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Can we Finance the Energy Transition?*

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Abstract

The energy sector is pivotal to our aspirations for a sustainable planet and yet two major challenges face policymakers worldwide. The first is to decide what set of technical choices provide the best solution to meet social, economic and environmental agendas; and the second is to decide how these choices can be financed. The bulk of new energy demand will come from the emerging economies where energy demand is expected to increase by 40% over the coming three decades and to have doubled by the middle of the century. However for a number of reasons the investment needs of the energy sector are likely to rise even faster than overall energy demand. This is due to a number of factors over and above the increase in demand and described in the paper, including, inter alia, subsidized prices; the substitution of traditional energy for modern energy; the growth in peak demand in the electricity sector; the rising costs of securing primary energy resources; and the urgent need to replace vintage capital stock (including the decommissioning of nuclear power plants), especially in the developed countries. Clean energy investment will also incur high upfront investment costs in order to reduce long-term recurrent costs (fuel and maintenance). High priority must be given to energy demand management (both to reduce energy use and to reduce energy capital) and investment in upgrading of existing capital stock can provide strong and quick returns. However, the net result of the long-term demand on the energy sector is that investment needs will grow dramatically, from around US $1.6 trillion per annum to over US $2 trillion per annum. The financial challenge is considerable. A level playing field is required that encourages greater competition of technology choice on the basis of correct pricing signals. It will require changes in subsidy policies in order to release finance and to encourage efficient investment; adherence to least-cost planning and investment decisions; changes in decision-tools especially the use of high discount rates and inadequate accounting rules; a stable and appropriate price for carbon, the largest economic externality in the sector; and a major uplift in efforts to conserve both energy and capital. Innovative schemes between public and private finance should be deepened. Long term institutional capital (such as pension funds and sovereign wealth funds) are an important growth area for energy funding. "Green bonds" have shown promise and are growing fast. Public finance, bilateral and multi-lateral, must be increased to address the major public good issue of climate change. However, at heart, lies a financial sector not equipped to provide finance to the real economy and to the kind of investment streams outlined in this report: an overhaul

* This note was originally submitted to the Annual General Meeting of the Club of Rome in Mexico, October 2014 as a background note for the discussion session *"World Energy Outlook and Sustainability in the World and its prospects."*

of the global financial sector must underwrite any of the specific financing efforts proposed in this paper.

1. Background

1.1. The energy sector (together with its sister sector, food and agriculture) remains pivotal to the future sustainability of the planet. Energy is required for all walks of life in all countries and by all people. It is also central to concerns about local health and safety as well as environmental concerns, especially global climate change.

1.2. All governments have an expressed desire to provide their citizens with clean, affordable and modern sources of energy. In doing so there are two essential and interconnected challenges facing policymakers. The ***first*** is what technical choices make the most sense from a social, economic and ecological point of view. The ***second*** is how (and indeed whether) the choices made can be financed in a manner that is feasible and fiscally prudent.

1.3. This paper explores both challenges and, while recognizing that technical choice is also a function of cost, notes that the financing challenge may be significantly more challenging than many realize and that, as a result, sub-optimal technical solutions may well result. It suggests that a major effort is required over the coming two decades to create the fiscal space for a major boost to energy investment on the one hand but also to place energy demand management as a much higher priority activity than it currently receives.

1.4. This note pays special attention to the electricity sector as the sector likely to be most influential in driving energy policy; in curtailing demand; and as the sector that will require the bulk of capital investment over the coming decades.

2. Global Primary Energy Resource Demand

2.1. Estimates vary with regard to the growth in energy demand but plausible scenarios suggest that a continuation of energy demand is likely. The past three decades have witnessed a doubling of energy demand, roughly in line with GDP growth. The current energy balance of primary energy consumption is broadly as follows: 78% fossil fuels (with oil at 33%, 21% natural gas and 24% coal); 5 to 6% from nuclear fuels; 17% from hydro resources (and other renewable energy resources) and the remainder 11% from biomass.*

2.2. There is a broad consensus on the likely trajectory of energy demand over the coming three or so decades. Most analysts predict around a 1.6% per annum increase in primary energy through to 2030 (a 36% to 40% increase) and a somewhat slower rise thereafter. This, in turn, implies a doubling of primary energy demand by 2030 and a trebling of demand by the middle of the century.

2.3. The main drivers of energy demand are:

* There are many studies of current global energy consumption but most are within the ranges quoted in this note. See Gian Paolo Beretta "World Energy Consumption and Resources: an outlook for the rest of the century" Dipartiemento di Ingenehneria Meccanica, Universita di Brescia. Also International Energy Agency, "World Energy Outlook"; and IIASA: "Global Energy Assessment". All are broadly consistent and for purposes of this note broad orders of magnitude rather than precision are in order.

- Population and demographic shifts with some 1.5 billion or so added to the global population (mainly from non-OECD countries) by 2030 and a large scale migration to urban areas.
- Income growth and the distribution of income: GDP growth is anticipated to double through 2030 with a growing middle income class with increased energy needs. Structural changes within the global economy will also have an effect.

2.4. What is of vital importance is the fact that all projections note that almost all of the energy consumption growth in that period will be in non-OECD countries (between 90% and 95% by most estimates)[*]. Energy consumption in OECD countries is expected to grow but at a slower rate and, depending upon the nature of energy demand measures, could plateau or fall slightly. What is also of importance is that primary energy utilized to generate electricity is expected to grow at faster rates than energy overall. This, in part, reflects the need to provide those, currently underserved, with clean energy.

2.5. Such estimates provide a useful benchmark against which policies on energy demand management; on the energy transition from traditional to modern energy sources; and on investment strategies can be formulated. There is considerable uncertainty around growth projections and energy demand is highly sensitive to income.[†] On the other hand from a strategic and global viewpoint general directions and understanding of choices are as important as reaching out for precision. There is no doubt energy needs will grow and under almost all plausible scenarios complex choices await the analyst and decision-maker.

2.6. If uncertainty pervades our understanding of overall energy demand it is also reflected in policies towards technical choice and fuel use. The past one hundred and fifty years have witnessed major economic, social and technological progress on the basis of fossil fuel based energy followed some sixty years ago by the promise of low cost nuclear energy. The present period is one of important inflection with regard to energy choice. New factors relating to shifting paradigms on investment and recurrent costs; the rising costs of fossil fuels; and the imperative of dealing with local and global environmental impacts have reshaped the debate and, indeed, investment strategies.

3. Global Energy Investment

3.1. While there is a clear link between the overall demand for energy resources and the required investment resources they do not perfectly co-vary. The demand for investment needs in the energy sector will be driven by a number of factors:

i. Overall growth in energy demand;

ii. The fundamental role of energy pricing;

iii. The level and pace of substitution of traditional energy for modern clean energy;

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* In all scenarios the Asia and Pacific region dominates in terms of expected future energy consumption.

† An article in the *The Economist* magazine (September 2014) noted that economic growth in many rapidly emerging economies had stalled and may rise at lower rates than previously expected. For purposes of discussion, modest changes to growth rates do not alter the overall assessment of an increasing demand for clean and modern energy.

iv. The growth in peak demand relative to base demand in the electricity sector;

v. The overall change in relative costs of securing new energy (renewable energy, fossil fuels) including the extent of rising costs of exploration, development and delivery in the oil and gas sectors;*

vi. The pace at which vintage capital stock turnover requires new or life extension investment; and

vii. The potential "lock in" or "path dependency" trajectories of decisions taken over the next decade.

3.2. These issues are considered below in order to form a view on the likely demand for investment resources in the energy sector. The expectation is that demand for finance is likely to rise at a faster rate than the demand for energy due to a number of factors that are discussed in the sections below.

Energy Demand

3.3. As noted the base case scenarios are all consistent with a 40% increase in demand by 2030 and perhaps a doubling by 2050. Most scenarios already make assumptions about improving energy efficiency: a straight line extrapolation from today's consumption would broadly lead to a doubling of demand by 2030 and a quadrupling by 2050! Certainly this would carry a global public health warning as a scenario that most would conclude as the paradigm of un-sustainability.

3.4. The curtailment of energy demand represents a key pillar of analysis of future consumption patterns. Historically, the relationship between GDP growth and energy use has been stable, at an elasticity of around 1. Electricity demand has typically outpaced overall energy demand with a GDP elasticity closer to 1.2. There are good reasons to wish to change this relationship and it seems to be technically feasible to do so. A wealth of literature has been developed which indicates that technical options now exist to reduce overall energy consumption dramatically while still maintaining economic growth. Ernst von Weizsäcker *et al.*[1] have ably demonstrated that significant savings are potentially available that could reduce consumption in energy use by up to 80%.† Many of the options in this and other publications point to the large range of negative marginal cost actions that could be taken to reduce energy consumption. These "no regrets" investments with seemingly highly attractive Financial Rates of Return (FROR) that are technically and economically viable have not been universally taken up: most analysts still draw marginal cost curves that begin under the zero axis and remain there for quite some time. The question is why? What are the barriers to achieving, in the first round, these energy savings? The underpricing of energy is certainly one factor.

Energy Pricing Policies

3.5. While there are many non-price barriers to securing major energy savings (such as

* At a time when the long run marginal cost of securing supplies is rising and, with recent price declines, the short run financial revenues are declining.

† The majority of case work under Factor Five is in the rich world (with some examples drawn from China).

asymmetric information, human capacity, knowledge etc.), the main driver is pricing or perhaps better formulated as the underpricing of energy. This unfolds along two broad issues. The *first*, and often unstated, is that (certainly in emerging economies with high economic growth) achieving a positive FROR (above the discount rate) is a necessary but insufficient condition for investment. Higher rates of return can squeeze out seemingly positive investments in energy efficiency. The *second* is that the "cost of un-served energy" to the economy in emerging economies often provides[*] an impetus for inaction when it comes to investing in energy efficiency[†]. But perhaps the larger effect is simply the level of subsidy provided to the energy sector.

"A calculation by IEA suggested that in 2010 only 8% of the global fossil fuel subsidy was provided to the poorest 20% of the population."

3.6. Subsidies are essentially of two types*: financial* (the market cost to the producer and consumer) and *economic* (the cost to society or, in the case of global public effects, the planet). Subsidies exist on both energy (fossil fuels in particular) and on energy capital (mainly in the electric power sector).

3.7. *Liquid and Gaseous Fossil fuel subsidies* are pervasive and vary with the international price of fuels. In 2008 it is estimated that they (oil and gas) reached a level of around US $400 billion. The International Energy Agency (IEA) has estimated that in the absence of a dramatic pricing reform agenda such subsidies could reach around US $660 billion by 2020, equivalent to 0.7% of global GDP.[‡] The rationale for such subsidies, which are highly distorting, varies but most often quoted is to protect poor consumers.[§] IEA as well as other assessments[¶] all point to the inefficiencies and level of leakage in such policies. A calculation by IEA suggested that in 2010 only 8% of the global fossil fuel subsidy was provided to the poorest 20% of the population: a high cost and inefficient subsidy.[**] Even more telling is that IEA estimates that removal of subsidies could cut fossil fuel consumption by over 4% by 2020.[††]

* When I worked on the energy sector in a number of Asian and African countries, the cost of un-served energy (in the form of electricity) was often quoted at around US $1 per KWh. This was defined as the cost to GDP growth of a KWh not delivered: and was approximate. In countries which were severely power short (many emerging economies) the electricity dispatcher (not to mention the local politicians) was keen to operate inefficient power plants well beyond their capacity, with no let up for routine maintenance and upgrading. Perversely this had both an economic and a political rationale!

† A recent study by the World Bank and summarized in *The Economist* magazine (September 27 – October 3, 2014) notes that the cost of un-served energy in Africa is significant. It notes "the World Bank reckons that power shortages trim more than two percentage points from an annual growth rate in GDP on average in Africa: in Nigeria the loss has been almost four percentage points a year". This can have several effects including the operation of highly inefficient power plants and private investment in sometimes sub-optimal private power facilities. Equally it could have a positive and offsetting effect if private investment in clean energy occurs.

‡ See International Energy Agency (IEA): "World Energy Outlook" 2011 as well as various papers produced by IEA. According to the International Monetary Fund (IMF), the 0.7 GDP figure had already been reached by 2011. This represents around 2% of total government revenues: a not inconsequential amount.

§ A second rationale is to promote and protect industrial development: again with high leakage and inefficiency outcomes.

¶ The World Bank routinely reviews the distribution of energy and electricity subsidies and invariably concludes that the level of leakage to higher income groups means that it is an extremely inefficient means to target poor consumers. Subsidy policies of this kind require strong institutions to administer and monitor. In the rich world lifeline tariffs are routinely managed to target poor consumers. The tendency in many countries is to provide broad-based subsidy underwrites rather than selective and focused targeting.

** The fossil fuel subsidy is evenly distributed amongst fuels with kerosene (at around 15%), the largest, and suggests that the driver behind subsidy policies is poverty alleviation.

†† This would simultaneously cut growth in GHG emissions by around 1.7 Giga tonnes during the same period.

3.8. *Coal and coal derivative subsidies* are not as large as liquid fossil fuels but nevertheless are substantial.* OECD has estimated financial coal subsidies (in OECD countries only) at around US $12 billion annually. A more recent survey by the International Monetary Fund (IMF) indicates a much larger global figure of around US $539 billion annually but this includes imputed figures for global and local damage functions (the economic subsidy as defined later in this note).†

3.9. *Subsidies to the nuclear energy* industry are pervasive throughout the nuclear fuel, construction and deployment cycles. It is hard to know where to begin. The largest subsidy appears to be in facilitating the buy down of investment costs and, in the future, there will be a need to add to this the costs of decommissioning. These are dealt with later in this note. Legacy subsidies that now count as sunk cost are also of intrinsic interest and estimates as high as US $5.9 cents per Kwh have been assessed.[2] The extent to which R and D functions are a subsidy is also clouded with uncertainty.‡

3.10. Smaller and more recent but nevertheless increasingly important is *the subsidy to new and renewable energy sources.* The most common financial subsidy is through feed-in tariffs providing an incentive to invest in renewable energy. Estimates are in the order of US $88 billion (2011).§ Typically, subsidies are provided through feed-in tariffs which require consumers to purchase electricity generated by renewable energy.

3.11. *Electric Power Subsidies* are also important. Some of the overall subsidy comes from the subsidized fossil fuels, coal, nuclear and renewable energy (including hydro) used in power generation but this may be only the tip of the "subsidy iceberg". The electric power sector is the most capital intensive of energy sectors and requires capital investment in the region of US $800 billion to US $900 billion per annum over the next few decades.¶ Subsidies are provided through a variety of means and a number ways of calculating them have been identified in the literature.

3.12. A simple concept is to consider an electric utility that funds its current energy assets and future expansion program. The financial subsidy (or surplus) is total expenditures on the recurrent fuel and non-fuel cost of generation, transmission and distribution of energy plus the cost of operations and maintenance, plus the cost of debt servicing the current and planned investment expansion program *minus* the revenue or income from sales of electricity (tariffs). Financially few utilities in the emerging world cover these costs with perhaps

* There are a number of important definitional problems in calculating coal subsidies. In particular producer subsidies are especially difficult to measure.

† The IMF imputes figures for damage functions at both the local and the global level and adds these to the financial (or what the IMF terms pre-tax subsidy) to derive a post-tax (or economic) subsidy. The IMF used US $25 per ton for GHG emissions (global external effects) and US $65 a ton for local pollution damage. The figure for global damages seems quite low: other studies range from 40 to around US $125 per ton. The figure for local damage is derived from research in the USA.

‡ For example stranded asset charges as an example of uneconomic subsidies were calculated by the Union of Concerned Scientists to be around US $110 billion by 1997: few updated figures seem to be available.

§ "The International Energy Agency (IEA)" estimated that in 2011 subsidies to renewable energy were US $88 billion. These are still overall small relative to fossil fuel subsidies although a counter argument is often made that on a per energy unit basis fossil fuel subsidies are three times greater than those for fossil fuels.The renewable energy subsidy refers to both small scale renewable energy and commercial hydro-electric dams.

¶ IEA estimates. In the author's view these may be under-estimates and the final figure may be closer to US $1 trillion. It is not clear whether the full costs, for example, of nuclear power decommissioning are included. In addition, since much of the capacity is in emerging economies the potential for real cost escalation and financing interest during construction (IDC) can balloon costs even further.

a 25% to 30% internal cash generation ratio at best (and many a great deal lower). In other words, the financial subsidy is large and likely growing and the incidence is disproportionately shared by developing countries.

3.13. Yet if the financial subsidy is confusing and flows from a myriad of sources, the economic subsidy in the energy sector represents a journey that is closer to seeking the "Holy Grail". The economic subsidy includes the financial subsidy as well as the cost of all externalities in the process of energy production, transformation and delivery and, importantly, it includes the costs of deviating from least cost economic investment. It is larger than the financial subsidy and represents a major drain on society's resources. The main drivers of the economic subsidy are:

i. The extent to which investment plans and decisions deviate from the economic least-cost solution;*

ii. The value of environmental externalities at both the global and local levels and, increasingly, the value attributed to greenhouse gas emissions;

iii. The value of water utilized in the extraction and use of energy, especially in the new non-conventional energy sub-sectors;† and

iv. The need to take long-term investment decisions and, given the high indivisibilities in large investments, an understanding of the shape and direction of the long run marginal cost curve for energy sources.‡

3.14. While large uncertainties exist about the precise nature and scale of subsidies and while methodological differences and nuances abound, there is little controversy over the fact that energy subsidies are enormous and appear to be growing, whether calculated on financial or economic grounds.

3.15. Energy subsidies have a number of important perverse and negative effects:

i. They can have a chilling effect on potential investors through low profitability and therefore discourage private investment;

ii. They have an adverse effect on fiscal balances and public debt;

iii. They crowd out other subsidy programs that would have a higher social and economic return in sectors such as education or health;

iv. They distort public and private investment decisions by sending market signals that do not reflect economic priorities; and

v. They induce excess consumption with low incremental social returns and negative environmental consequences as well as increase leakage and sub-optimal consumption.

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* This is often the reason given for high subsidies in Africa for example. See IMF op. cit. and World Bank studies.

† A recent report by the World Resources Institute (WRI) has evaluated the impact of water use in hydraulic fracturing ("fracking"). Almost 40% of shale resources are in arid and semi-arid areas where water costs are high (and rising) and downstream water pollution represents a high economic diseconomy.

‡ Several studies on energy subsidies have made the point that a major part of the subsidy is taken up by the mere fact that decisions in the sector produce sub-optimal economic investment. The economic subsidy could be reduced considerably by better planning.

3.16. In sum, any attempt at re-shaping our global energy systems and seeking the finance to do so must start with a critical look at subsidies, their rationale, and their eventual elimination other than for highly targeted social objectives. Phasing out of both financial and economic subsidies over a clearly defined period while adjusting relative energy prices can be achieved. Linking such decisions with technical investment in energy demand management and in forward planning least-cost investments could make a major difference to overall costs and financing needs.

The Substitution of Traditional Energy for Modern Energy

3.17. The desire to provide clean modern and accessible energy to citizens is almost a universal aspiration. It changes energy demand only marginally but can have a profound impact on investment needs and explains why electricity demand is often greater than overall energy demand.

3.18. In many countries of the world citizens consume too little and not too much energy. They do so through the drudgery of seeking traditional and often inefficient fuels and they often place access to clean energy as high a priority as access to clean water and food. The numbers remain staggering with an estimated 1.3 billion people (18% of total population) without access to electricity and 2.6 billion (38% of total population) without access to clean cooking facilities. More than 95% live in Sub-Saharan Africa. An OECD/IEA report has estimated that a cumulative investment of around US $1 trillion will be needed through 2030 to meet the United Nations' aspiration of energy for all. This represents around US $50 billion a year, almost a fivefold increase in current investment levels.*

3.19. Not only has the demand in emerging economies for modern energy accelerated but demographic factors have also played an important part in driving investment. In particular, the growth in urban areas and the continued migration out of rural areas has increased demand for urban electricity distribution. Many developing countries have found it impossible to keep up with the demand and this has resulted in sub-optimal investment strategies and weak management arrangements. As a result, losses in the transmission and distribution (T&D) systems of many countries have increased. In the rich world losses average 8% but in developing countries the average is around 15%, with some low income countries experiencing losses of over 50%.† This places a major strain on the financing of distribution, especially given the rapid rise in urbanization and urban energy demand.

The Growth in Peak Demand

3.20. As noted, the energy sector is both energy and capital intensive. Electricity systems must meet energy (KWh) needs but they must also have sufficient physical capacity to meet capacity demand (KW) when it is at its highest. Much attention, more recently, has focused on the need to reduce energy use on both efficiency and environmental grounds. However, if

* There are many studies that have reviewed the energy poverty nexus. See for example: Shonali Pachauri and Daniel Spreng "Energy use and energy access in relation to poverty", Centre for Energy Policy and Economics, Swiss Federal Institute of Technology. Also see OECD/IEA website on "Modern Energy for All" and various World Bank and United Nations publications. All recognize the importance of universally providing modern and clean energy both as a cost factor but also in terms of environmental (climate change and forest loss) and social impacts (reducing drudgery especially amongst women).

† For example: Botswana (58%), Haiti (55%) and Republic of Congo (46%). These losses are both financial and economic as they include technical losses and non-technical (mainly illegal connections in slum areas). This is an unusual case where economic losses are smaller than financial losses as illegal connections provide no financial revenue but energy is still provided.

attention is not simultaneously paid to both aspects it can lead to financial problems for the sector. If peak demand is not reduced then reducing energy use simply reduces revenue but not capital investment requirements. Energy demand and capital use must go hand in hand: peak shaving is as important as reduced energy.

3.21. Peak demand is driven by many factors: temporary movements of population in times of tourist seasons; extremes of temperatures and the demand for air conditioning or heating; and unforeseen events. It is plausible that demand is becoming "more peaky" as incomes rise and middle income requirements for air-conditioning must be met. In a similar vein, setting a "reserve margin", especially where intermittent energy sources are an integral part of the system can also lead to spiraling additional capital costs. Setting appropriate reliability standards and carefully managing capacity reserve margins will become a key issue for energy investors.* Nevertheless, there is a plausible argument to suggest that the drive to reduce energy use in the absence of capacity use will affect levels of investment and potential financial viability. It is an area at least to factor in to the investment equation globally.

The Changing Costs of Securing Primary Energy Resources

3.22. There is a growing body of literature about peak oil and its potential implications. This note does not concern itself directly with that issue but rather postulates that irrespective of when peak conditions may be met, almost all forms of primary energy supply are facing a steep and, in some cases, a discontinuous marginal cost curve and as the search for ever more expensive resources accelerates it drags with it significant investment resources. As prices have risen, especially in the fossil fuels sector, the expected fuel switching to alternatives has been obfuscated by a tendency to move up the marginal cost curve to ever more costly alternatives. A prominent oil company has noted: "High prices and technological innovation have unlocked vast unconventional resources in the US, reversing the trend of falling output and altering global energy balances." It further notes, "Globally there are an estimated technically recoverable resources of 240 billion barrels (Bbls) for tight oil and 200 trillion cubic meters (Tcm) for shale gas".[3] It is estimated that Asia has about 57 Tcm of shale gas and 50 Bbls of tight oil. Whether the non-conventional boom is a temporary bubble remains to be seen but it is dragging new investment funds into the sector and potentially away from less polluting sources. The economic costs of exploration, recovery, and transportation are somewhat unknown. The costs of energy required, extensive water use, potential land disturbance, and chemical usage are also contentious. Technologies for the recovery of shale gas hold other uncertainties related to the potential for fugitive methane emissions. New risks, higher costs and potentially important environmental consequences are as unconventional as the technologies themselves. The extent to which investment in shale and other non-conventional oil and gas sources (such as tar sands) will rise depends on many factors. Nevertheless, major oil and gas corporations appear to have forgotten earlier promises to move beyond petroleum and towards a new generation of low polluting fuel sources. Most oil companies have returned to their roots and are willing to invest in higher exploration and production costs for fossil fuels.

* There are many ways in which levels of reliability (called "loss of load probability") can be measured and factored into investment decisions on electricity systems. As will be noted later in this note, managing energy and electricity as a system can provide the basis for significant savings.

3.23. Investment costs in hydro-electric facilities are also facing an upwards cost curve. The "low hanging fruit" hydro projects were exploited over the past hundred years* and while considerable potential remains unexploited (estimated at some 4.8 times greater than today's hydro electricity generation) it is almost certainly likely to require a major uplifting in capital costs. For many years a useful rule of thumb was around $1,000 per KW installed. This is now at the lowest end of the cost spectrum with costs rising as high as $7,650 per KW (for large hydro) and over $8,000 per KW for small hydro plants.[4] Environmental and social factors have also become a major additional cost and political issue for hydro development including resettlement costs (including those affecting traditional and indigenous peoples), loss of biodiversity, downstream effects and concerns over reservoir management (e.g. methane emissions). These costs, largely social and economic, are rarely factored into the financial cost base. Two other "hidden" costs are likely to drive up overall cost estimates also. The *first* is that, especially in the case of large and complex hydro sites, delays (often measured in years and months) can increase interest during construction (IDC).† The *second* is that climate driven variability may induce greater operational uncertainty and potentially lower levels of electricity generation than originally planned.‡

3.24. Natural gas has played a central role in the transformation of the energy sector and recent estimates[5] suggest that there are at least a further 250 years' worth§ of natural gas globally to be exploited, in large measure due to the new techniques of extraction from "non-conventional" sources and by new techniques (such as hydraulic fracturing).¶ Natural gas has been heralded as clean, low cost and of flexible supply.** However, natural gas also faces the uphill journey on the cost curves as next generation gas is either far from demand centers or, as noted, must come from high cost new generation techniques. From a global viewpoint, natural gas leakages are important as their global warming potential is significantly above that of carbon dioxide.†† In addition, some countries have concerns over the security of piped supply:‡‡ for example, recent concerns expressed in Europe over dependency on natural gas from Russia or issues that have arisen between Chile and Argentina. Placing a price premium on security of supply would provide an incentive for localized production, especially of renewable energy.

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* Worldwide there is about 1,000 GW of installed hydro capacity with ten countries accounting for two thirds of installed capacity. Worldwide hydro accounts from about 16% of total electricity generation with a wide range including Norway, Brazil and Venezuela where it represents more than 70% of generation.

† These are costs incurred by the developer and project owner when interest is due on debt but the asset is not producing revenue. Delays in construction can often balloon the overall cost of the project.

‡ The author already has witnessed this effect in Chile in the early part of this decade. As a result of fluctuating and unexpected hydro conditions electricity generation from Chile's hydro system was reduced considerably with a high economic cost to the economy.

§ Estimated in 2013 at 6,846 trillion cubic feet of dry natural gas (IEA).

¶ As an example of the growth in such sources of natural gas, the USA in 2009 was a net gas importer. By 2014 it was the largest producer of natural gas in the world.

** This adds to its attractiveness in a system with high intermittent energy sources such as wind or solar energy.

†† Estimates vary but some estimates place the global warming potential between 86 and 105 times as powerful as carbon dioxide at disrupting climate change, over a twenty year period. Others estimate the effect close to 25 times. Whatever factors are used, leaked raw natural gas (methane) is a powerful greenhouse gas.

‡‡ Other forms of gas such as Liquefied Natural Gas (LNG), Compressed Natural Gas (CNG) or "town gas" (coal gasification) are also important and offer somewhat less concerns over security of supply as they can be sourced from multiple sources. It is interesting to note that of the 17.25 million CNG fuelled vehicles worldwide some 13.3 million are located in developing countries.

3.25. The hope that renewable energy (solar, wind, biomass, small hydro, wave etc.) will lead the energy transition remains high. Indeed, over the past twenty years the world has witnessed a revolution in the growth of renewable energy. Investment in renewable energy in 2012 was estimated at US $244 billion,* a reduction of 12% compared with 2011 which witnessed the highest level of investment to date (US $279 billion),[6] and equivalent to 6.5% of total electricity produced globally. Investment is now larger in developing countries than in developed: a shift that started in 2010. It is noteworthy that investment in developed countries dropped by 29% in 2012, in part due to increased instability in regulatory and policy frameworks that began to grip the rich world.† However, a countervailing impact was that unit costs continued their downward trend: investors continue to get more energy per dollar invested than at any time over the past decade. Large scale PV system costs fell by around 40% and, although investment in solar declined by 11% globally, installed capacity increased by 6%. A similar story occurred in wind power. Renewable energy can be highly competitive in many applications, especially in distributive systems. However, in the developed world, it has relied on supportive pricing policies, largely through feed-in tariffs and in developing countries it has often relied on low interest funding. Press reports‡ suggest a growing apprehension amongst some consumers that electricity prices are rising and may even affect competitiveness. The problem (along with nuclear and large scale hydro) is that these technologies are higher capital cost than alternatives even where their recurrent cost (fuel) is very low: our economic and financial systems with high discount rates tilt the balance of costs unfortunately as does the absence of a reasonable and plausible price for carbon avoided. An additional cost implication with many renewable energy sources is that their intermittent nature requires significant back up or standing reserve capacity. Bio-fuels and other forms of biomass are important in specific *in situ* locations but are unlikely to make a major dent in global energy supply. Bio-fuels have become controversial, in part because of large subsidies and in part because they are seen to crowd out valuable land that could be utilized for alternative crops (food). The truth is that bio-fuels are only likely to be economic (or close to economic) in very few locations globally.

Vintage Capital Stock Turnover

3.26. Energy investments are typically made for the long term. In the electricity sector hydro-electric facilities are built for many decades; thermal and nuclear power plants have life expectancy of thirty to forty years and other plants such as gas turbines perhaps twenty five years. There is, in fact, a rather large stock of invested capital in the energy sector that has dutifully fulfilled its operational expectations: it needs rehabilitating, replacing or decommissioning. Investment costs vary but they have important consequences as there are incremental costs associated with closure and for new replacement plants. While some costs can be offset by important energy efficiency gains overall the replacement of vintage capital stock represents an important financial drain on the energy sector.

* By comparison the investment levels in coal, oil and gas was estimated at US $262 billion, higher than the total for renewable energy.

† This was not, however, universal: Japan witnessed an investment surge in solar energy. While countries in Europe witnessed a decline (including Germany where investment dropped by 35%. China now leads the world in investment in renewable energy).

‡ *The Economist* for example carried articles on Germany and the UK.

3.27. Nuclear energy, in particular, is in focus in this regard. There are around 435 nuclear reactors in the world today (with a combined capacity of 370 billion watts (GWe). Of these 138 are more than thirty years old and some 24 or so are over forty years old. While life extension is, of course, possible well beyond 40 years the pressure to upgrade or close and then decommission nuclear power plants is an important option in many countries.

3.28. While many nuclear plants have closed, the full costs of decommissioning are still rather vague. Estimates seem to vary between US $500 million and US $1 billion per plant reflecting the nature of the plants and the means by which decommissioning is planned.[*] In some cases where re-processing plants are also decommissioned with the power plants costs can be extremely high.[†] One consistent characteristic is that costs continue to spiral and are typically several fold greater than original estimates.

3.29. Investment funds will be needed at a very large scale over the next two decades as more and more nuclear plants move into their mature phase and require substantial life expectancy investment or closure and ultimately decommissioning. Few countries or utilities appear to have provisioned adequately for such costs and it is likely that some form of public budget support will be required.[‡] It is not clear to what scale or extent of impact such funding will have on other energy sectors but the funding needs will clearly not be trivial.

3.30. The aging stock of hydro-electric facilities, more often than not performing below nominal rating, represents a major opportunity to increase energy production at relatively low-cost. Estimates for refurbishment, life extension and upgrading are significantly lower than new investment. This can help reduce operational costs and, in some cases, provide additional generation but requires new investment and capital expenditures. Nevertheless, adding capacity at existing hydropower schemes can cost as little as US $500 per KW installed, a fraction of new plants.

3.31. Coal fired plants[§] also offer large opportunities for upgrading, especially in dramatically improving their thermal efficiency and output. Many coal fired plants are coming to the end of their life. Driven by concerns over local pollution, rising costs of fuel and, in some countries, a commitment to reducing GHG emissions, many coal fired plants will be phased out over the next twenty years. These will need to be replaced by new generation, an additional investment cost to meet the same demand for energy. New technologies are under review to decrease emissions from existing plants. These include integrated gasification combined cycle (with the potential for 50% thermal efficiency), and conventional improvements using super critical boilers etc. It has been estimated that a 1% improvement to a conventional pulverized coal fired plant results in a 2% to 3% improvement in GHG emissions.[¶] Despite the clear scope for rehabilitation and upgrading a sobering assessment by the IEA

* There are basically three approaches to decommissioning: (i) *Immediate dismantling* of all radioactive equipment; (ii) *safe enclosure* which requires the removal of spent fuel rods; and (iii) *entombment* of all spent fuels and then placed in safe concrete or glass vessels and stored in geologically safe spaces.

† For example, in Sellafield in the UK it has been estimated that the total cost of decommissioning will be over £70 billion. This includes not only decommissioning of the power plants but also costs associated with reprocessing of nuclear waste (including from sites in the UK other than Sellafield).

‡ It is understood that Sweden, for example, has a decommissioning tax on its electric tariffs (TBC)

§ There are over 2,300 coal fired stations globally (620 in China) producing around 40% of total electricity.

¶ World Coal Association estimates.

Clean Coal Centre* suggests that it will be still necessary to invest in Carbon Capture and Storage (CCS) if the current globally agreed emissions reduction is to be met and if, as seem likely, coal fired electricity generation will continue. Adding CCS to existing plants appears to be an expensive and, as yet, not totally proven technology. Either way it suggests new and additional capital investment will be needed.†

3.32. Transmission and distribution systems are also in need of major overhaul and upgrading, especially in emerging economies. As noted, reducing losses is of primary importance as is meeting existing demands through new investment. In some cases, especially long distance transmission, it may be economical to invest in high voltage DC lines. Such investments are high cost relative to more conventional AC lines but offer major energy savings. Financing distribution is likely to be an important challenge.

The Potential Importance of Path Dependency

3.33. Our energy systems and our energy utilization have been driven very largely by technological "lock in" or path dependency. For example, transportation systems may have locked us into fossil fuels with the potential to move to new low carbon pathways stymied by high cost.‡ The great danger in developing high cost non-conventional fossil fuels is that pathways may be perpetuated for many decades. Given the importance and urgency of moving to a low to no carbon world,§ the issue of carbon "lock in" is a major concern and could result in either uneconomic investment or a significant problem of stranded assets.

3.34. Another, somewhat obscure form of "lock in", relates to the planned increase in nuclear power investment. In the past, as developed countries embarked upon a nuclear power expansion program they also opened up the possibility of below market non-fungible finance for other countries. Many nuclear power facilities in emerging economies have been funded, in part, through accession to export credit and other forms of subsidized credit.¶

The Impact on Investment Needs

3.35. A perfect financial storm is approaching the global energy sector. It is driven by the factors noted above: the need to meet the rising demand for clean energy, the rising costs of securing conventional energy, the need to replace and upgrade vintage stock and the potential repercussions of unintended path dependency concerns.

3.36. While a great deal of investment throughout the world is likely to be required to

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* John Topper, Managing Director, IEA Clean Coal Centre.

† This is added to the problem that worldwide we are adding coal fired generation at a rate faster than we are mothballing existing vintage plants. Between 2010 and 2012 some 89 GW of new coal capacity was added. See technical paper prepared by Steven J. Davis and Robert H. Socolow, University of California, Irvine, 2014

‡ The two are, of course, synergistic, initially cheap fossil fuels locked in transportation systems. Today, it may be that long term investment in transportation systems (especially roads) will lock in future fossil fuel requirements and continue the drive up the long run marginal cost ladder.

§ A political consensus (although by no means a scientific consensus) seems to have emerged that stabilizing eventual temperature change (relative to pre-industrial levels) at 2°C is required to avoid major social and economic disruption. This, in turn, requires a stabilization goal of around 450 ppm of CO_2e. An ambitious target when we are currently at about 400 ppm and the evidence of investment lock in the coal sector for example would suggest that the 450 ppm is, at best, overly ambitious.

¶ The author is reminded of a personal conversation with a colleague from the French nuclear energy industry who claimed that for France to maintain its nuclear energy infrastructure it is required to build a plant every five years. As domestic demand slowed the main alternative was to provide non-fungible finance to other countries to adopt French know-how and technology.

upgrade existing capital stock, the new investment required to meet growing demands will almost all come from the developing world, regions where financial constraints are greater and access to long term financial capital is least favorable.

"Financing the energy transition while meeting the aspirations of those currently underserved with clean energy is a major challenge."

3.37. Least-cost analysis would suggest that investment and technology choice be dictated by the combined discounted economic cost stream of capital and fuel costs. We are entering a period when the more promising low carbon technologies − renewable energy, hydro-electric power and nuclear − are capital intensive but rely on low cost (or no cost in the case of solar and wind) recurrent costs. While this is often perceived as an advantage it does require a front loading of finance for future energy systems. It also requires deeper consideration of both economic analysis (including externalities such as climate change) and of discount rates used in project evaluation.*

3.38. One important potential advantage however is that for some no and low carbon technologies (especially new and renewable energy investment) economies of scale are of significantly less importance. Decentralized systems are beginning to compete with larger systems in terms of unit costs. This may be an advantage in terms of how finance can be sought at local levels and by communities and even individual households. In particular, this could be an offsetting cost to the high cost integrated electricity networks at the distribution level.

3.39. Yet the bottom line remains: Financing the energy transition while meeting the aspirations of those currently underserved with clean energy is a major challenge. Few integrated estimates exist of the total financing challenges but perhaps the most comprehensive is that of the International Energy Agency (IEA) which has compiled data and estimates through to 2035.[7] The IEA estimates that through the period 2035 some US $48 trillion will be required in investment. It notes that the current investment levels of around US $1.6 trillion will need to rise to over US $2 trillion per annum.† In particular, according to IEA, investment in energy efficiency will need to rise from US $130 billion per annum to more than US $550 billion by 2035 (2012 prices). It notes that the majority of investment today is in fossil fuels and anticipates a major rebalancing with other sources of fuel increasing. Nevertheless, of the US $48 trillion around US $40 trillion is for increased supply and the balance for energy efficiency. In regard to the estimated investment in energy supply a staggering US $23 trillion is in fossil fuel extraction, refining and transportation and US $10 trillion in electric power generation including renewable energy (US $6 trillion) and nuclear energy (US $1 trillion).

3.40. By its own admission the IEA's analysis is what can be expected given current trends and shifting paradigms of energy investment. However the expected investment pattern

* An example illustrates this amply. The "levelized" costs of say a hydropower plant costing US $3,000 per KW over a lifetime of 80 years are US cents per KWh cents 4.4 (at a discount rate of 3%): Kwh 7.3 cents (at a discount rate of 7%) and KWh 9.5 cents (at a discount rate of 10%).

† In the author's view this is likely to be a very conservative estimate for capital investment in the energy sector. The reasons for assuming a higher figure are laid out in this note and include primarily the additional costs for securing a global GHG emissions target and the need to replace at high cost vintage stock.

reported by IEA falls well short of reaching agreed climate stabilization goals. Neither market signals nor government resolve currently appears strong enough to suggest a more dramatic strategy. Delays in reaching such an agreement simply increase the costs that will eventually have to be incurred. Furthermore, the costs of nuclear decommissioning may be understated, as reported costs are often well below actual costs. The likelihood is that to meet the goal of modern clean energy available to all and simultaneously meet the climate stabilization goal will require an even larger investment strategy. Even the doubling of energy investment in no carbon and high efficiency may be insufficient. Quite what the correct overall number should be is perhaps impossible to say as feedback loops on GDP growth, changing costs in technology, and uncertain policy environments must be taken into account. What we do know is that financing the growth and transition of the global energy sector represents a major challenge: it is a very big deal.

"What is clear is that any attempt to transform the energy sector into a sector charged with delivering energy efficiently in a manner that ensures it is, in turn, consumed efficiently must start with a re-calibration of pricing policy problem."

4. The Financing of the Energy Transition

4.1. There are many challenges to financing the energy transition and meeting future demand. For cash-strapped developing countries the search for long term capital at the scale required is particularly onerous. Many developing countries also find it a challenge to mobilize domestic (local) funds to meet local costs, especially in the distribution of electricity.

4.2. During the 1990s the wave of free market euphoria failed to bypass the energy and electricity sector. Markets, free and under-regulated, were expected to drive private investment into the energy sector both at an unprecedented scale and with optimal results. Nothing could be further from the truth. Electric utilities* were expected to practice full cost recovery in order to reduce external subsidies and to ensure full and healthy financial viability. This proved, in almost all countries, to be elusive. Despite the adherence to a free market philosophy that should have abhorred subsidies, they grew, sometimes at alarming rates. In many emerging countries it was estimated that electricity tariffs would need to rise by between twofold and tenfold[8] in order that consumers would pay close to the full costs of supply: a political impossibility. However, developing countries were not alone in suffering from distorted pricing and subsidy policies: subsidies to the nuclear industry and for renewable energy were also prevalent.

4.3. What is clear is that any attempt to transform the energy sector into a sector charged with delivering energy efficiently in a manner that ensures it is, in turn, consumed efficiently must start with a re-calibration of pricing policy. Broad-based subsidies are rarely the best

* A similar hope was that water utilities would follow a similar path. Water subsidies may be as large as energy subsidies and sub-optimal investment and operating practices remain widespread in the water sector.

way of achieving selective goals (poverty reduction, technology stimulation etc.). However, it is equally clear that the immediate dismantling of energy subsidies has little chance of winning favor in political circles. What is needed is a smart "energy" pricing policy that is comprehensive, reduces major distortions and negative impacts, and is introduced in a sequential, prudent manner to allow political acceptance and time for adjustment. The design of such policies is beyond the scope of this note but it is clear that a goal of reaching *first,* the elimination of the financial subsidy followed *secondly,* by the elimination of the economic subsidy (especially through the inclusion of a price for carbon), should be a matter of priority for all countries: ideally a global debate and acceptance of such measures would also reduce the highly sensitive issue of competitiveness: an emerging sore point in the renewable energy debate.* Full economic pricing would have the triple advantages of reducing overall energy demand and energy capital demand; encouraging economic fuel switching; and providing significant domestic finance to cover costs and contribute to expansion programs.

> *"It is clear that we have a financial sector out of control, divorced from the real economy and incapable of providing the liquidity at the scale needed to address key sectors of the real economy."*

4.4. Improved pricing regimes could also pave the way for promoting another key element in financing the energy transition: the need to ensure that investment plans are based on least economic cost. As noted earlier, a major element of the economic subsidy is that poor investment choice and sub-optimal decision making on technology choice increases costs. The corollary of the free market spirit of the 1990s was that careful energy system planning was thrown out of the window and in came project by project analysis, simplistic independent cost curves (with no added systems costs for reserve margins), and poor technical options. In the electric power sector there is likely little doubt that sub-optimal investment strategies were implemented in many countries of the world. A return to system planning, especially in the electric power sector should be encouraged: it could lower reserve margins, encourage synergy between technologies and reduce capacity costs for meeting peak demand.† A new development in advocating for a clear carbon price is gathering support. Led by the World Bank it now has a number of countries supporting a price for carbon to be used in investment and policy decisions. A global carbon tax would not only facilitate revenue but would also shift investment behavior and appetite towards no carbon technologies: it would help level the pricing playing field. Furthermore it would facilitate the promotion of a new generation of carbon markets, of which the majority of finance would be for the energy sector. Just how high such a tax should be is a matter for debate: views on the range are considerable.

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* *The Economist* magazine recently reported on the concerns of German consumers and German industry where the claim is that feed in tariffs and renewable energy targets have made German electricity an issue of global competitiveness. The claim is that German electricity prices are now double those of the USA.

† For example, system reserve margins (for planned and unplanned outages) can be lowered for the total system. Optimizing the mix of technologies and fuel use can result in considerable recurrent cost savings.

4.5. But even if full economic pricing could be realized and even if improved system planning reduced the overall demand for local and foreign funds, new finance will be required. Better pricing and investment decisions would likely shave off several percentage points of investment requirement but the balance finance is still large and looming. The pious hope that markets and private capital would do it all now needs to be replaced by a healthy sense of pragmatism. Moving the world towards an efficient and effective global energy sector will result in both private and public gains: Energy is both a private good and a public good. As climate change concerns escalate, the energy sector has emerged as the primary carrier of the most important global public good of our era, climate change.

4.6. A new wave of financial innovation is required, especially in the mobilization of private capital. But a start must be made in reforming the financial sector from where such resources must be drawn. A discussion on the current financial sector is beyond the scope of this note* yet it is clear that we have a financial sector out of control, divorced from the real economy and incapable of providing the liquidity at the scale needed to address key sectors of the real economy. Furthermore, as some of the investments required produce only public good benefits (e.g. nuclear decommissioning, R and D in renewable energy) and as the bulk of new investment is in low income (and perceived riskier countries) the ability of turning financial markets to address the scale of the investment will require enlightened public policy and potentially new partnership arrangements.

4.7. While equity will play a role, especially in smaller scale energy markets and technologies the bulk of new funding for large scale investments will need to be provided through long term debt instruments.† Raising funds through debt markets requires either direct lending through a variety of sources or creating long-term debt through the bond market. For many developing countries Foreign Direct Investment (FDI) has dried up and international finance institutions' funding remains a relatively small source of total finance.

4.8. Dedicated climate finance has also facilitated investment especially in the small scale renewable energy sub-sectors. The Kyoto Protocol's Clean Development Mechanism (CDM); the Global Environment Facility (GEF); and dedicated bilateral climate funds have played an important role in renewable energy development and in pioneering new no carbon energy technologies (such as methane capture, biomass etc.) and building knowledge in developing countries. The newly created Green Fund will also play a role in the future, although it has yet to disburse substantial funds.‡

* However see article, Crises and Opportunities: A Manifesto for Change by Ian Johnson and Garry Jacobs in *Cadmus* (the journal of the World Academy of Art and Science (WAAS)) which outlines some of the main challenges facing the financial sector. http://cadmusjournal.org/article/issue-5/crises-and-opportunities-manifesto-change

† Bloomberg notes that both solar and wind were the main recipients of equity capital, although even in these two subsectors 2012 witnessed a modest decline. Equity interest in bio-fuels and biomass witnessed a major reduction, by 63% and 33% respectively, suggesting that investor appetite in these two sub-sectors may be waning.

‡ There are a myriad of specialized climate funds dedicated to both mitigation and adaptation. Despite their rapid growth they remain relatively modest. The World Bank's carbon funds have been in existence for about a decade and have provided funding of around US $4 billion. In 2010, Governments made a pledge to provide by 2020 US $100 billion per annum (drawn from public and private sources) and to put in place a "fast track" funding of US $30 billion. These funds are not dedicated solely for the energy sector but some part will likely be used to fund energy efficiency schemes, renewable energy and hydro-electric projects.

4.9. Long term institutional investors such as pension funds are a potential major financier.* However, given that the bulk of investment needs is in emerging economies, with higher than average perceived risk, the potential for scaling up these funding sources has yet to be realized.

"Clean energy is not just about turning on a light switch; it is an integral element of a changed lifestyle and a changed ethos."

4.10. In a similar vein, the newly emerged sovereign wealth funds offer enormous potential also. Sovereign wealth funds have grown appreciably over the last two decades. Many come from the exploitation of natural resources (mainly from oil revenues) and are under the guardianship of governments. In many respects these should be ideally positioned to finance a major expansion of the energy transition. In total some US $20 trillion of funds were under sovereign wealth management.†

4.11. Unlocking institutional and sovereign wealth funds for the energy transition and at a commensurate scale represents a major challenge. The fact that these funds are under public management may make them more amenable to taking a longer term view of investment and to incorporating new public good standards related to climate change. In time, institutional capital could be motivated to become a major financier of the energy transition.

4.12. The fixed income bond market is currently estimated to have assets of around US $80 trillion. Over the past few years an attempt has been made to earmark some of these bonds to focus on climate change and other environmental investments. The rise in "Green Bonds" over the past five years has been remarkable. This year has been a record year for the issuance of green bonds: a record US $16.6 billion has been issued with the expectation that by the year's end some US $40 billion will have been issued, triple that of 2013.[9] Of course this is a small fraction (less than 1%) of the total global bond market but it nevertheless represents an important funding source. Many for these bonds focus on clean energy or on specific sub-sectors such as wind, solar etc. Green bonds are provided from private capital,‡ government backed bonds, and multilateral banks.§ A forward looking carbon price together with clear rules and accountabilities related to use of funds could encourage new entrants into the green bond market. Given the public good nature of climate change some public private partnership finance could also be warranted.

5. Conclusion

5.1. The urgent challenge of accelerating a major global energy transition is daunting.

* For example the USA and Canadian pension funds have been active financiers of long-term investment in natural gas and natural gas infrastructure. See also report by the World Pensions Council (WPC).

† This included US $5.78 trillion (directly in sovereign wealth funds); US $7.20 trillion (in pension reserve funds); and US $8.1 trillion (in foreign exchange reserve funds).

‡ Bloomberg notes that while "bonds issued by corporations with proceeds ring fenced to green investments their repayments are from general corporate funds. Issuers have not been able to realise pricing advantages through green labelling as investors are unwilling to take lower than expected coupons simply for the ability to "go green". This is an important finding as it places pressure on project developers to deliver quality investments.

§ The World Bank Group and IFC have, since 2008, issued bonds valued at US $10 billion.

Providing clean and modern energy to all requires complex policy choices and difficult financing decisions. The energy sector is perhaps the most pivotal in the fight against climate change. Clean energy is not just about turning on a light switch; it is an integral element of a changed lifestyle and a changed ethos. The changes needed revolve around difficult technical, pricing and financing choices. Yet the direction of change is obvious if we want to meet the twin objectives of moving to an energy-poverty free world and a world that manages within the safe limits of anthropogenic climate change: essentially a world of carbon free energy and energy access for all.

5.2. A start must be made on pricing the planet's scarce energy resources in line with their real values and resource cost. We need to eliminate financial subsidies and then impose a carbon tax. This need not occur overnight; it can be phased in over a period and protective measures for those negatively affected can be easily designed: indeed unraveling the network of subsidies and designing a new level-pricing "playing field" requires careful assessment as relative prices between energy sources are as important as absolute prices. Energy subsidies are not free gifts as they simply transfer funds from one part of the economy to another. They are often the least efficient means to meet social objectives. In a similar manner a carbon tax should not be viewed as yet another punitive revenue earning tax but rather a means to price the negative externality of climate change. This requires communications skills: an unholy alliance between economists and communications specialists.

5.3. Funding needs are large. The IEA estimates, which are, in the author's view too low, of US $2 trillion per annum are already eye watering and yet even this level of investment is insufficient to meet climate goals of a 2°C stabilization and price contingencies on such investments as nuclear power plant decommissioning or cost over-runs of large scale energy investments have not been factored in. The reality is that significantly more than US $2 trillion per annum will be required. This suggests that the following actions are central to energy policy reform:

- Major investment is required in energy demand management both to conserve energy and to reduce capital expenditures. Attention is required, in the electricity sector, to reducing and managing peak demand in order to reduce capital expenditures. Such actions represent the highest economic and financial return to the energy sector. In particular attention should be paid to off-peak no-carbon activities such as domestic and commercial heating and cooling and potentially electric automobiles.*
- Energy subsidies, as noted, must be addressed as a matter of great urgency. They not only drain the sector of critical funds but also induce highly sub-optimal investment and energy use. Attention is not only needed to reduce financial subsidies but also to address economic subsidies, in particular, setting a price for carbon: a price that will clearly induce inter-fuel substitution towards non-carbon investment. There is a great deal of confusion and a wide range of metrics surrounding energy subsidies, especially how

* The growth in electric automobiles could be a "life saver" for the electric utilities industry as it would allow for off-peak (over-night) charging at a large scale. It must be recalled that energy saving in the electric sector is the environmentalist's dream but the accountant's nightmare! For every KWh saved is one unit less of revenue.

to account for economic subsidies and subsidies to capital investment. An important policy dialogue is needed on the basis of a clear understanding of the flows, drivers and consequences of the wide array of subsidies provided to the sector.

- Efforts must be turned towards least-cost economic planning in the energy sector to ensure that synergies between and within investments are made. This is not a call to return to top-down centralized planning but rather a call to recognize that the energy sector is more efficient when it operates as a system rather than when it operates as a set of discrete and independent projects. Good planning can pave the way for good investment and improved operational management.
- Least cost energy expansion programs that build in climate concerns are likely to lead to higher capital cost but lower recurrent cost expenditures. Accounting and economic rules that require highly positive discount rates or inappropriate depreciation rules need to be adjusted. Such investments, with the possible exception of nuclear power, reduce long-term risk by sourcing a secure and low cost energy supply.
- High priority should be given to upgrading, life extension and efficiency improvements in the production of electricity, especially in the hydro and thermal power sector.
- Informed public debate on technology choice, real costs and next generation decisions is needed. Today the debate is obfuscated by misunderstanding of real resource costs and needs to take place if there is to be a consensus about moving towards a non-carbon energy world. In particular, the current debate on "fracking" and new and non-conventional oil and gas sources offers an opportunity to graft on a broader debate around the real costs and risks of future choices. An increased understanding of the efficacy and costs of carbon capture and storage is needed as this may also be an area that requires considerable increase in funding.
- Assistance will be needed at the level of distribution (especially of electricity) to seek out low cost options and where local funding constraints are a major impediment.

5.4. The financial sector needs urgent reform. It needs to become closer to the real economy and provide the requisite finance. It needs a major retrofit to be made fit for purpose: providing much needed liquidity for the global transition (on energy and other forms of infrastructure). Long term finance is required; new metrics are needed and internal money transfers by way of speculation and non-productive investment must be mitigated. There is a strong role for public policy to set out new rules of the game for the financial and banking sector and for investment in long-term assets that have high upfront costs.

5.5. The rich world must step up to the plate by offering inducements to crowd in private and quasi-public institutional capital. In this regard sovereign wealth funds may have a critical role to play. However, to do so will require enlightened public policy and clear standards, metrics, independent rating of assets etc. The public sector can also play a major role in reviving the carbon market, either through a reformed Clean Development Mechanism (CDM) or by other means. Developing a sufficiently large carbon price would offer a major inducement to expanding the carbon market[*] and providing much needed liquidity to small and medium-sized firms operating in the energy efficiency and renewable energy space.

5.6. The public sector will also need to play a role in securing the public good benefits of future investment. With regard to the large and ever increasing cost of decommissioning the stock of vintage nuclear facilities it is likely that special purpose funding instruments will be needed. Such funds are likely to be special purpose public funds and not conflated with energy investment *per se*.[†]

5.7. The international financial system needs to be expanded to provide funding to least developed countries. The current level of finance provided, whether through lending or through special purpose climate and clean energy funds is too low. Governments must immediately meet their obligations of funding climate change at a level of US $100 billion per annum and demonstrate unambiguous and significant progress towards that goal.

5.8. Efforts to sequester part of the bond market and drive it towards clean energy are welcome and should be intensified. This again will likely require some level of public support. International Financial Institutions (IFI) bond issuance should also be supported and expanded. There appears to be no reason why bond markets (with an appropriate public support system) could not be expanded exponentially to facilitate clean energy investment.

5.9. The above actions, *prima facie*, appear almost un-surmountable. They are not. What is required is careful and prudent analysis as the basis for sound public policymaking. The rich world has a special responsibility to lead: while it has vintage stock issues to deal with and a heavy nuclear power legacy to fund, it also has the luxury of low growth energy demand and high income. It must take the lead in setting a fair carbon price, in meeting its "differentiated obligations" under the climate treaty, and it must increase the volume of funding and non-funding assistance to the energy economies of the developing world where over 80% of total investment will be directed.

5.10. Difficult financing decisions will no doubt need to be taken to meet both legitimate energy needs and to de-carbonize the sector. The energy transition will take time to complete, perhaps several decades. In the meantime urgent actions will be required to meet the challenges of climate change.[‡] Land management and attention to the forestry sector can offer low cost opportunities to sequester large amounts of carbon at relatively low cost and, in doing so, buy strategic time for the energy transition to be completed. A "30 year land wedge" geared towards carbon sequestration could offer opportunities to provide the space for that transition.

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* Other factors include a stable regulatory regime for carbon markets including potentially a price stabilization scheme. At the present time many independent carbon market schemes are in existence: a degree of rationalization would likely induce an expansion in this market.

† Other factors related to safety, security and military concerns will also be factored in.

‡ This note has not focused on climate change per se but only as it affects the technical and policy choices affecting the energy sector. A more comprehensive view of actions for mitigating and adapting to climate change is beyond the scope of this note.

Notes

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2. Doug Koplow, "Nuclear Power: Still not viable without subsidies," *Union of Concerned Scientists* http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nuclear_power/nuclear_subsidies_report.pdf
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