1985.

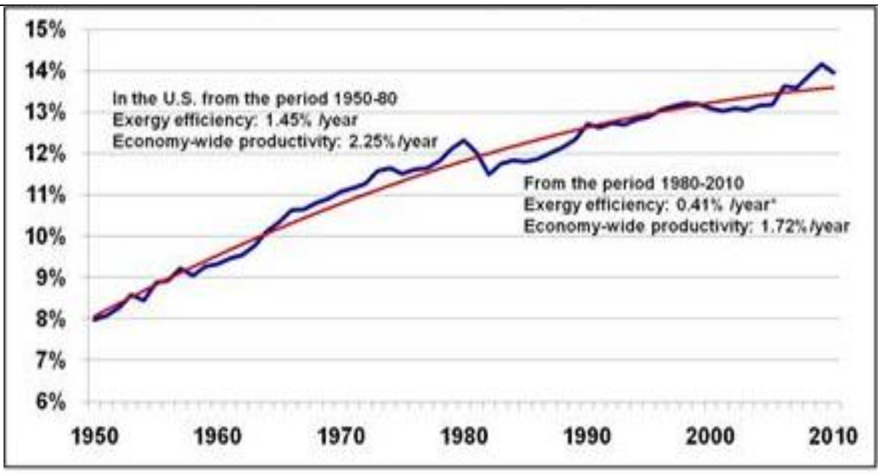

Figure 19: USA Productivity improvement rate Decline Correlates with a Decline in the Rate of Exergy Efficiency Improvement. (Source, ACEEE, 2013[241])

Therefore Aryes et al and Leitner's studies respectively suggests that the rate of improvement of exergetic efficiency of the economy (ie increasing thermodynamic efficiency of the economy) could be closely related to the measure of multi-factor productivity (Aryes et al, 2003-2013)[242] and overall productivity. Aryes et al, [243] have argued that the reason for this is the following positive feedback cycle outlined in Figure 9 below and explained by the following steps listed next.

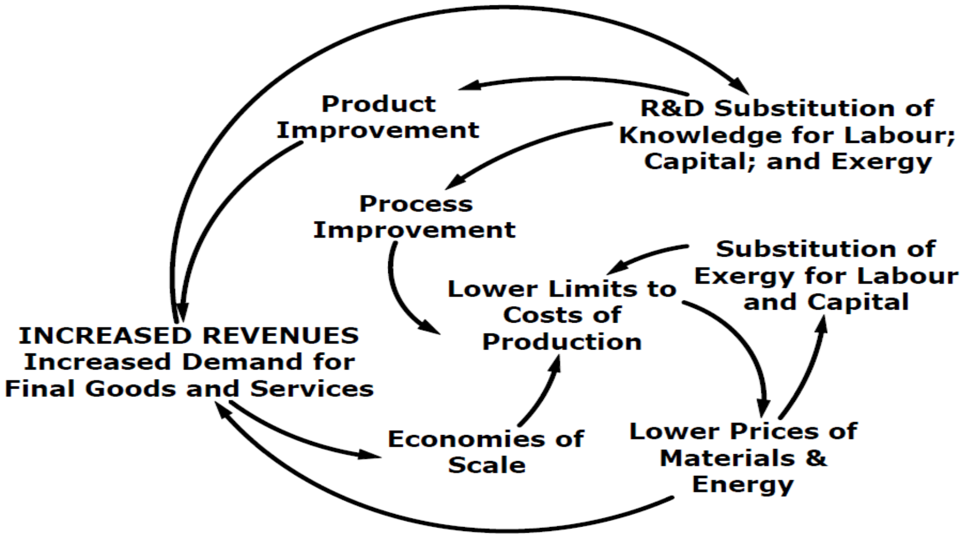

Figure 20: Virtuous cycle driving and underpinning economic growth. (Ayres et al, 2006)

Namely:

- (1) R&D technical Innovation – product or process improvement - enables a step change in the exergetic efficiency, ie the amount of useful work produced compared to the actual theoretical maximum potential work any system could produce per unit of energy input [See BOX below listing historical examples of innovations- See Figure 10.

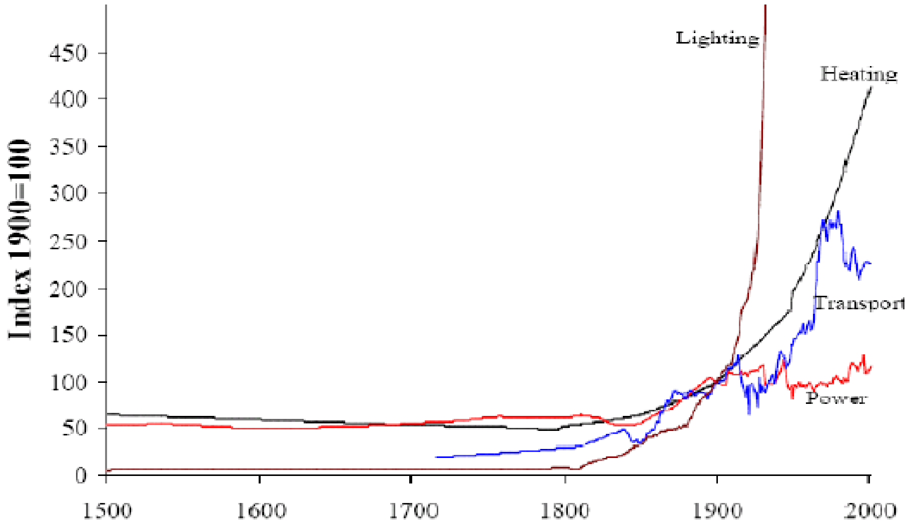

Figure 21: Efficiency of energy technologies, 1500-2000 (Source: Fouquet (2008), Heat, Power and Light, E. Elgar Publishing, UK)

- (2) Lowers costs of production and costs of delivery of the services (Figure 22) making the technology/product or service more affordable to more people which increases customer demand and enables markets to grow for these new innovations. Economies of scale and learning curves further reduce costs and increase demand (Figure 22)

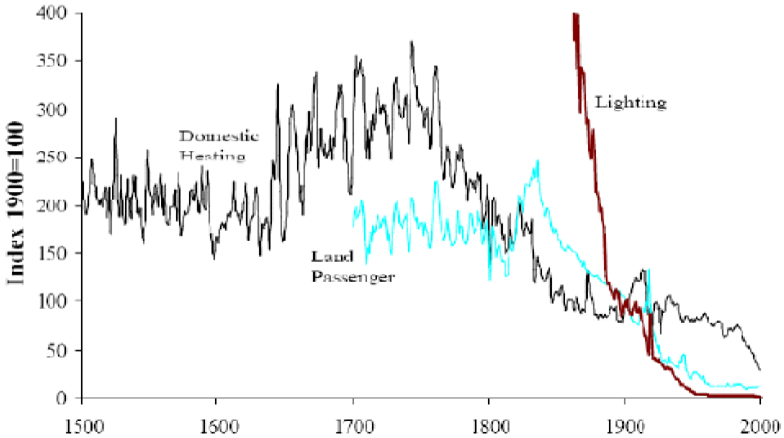

Figure 22: Cost of consumer energy services, 1500-2000. (Source: Fouquet (2008), Heat, Power and Light, E. Elgar)

- (3) A critical mass of technological innovation enables greater access to underground energy and material resources that further increases the availability of resources. Technological innovation also increases the efficiency with which resources for energy and materials can be extracted and processed. A greater array of raw resources and technical innovation enables a revolution in materials science that creates numerous substitutions for timber and steel.

- (4) The combination of lower energy and resource input prices and increased energy and resource efficiency of technologies, leads to reductions in the overall energy and resource costs of supplying all key services. This increases consumer demand for these goods and services. This virtuous cycle underpins and drivers overall productivity improvement and economic growth over the 200 years up to 2000. (Figure 23)

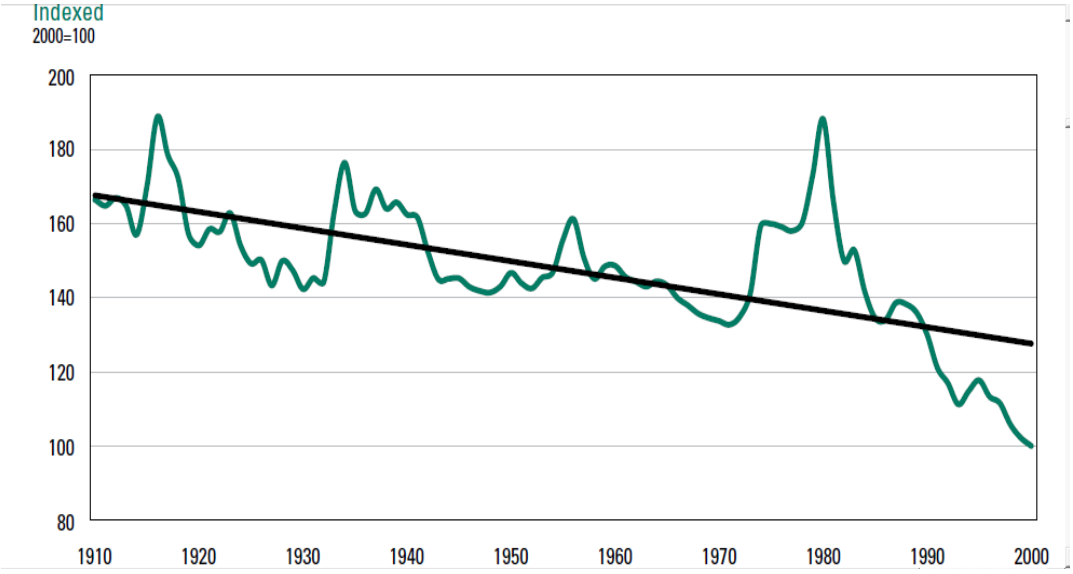

Figure 23: Technological advances in resource extraction and processing has contributed to falling resource and energy commodity prices for 200 years r

Aryes et al and Leitner's work suggests that the above process has been a driver of growth over the 19th and 20th centuries. The strong correlation between multi-factor productivity/exergetic efficiency and technical innovation can also be shown by the major waves of technical innovation historically. (See BOX 7 below)

2.4 The Economic Value of EP–Lessons from the First Industrial Revolution

BOX 7 Technical innovation to improve exergetic efficiency has driven economic growth since the start of the industrial revolution

Since the start of the industrial revolution, achieving advances in the energy efficiency and exergetic efficiency has been at the heart of technical innovation.

All the major industrial revolution technical innovations contributed to this virtuous cycle. For instance,

- Steam engine energy efficiency - James Watt's improvements on the design of the 1712 Newcomen steam engine, between 1763 to 1775, more than doubled the energy efficiency of steam engines at that time (Figure 24). In addition, the rotary motion of Watts's steam engine was better at converting steam into mechanical work than the oscillating beam of Newcomen's engine. Watt's engineering innovation increased the energy efficiency with which energy could be converted into useful mechanical work thus improving the exergetic efficiency of the system. The rotary motion gave the engine potential to do mechanical work which enabled labour productivity to be significantly improved as well.

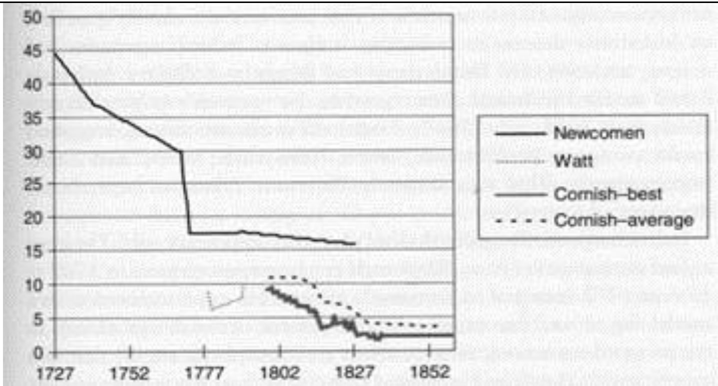

Figure 24: Coal Consumption in pumping engines: Pounds of Coal per horsepower-hour (Source: Watt, Scottish Engineering Hall of Fame Presentation[244])

- Thermodynamics invented to improve engine efficiency - The field of thermodynamics, the science of the 'flow' of heat, was developed in the 1800s, by engineers like Nicolas Léonard Sadi Carnot, out of the study of how to further improve the thermal energy efficiency of steam/heat engines and heat pumps. Carnot's 1824 monograph Reflections on the Motive Power of Fire, provided the first theory of the maximum efficiency of heat engines. This is an example of a learning effect, just as developments in mobile phone and IT drive rapid and large efficiency improvements and underpin further improvements into the future.

- Innovations in engines/power cycles - In the 19th century, the leading mechanical engineers of their generation were focused on inventing new engine cycles to improve their energy efficiency leading to the invention of new engines and power cycles. The "Otto", "Diesel[245]", "Brayton", "Rankine", and "electric" engine cycles were all attempts by leading engineers of the day to reduce inefficiencies in engines and better approximate the ideal level of Carnot cycle efficiency. These engines enabled rail transportation in the 19th century in the UK, which was the critical innovation for significantly bringing down the price of coal relative to timber long term. This significantly reduced the energy input costs for the UK economy, which further stimulated demand and economic growth.

- Innovations in the manufacture of chemicals and materials- Designing industrial chemical plants to be as energy efficient as possible was critical to enable many key 19th and 20th century technical innovations. For instance, chemical engineers invented the Haber-Bosch process which enabled a four-fold improvement in energy efficiency of ammonia production, a precursor to nitrogen fertilisers. Only through this energy efficiency improvement could artificial fertilisers be made in a cost competitive fashion. Through improving the exergetic efficiency of the system, artificial fertilisers became cost competitive and transformed 20th century food production, which enabled significant population growth which further contributed to increased national and global economic growth. (Figure 25)

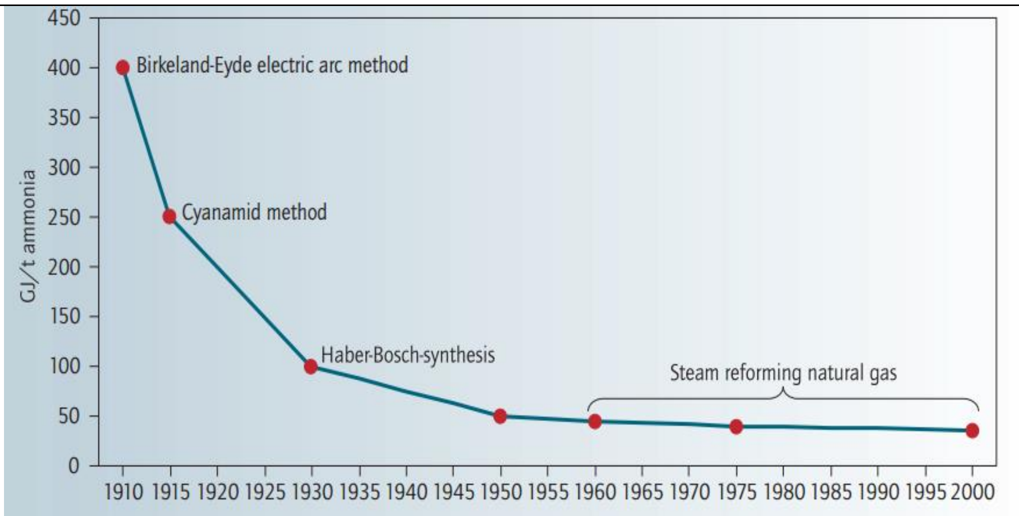

Figure 25: Energy intensity of ammonia production. (Source: IEA (2011[246]))

- Hydroelectric power with electricity enabled conversion energy efficiency to be improved from 20-30% from fossil fuel power stations to closer to 80%.
- The Alternating current revolution- In the early 20th century, the world chose alternating currents (AC) instead of direct currents (DC) because alternating currents were more energy efficient to transport over long distances.[247] Electrical engineers rapidly reduced transmission losses. These innovations enabled electric powered motor driven systems to replace steam engines in many cases to improve efficiency significantly in the 20th century.

For centuries, most economists and policy makers have focused on improving economic growth and productivity through a focus on improving labour, capital productivity and innovation, whilst ignoring the key role of energy and resource inputs, and the efficiency with which they are used, play in driving economic growth. The principal economic models still used to explain the growth process[248] do not include energy or resources as a factor of production. Yet as Dr David Stern[249] has pointed out there are now many energy and ecological economists, economic historians and geographers whose work shows that energy related innovations and the growth in the supply and quality of energy play a crucial role in economic growth. This recent literature suggests that energy productivity has been a key driver of economic growth through technical innovation which improves the exergetic efficiency with which energy and resources are used[250]. This literature provides insights into how improving energy productivity could assist nations in the 21st century to boost multi-factor productivity growth.

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