Historical Case Studies of Energy Technology Innovation

CASE STUDY 18: GLOBAL FINANCIAL RESOURCES.

GLOBAL R&D, MARKET FORMATION, AND DIFFUSION INVESTMENTS IN ENERGY TECHNOLOGY INNOVATION

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AUTHORS' SUMMARY

This case study provides a quantitative overview of the financial resources mobilised globally as fundamental inputs in to the energy technology innovation system. Available data from a diverse range of sources is compiled and summarised throughout the innovation lifecycle from research and development (R&D) through market formation to widespread market diffusion. Attention is paid to the less well reported types of financial resource inputs including private (as well as public) R&D, and niche market investments by risk-taking venture capital. The resulting synthesis provides a first order snapshot of relevant financial flows for energy technology innovation, and provides a framework to situate additional detailed case studies on research, development and demonstration (R,D&D) expenditures outside the IEA member countries, and commercial or 'diffusion' investments into end-use technologies. Taken together, these case studies paint a comprehensive picture of financial resources mobilised for energy technology innovation. The key elements of this picture are: (1) the scale of resource mobilization increases dramatically across successive innovation stages; (2) the structure of current energy investments is highly asymmetrical, with end-use technologies dominating diffusion investments but energy supply technologies, particularly fossil fuels and nuclear energy, dominating early stage innovation investments; (3) six major emerging energy economies now account for a significant proportion of global energy innovation investments. These findings point to the need for new institutional arrangements for the comprehensive and systematic gathering and assessment of energy innovation investments to inform decision making.

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1 INTRODUCTION

In this case study, we collate and summarise available data on the financial resources mobilised to support and induce energy technology innovation throughout the lifecycle from research and development (R&D) through market formation to widespread market diffusion. We provide what - to our knowledge - is a first attempt at a comprehensive quantitative overview of financial investment inputs throughout the energy technology innovation system. We attend to the less well reported types of financial resource inputs including private (as well as public) research and development (R&D), and niche market investments by risk-taking venture capital (see Box below for definitions). Novel empirical data on two particularly underreported types of financial investments are treated in more detail in companion case studies on R,D&D expenditures in the major developing countries, and on commercial or 'diffusion' investments into end-use technologies. This case study provides the synthetic overview necessary to piece together these various facets of the resource mobilisation story. Taken together, they paint a comprehensive picture of financial investments in energy innovation.

Evidently, money is not the only resource that needs to be mobilized: the development of knowledge, skills, supporting institutional settings, and so on are all also important. Financial resources should not be interpreted as a single metric through which the system for energy technology innovation can be comprehensively described. Yet financial investments are an important and observable form of innovation input, a core element of any embodiment of technological change, and data - albeit far from comprehensive - are more readily available than other input, output, or outcome metrics. (We discuss this at length in the case study on assessment metrics). In addition, financial investment data offer a commensurable metric across technologies, across innovation stages and processes, and across different sectors and markets. Finally, financial data are useful for policy makers and industry alike as both operate under budget constraints.

Table **1** provides an overview of the investment estimates which are discussed in detail in this case study. Investment and expenditure data are expressed in international $ using purchasing power parity (PPP) in order to improve comparability between economies (although a drawback of PPP is that simple *ex post* adjustments to a common base year are not possible for international, cross-country statistics).

We classify our investment estimates by broad technology class and by innovation stage. The first innovation stage is characterized by research, development and demonstration (R,D&D) expenditures. These are a well-defined expenditure category in macroeconomic and corporate accounts. Thereafter, definitional boundaries become unavoidably blurred. The market formation stage is described by investments that either rely on risk-taking private finance including venture capital or private equity funds, or that require policy inducements and market incentives such as feed-in tariffs or production tax credits. The final widespread or mass market diffusion stage represents the commercialization of mature technologies which no longer require dedicated policy incentives. This distinction from the market formation stage is inevitably somewhat arbitrary as the broader market environment with its relative prices, tax regimes, rules and standards and so on, is strongly influenced by policy. But in the diffusion stage, these are not dedicated to supporting specific technologies.

TABLE 1. SYNTHESIS OF GLOBAL INVESTMENTS (2005$ BILLION PPP) IN ENERGY TECHNOLOGY INNOVATION. NOTES: FIRST ORDER ESTIMATES OF INVESTMENT DATA BY INNOVATION STAGE (COLUMNS) AND TECHNOLOGY CLASS (ROWS). SOURCE: SEE TABLE NOTES FOR DETAILS.

Technology Class	Innovation Stage					
	R,D&D		Market Formation		Diffusion	
End-use & efficiency	>>8	[1]	5	[8]	300-3500	[15]
Fossil fuel supply	>12	[2]	>>2	[9]	200-550	[16]
Nuclear	>10	[3]	0	[10]	3-8	[17]
Renewables	<12	[4]	~20	[11]	>20	[18]
Electricity (Gen+T&D)	>>1	[5]	~100	[12]	450-520	[16]
Other* and unspecified	>>4	[6]	<15	[13]	n.a.	
Total	>50	[7]	<150	[14]	1000-<5000	[19]

Notes: * Other includes hydrogen, fuel cells, other power & storage technologies, and basic energy research.
R,D&D investment data from IEA, 2009b; WEC, 2001; Kempener et al., 2010; see also the case study on Emerging Economies: [1] public + private R,D&D of 1.8 billion + >>6 billion respectively; [2] public + private R,D&D of 2 billion + >10 billion respectively; [3] public + private R,D&D of >6.2 billion + >3.4 billion respectively; [4] public + private R,D&D of 2-5 billion (range from IEA, 2009b; Kempener et al., 2010 vs. NEF/SEFI, 2009) + 7 billion respectively (private R,D&D data includes renewable electricity); [5] & [6] public R,D&D only; [7] rounded lower bound.
Market formation investment data from (NEF/SEFI, 2009): [8] includes 2 billion asset finance + estimated 2 billion venture capital; [9] estimated 2 billion from venture capital only; [10] mature technology at diffusion stage; [11] estimated 2.4 billion venture capital + 24.8 billion biomass/biofuels - 8 billion Brazilian ethanol considered mature technology at diffusion stage); [12] estimated 90 billion asset finance + 8 billion venture capital; [13] unaccounted for technology categories; [14] rounded upper bound.
Diffusion investment data: [15] first order estimate from Wilson and Grubler, 2011; see also the case study on End-Use Investments) with range spanning end-use technologies (upper bound) to just energy-using components of end-use technologies (lower bound); [16] & [18] see Table 3 for details; [17] estimate based on 2-3 GW reactor completions per year (IAEA-PRIS, 2010) at $1500-2500/kW; [19] rounded range.

2 R,D&D INVESTMENTS

Research, development and demonstration (R,D&D) expenditures at the macroeconomic level are routinely collected by national and international statistical agencies (see OECD, 2007). The data are usually differentiated by funding source (public or private sectors), by R,D&D performing institution (government laboratories, universities, or private firms), and by economic sector. Methodologies, data collection, and compilations are well established (OECD, 2002). But energy-related or technology-specific R,D&D data are not reported separately in these macroeconomic statistical frameworks. This creates data challenges for assessing energy technology innovation (Dooley, 2000). The exception is for public sector R,D&D expenditures in member countries of the International Energy Agency or IEA (IEA, 2009a). Comparable information for non-IEA countries (including Brazil, China, and Russia) is sparse and for private sector R,D&D is extremely fragmented. Yet our estimates suggest they account for around three quarters of all energy-related R,D&D globally, and rising. Comprehensive data to separate out demonstration investments from R&D expenditures are also few and far between.

2.1 Public Sector Energy R,D&D

Figure 1 summarizes the trends in public sector energy R,D&D since 1974 in IEA member countries and contrasts it with total public R,D&D expenditures. Two defining characteristics of energy R,D&D are its comparably small magnitude (5% of total government R,D&D) and its cyclical 'boom and bust' profile with rapid expansion in the wake of the oil crises of the 1970s, subsequent collapse, and only gradual recovery after the year 2000. This is in stark contrast to the continually expanding total R&D budget in OECD countries. These trends are extensively discussed in the literature (e.g., Dooley and Runci, 2000; Doornbosch and Upton, 2006) and used to argue for a persistent "R&D under-investment" in energy innovation by both researchers (e.g., Nemet and Kammen, 2007) and business executives (e.g., AEIC, 2010).

The contribution of demonstration investments to the totals shown in Figure 1 is unclear. IEA (2009a) reports a total of some $0.55 billion for seven countries for which demonstration-specific data are available, with the US accounting for over $0.44 billion. This total equates to some 4% of total public energy technology R,D&D in all IEA member countries in 2008, pointing to the dominance of R&D over technology demonstration proper.

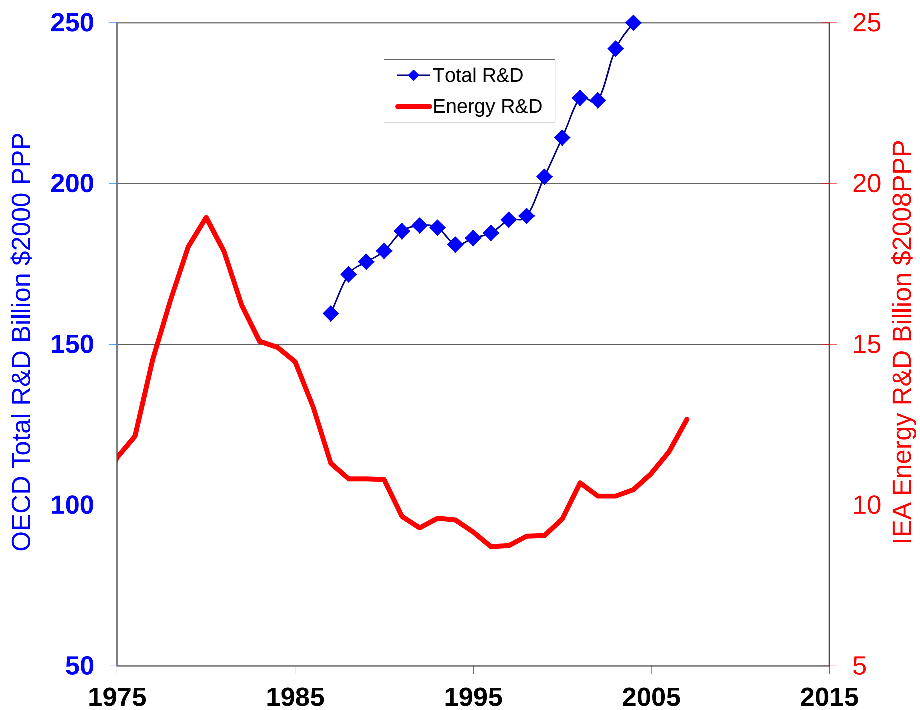

FIGURE 1. OECD PUBLIC R&D EXPENDITURES (2000$ PPP) VERSUS PUBLIC ENERGY R,D&D IN IEA COUNTRIES (2008$ PPP). NOTES: Y-AXES EXPENDITURE SCALES DIFFER BY A FACTOR OF 10. 1985-2000 SHOW OPPOSING TIME TRENDS. SOURCES: OECD DATA FROM DOORNBOSCH AND UPTON, 2006 ; IEA DATA FROM (IEA, 2009B).

Figure 2 summarizes the historical evolution of IEA member country energy R,D&D by broad technology class, illustrating a third defining characteristic: asymmetries in public R,D&D portfolios. Total public R,D&D in IEA member countries in 2008 amounted to some $12.7 billion. Close to $5 billion was spent on nuclear (fission and fusion), $3 billion on "other" energy technologies (hydrogen, electricity transport and distribution, basic energy research), and about $1.5 billion apiece on both fossil fuels and energy efficiency. Fossil fuel and nuclear technologies receive the lion's share of R,D&D funding in both IEA member countries and the major developing economies (see below).

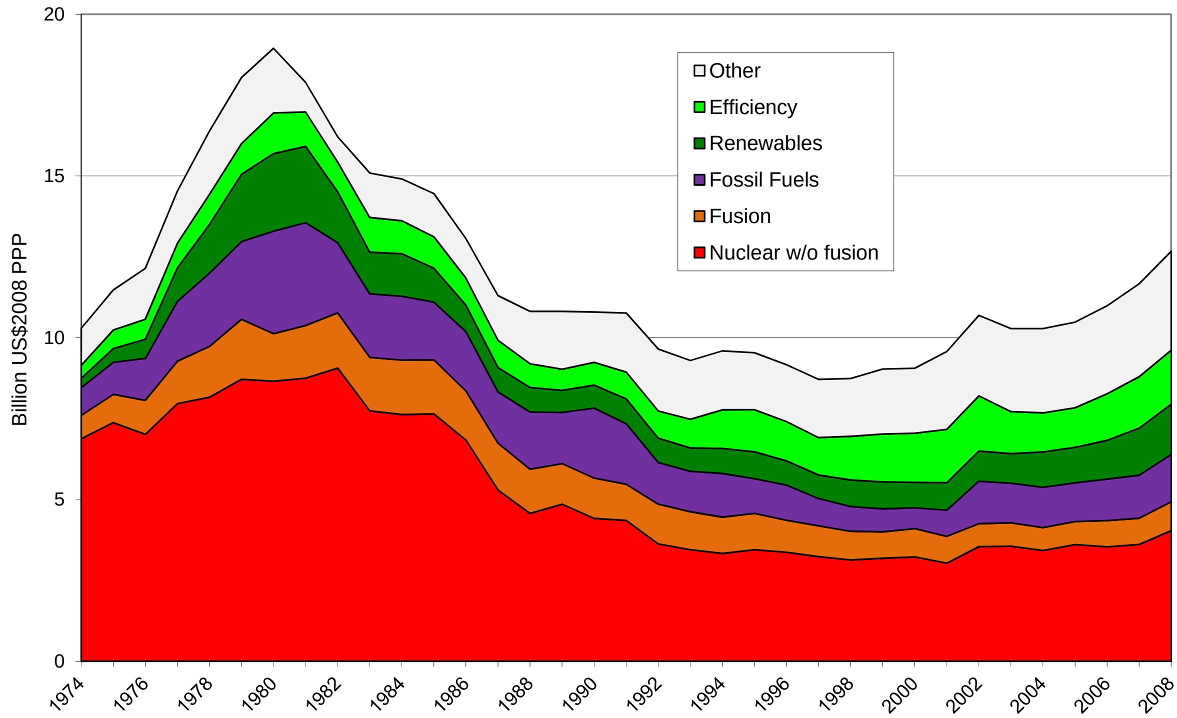

FIGURE 2. PUBLIC ENERGY R,D&D IN (2000$ MILLION PPP) IN IEA COUNTRIES BY TECHNOLOGY CLASS (1974-2008). SOURCE: BASED ON (IEA, 2009B).

As noted, comparable R,D&D statistics for non-IEA member countries are lacking, giving rise to the incorrect perception that energy R,D&D and technology development is primarily performed in developed economics. The companion case study by Kempener and colleagues provides a survey of available R,D&D data in non-IEA major energy economies or 'BRIMCS' countries (Brazil, Russia, India, Mexico, China, South Africa). This survey reveals that public energy R,D&D in the six BRIMCS countries amounted to some $2.7 billion compared with US$4.4 billion in the US in 2008 (IEA, 2009a).

In the BRIMCS countries, traditional distinctions between public and private sources of R,D&D funding become increasingly blurred by the dominant position of whole or partially state-owned enterprises. R,D&D expenditures in state-owned oil, gas and electricity companies are strongly determined by government policies. Including these raises the six BRIMCS countries' total current energy R,D&D expenditures to some $15 billion which is equivalent to the entire $13 billion public energy R,D&D budget of the 28 IEA member countries and about half the estimated $25 billion combined public and private energy R,D&D in OECD countries.

2.2 Private Sector Energy R,D&D

Macroeconomic R,D&D statistics by economic sector are available for a sample of 19 OECD countries in the OECD Structural Analysis database (OECD, 2009). However, the latest year reported is 2002. Data for other countries are not collected and available in any internationally comparable form. As noted by the Directorate General for Research of the European Commission: "Despite the growing need, statistics on energy R&D expenditures in the private sector remain a problem" (EC, 2005).

In 2002, business enterprises excluding extractive industries (coal mining, oil and gas extraction) performed R&D equivalent to $433 billion (PPP in 2000$) in the 19 OECD countries sampled. The only sectoral breakdown relevant for energy innovation are "coke, refined petroleum products and nuclear fuel" ($2.7 billion) and "electricity, gas, and water supply" ($2 billion), with an OECD total of energy-related private sector R,D&D of less than $5 billion. Of course, R,D&D performed in the manufacturing sector has a bearing on energy use, such as in electrical machinery ($13 billion), motor vehicles ($50 billion), or aircraft ($20 billion; see NSF, 2010). How much of the R,D&D performed in these sectors is energy-related remains unknown. The six automobile manufacturers listed among the top 25 global corporations in 2006, spent between $4.6 billion (Honda) to $7.5 billion (Toyota) on R&D, with a total of some $39 billion. Other corporations, whose R&D is likely to include an important energy component are Siemens ($6.6 billion), Samsung ($5.9 billion), Matsushita ($4.9 billion), Sony ($4.6 billion), and Bosch ($4.4 billion) (NSF, 2010). The consumer good and appliance products of these companies also suggest that private energy-related R,D&D may be dominated by energy end-use technologies.

The only available survey of private sector R,D&D specific to the energy sector is the study conducted by the World Energy Council (WEC, 2001), covering the period 1997-2000 for a sample of seven OECD countries and expressed in 2001$ billion (PPP). Total private energy R,D&D amounted to some $12 billion annually. The Kempener et al. (2010) survey on BRIMCS countries (see also the case study on End-Use Investments) puts these OECD numbers into perspective, with private sector and state-owned enterprises also investing around $12 billion (in 2008 PPP) albeit based on more recent data.

The WEC data are summarized in Table 2 and although dated, usefully illustrate the magnitude and technology allocation of private energy R,D&D. It is also noteworthy that, with the exception of Japan, private R,D&D on energy efficiency is either unrecorded or subsumed within the "other or non-specified" category. Private sector energy R,D&D thus appears to track the public R,D&D portfolios emphasis on energy supply technologies, particularly nuclear and fossil fuels.

TABLE 2. PRIVATE ENERGY R,D&D (IN 2001$ BILLION) FOR SELECTED OECD COUNTRIES. NOTES: LATEST AVAILABLE DATA FOR US SHOWN FOR COMPARISON (NSF, 2009). SOURCE: WEC, 2001.

R,D&D Expenditure (2001$ Billion)	**US**	**US**	**Japan**	**Korea**	**Sweden**	**France**	**Denmark**	**Spain**	**Total**
reference year	*2000*	*2004*	*1997*	*1998*	*1997*	*1998*	*1993*	*1998*	*~2000*
Efficiency			6.10						**6.1**
Fossil fuels	0.81	1.04	0.84	0.03		0.56			**2.2**
Nuclear	0.03	0.03	1.00			1.17			**2.2**
Renewables			0.29						**?**
Other or non-specified	0.36	1.21				0.05			**?**
Total	**1.20**	**2.28**	**8.6**	**0.06**	**0.1**	**1.78**	**0.08**	**0.08**	**11.9**

Time series data from the US shows that private energy R,D&D follows comparable trends to public energy R,D&D (see Figure 3). Both are influenced by the rise and fall of oil prices. Nemet and Kammen (2007) argue that "the signal of commitment that a large government initiative sends to private investors outweighs any crowding-out effects associated with competition over funding or retention of scientists and engineers". In other words, 'shared expectations' - an important institution within the energy technology innovation system - may help explain the trends seen the inter-relationship seen in Figure 3. And expectations may wane as well as wax: a coupled decline in R,D&D budgets is seen post-1985.

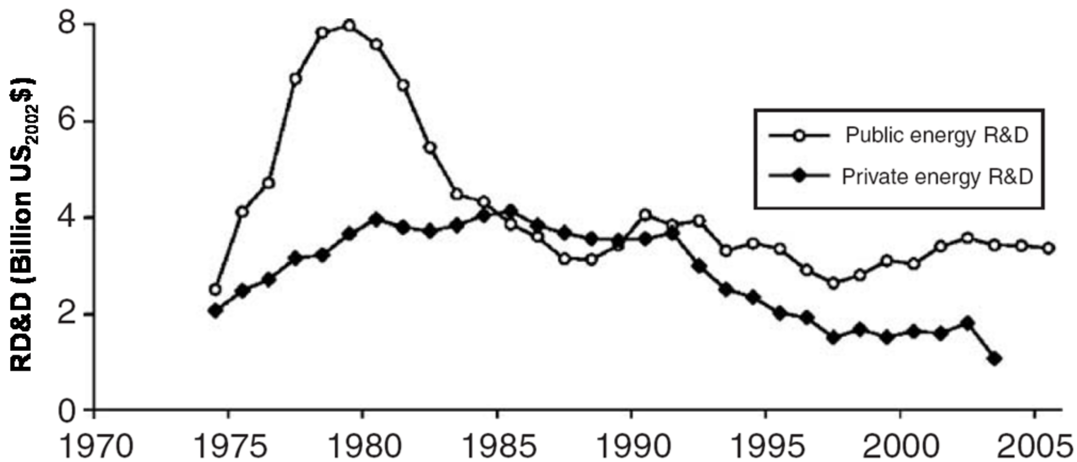

FIGURE 3. TRENDS IN US PUBLIC AND PRIVATE ENERGY R,D&D (US2002$ BILLION). SOURCE: NEMET AND KAMMEN, 2007.

2.3 Total Energy R,D&D

Based on the limited data available, the order of magnitude estimate of global energy R,D&D amounts to some $50 billion per year with some $15 billion in public sector R,D&D and up to $35 billion invested by the private sector (see Table **1**). About half of all energy R,D&D is spent on fossil fuels and nuclear technologies.

An alternative estimate by the Sustainable Energy Finance Initiative (SEFI) of global sustainable energy R,D&D amounts to some $12.4 billion in 2005 (UNEP/SEFI/NEF, 2009). This breaks down as $5.6 billion public and $6.8 billion private R,D&D, although there is insufficient detail provided to allow a more in-depth comparison.

3 MARKET FORMATION INVESTMENTS

Market formation investments include public and private investments in the initial phase of diffusion during which technologies are often in "niche markets". These are characterised by a high willingness-to-pay by end-users for novel performance advantages, and some degree of insulation from the cost pressures of a competitive market. Niche markets are often created or protected by policy incentives or regulation.

For the purposes of tracking investments against conventionally reported categories, we define market formation investments as investments in or by companies that have solved the core technological problems out of R&D and that are now seeking to commercialise their products into relatively small, specific markets, at least initially. These investments are not, on their own, commercially viable, and so are too early for mass market adoption (and so 'diffusion' investments). We thus emphasize private investments that take advantage of markets created by government policies, such as renewable electricity portfolio standards or feed-in tariffs, and renewable fuel regulations. Even with this definition, market formation investments in the energy sector are difficult to estimate because many transactions are unreported, and there is no accepted measurement approach.

3.1 Estimating Market Formation Investments

Investments in most renewable energies can be classified as market formation investments given their reliance on policy incentives. A recent UNEP/SEFI/NEF (2009) report analysed investments into "sustainable energy" which it defined as solar, wind, biofuels, biomass and waste to energy, marine and small-hydro, geothermal, efficiency, and other low-carbon technologies/services. It excludes large-scale hydro (>50MW) and all nuclear power. The UNEP/SEFI/NEF study reported investments into sustainable energy had risen to US$223 billion in 2008, although this includes $67 billion of purely financial transactions including mergers and acquisitions, refinancings, and buyouts (UNEP/SEFI/NEF, 2009). These transactions represent changes in ownership rather than investments into the formation of markets for energy innovations (see Box for definitions of investment types).

Box. Definition of Types of Market Formation Investment. Source: UNEP, 2011.

- *Venture capital and private equity (VC/PE)***:** all money invested by venture capital and private equity funds in the equity of companies developing energy technologies. Similar investment in companies setting up generating capacity through special purpose vehicles is counted in the asset financing data.
- *Public markets*: all money invested in the equity of publicly quoted companies developing energy technologies and power generation. Investment in companies setting up generating capacity is included in the asset financing data.
- *Asset financing*: all money invested in energy production or electricity generation projects, whether from internal company balance sheets, from debt finance, or from equity finance. This excludes re-financings.
- *Mergers and acquisitions (M&A)*: the value of existing equity purchased by new corporate buyers in companies developing energy technologies or operating energy projects.

Of the US$160 billion technology-specific investments reported by UNEP/SEFI/NEF (2009), US$103 billion comprised various types of risk-taking private finance (venture capital, private equity, asset finance, and new equity issuances – see Box for definitions) which we consider as clearly constituting market formation investments. A further US$18 billion was on public and private R,D&D, and the remaining US$35 billion on small and residential projects and the Brazilian ethanol programme could be considered diffusion investments.

A breakdown by asset class of private market formation investments in sustainable energy technologies is shown in Figure 4. Asset financing comprises the dominant share. Asset finance includes the building of new assets (projects, plants, etc.) using either project finance which ring fences the asset in a 'special purpose vehicle', or using balance sheet financing. Asset finance is more common for investments in large and more mature technologies but in this context are considered market formation investments given their exposure to and reliance on government subsidies and other market incentives.

New listings on public markets grew sharply from 2006-2007, but has settled back to broad equivalence in magnitude to venture capital (VC) and private equity (PE) investments. The compound annual growth rate across the three asset classes from 2004-2008 was 63%. The principal technology class invested in was wind power; investments from 2004-2008 grew annually at 51%. Investments in energy efficiency were small (only 2% of total investments from 2004-2008). The principal regions invested in were OECD countries, notably Europe (45%), and North America (30%).

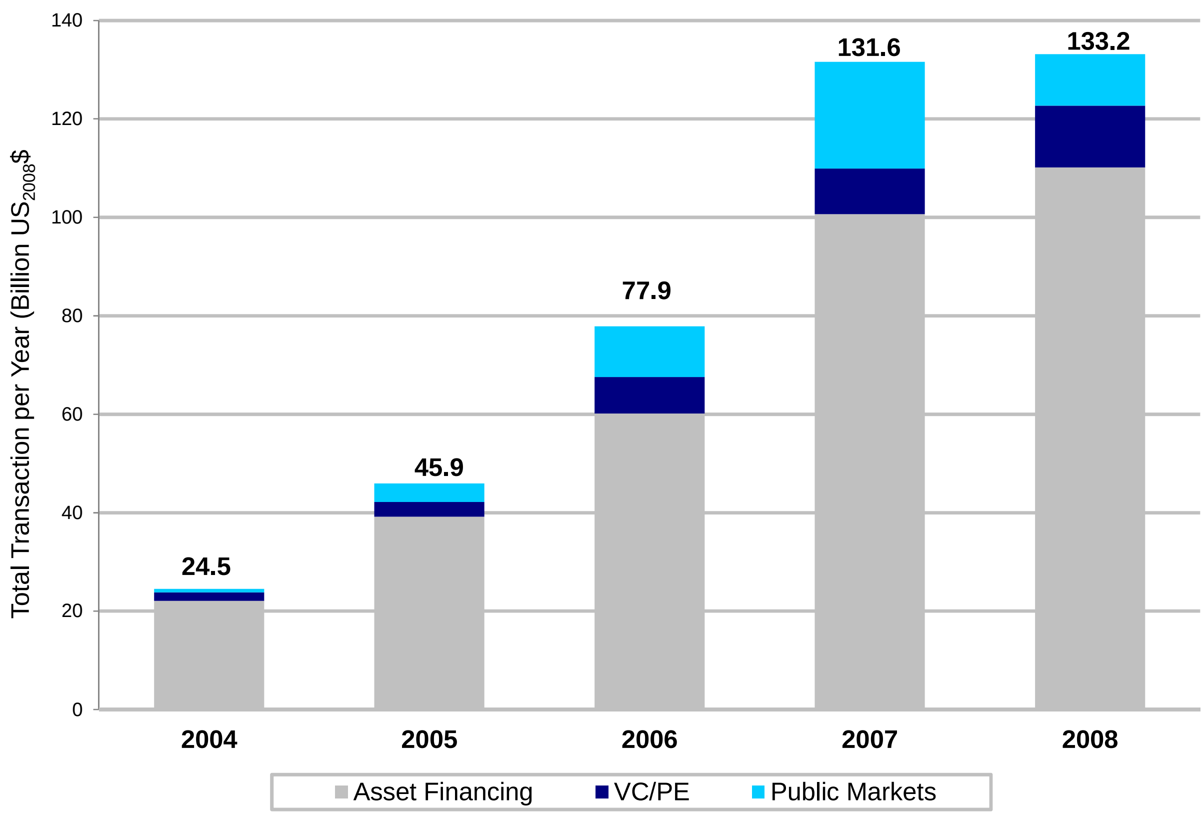

FIGURE 4. ANNUAL INVESTMENTS (US2008$ BILLION) IN MARKET FORMATION FOR SUSTAINABLE ENERGY TECHNOLOGIES (2004-2008). NOTES: 2008 DATA EXCLUDES US$8 BILLION IN BRAZILIAN ETHANOL. SOURCES: UNEP/SEFI/NEF, 2009; O'ROURKE, 2009; BLOOMBERG NEW ENERGY FINANCE DATABASE, COURTESY OF ERD3 PROJECT HARVARD, (UNEP/SEFI/NEF, 2009).

3.2 Venture Capital and Private Equity (VC/PE) Investments

Although more risk-taking than conventional debt and equity investors, venture capital (VC) and private equity (PE) investors typically only commit to a technology once much of the innovation risk has been mitigated, when markets are at least somewhat defined, and when the innovating company is formed and functioning. VC/PE investors aim to profit from the rapid scaling up of the technology in early markets demonstrating commercial potential to allow them to sell their equity stake at a high multiple of the initial investment. VC/PE investors' core role is to bring not just capital but also commercial skills and expertise to aid and accelerate this transition from demonstration to diffusion. In the energy sector, this is particularly relevant for the less mature sustainable energy technologies.

The UNEP/SEFI/NEF (2009) data combined with data on fossil fuel investments in the Thomson/Reuters VentureXpert database (Thomson Financial, 2009) show dramatic growth in VC/PE investments into energy – and specifically into clean energy technologies – since the mid to late 2000s. From 2002 to 2008, the total amount of energy (fossil and non-fossil) investments made by VC/PE investors worldwide grew from US$1.1 billion to some US$14.6 billion with a 53% compound annual growth rate (see Figure 5). This is a likely under-estimate as VC/PE investments are often not publicly reported, investments made by individual investors are usually not reported, and data outside the North American and European dominance of professional VC/PE firms are limited. Over the 2002-2008 period as a whole, at least US$40.9 billion was invested in energy technology firms in some 2,375 transactions. The number of investment rounds (or transactions) grew at 26% per year. The bulk of investments were into North American and European companies with non fossil-based energy technologies.

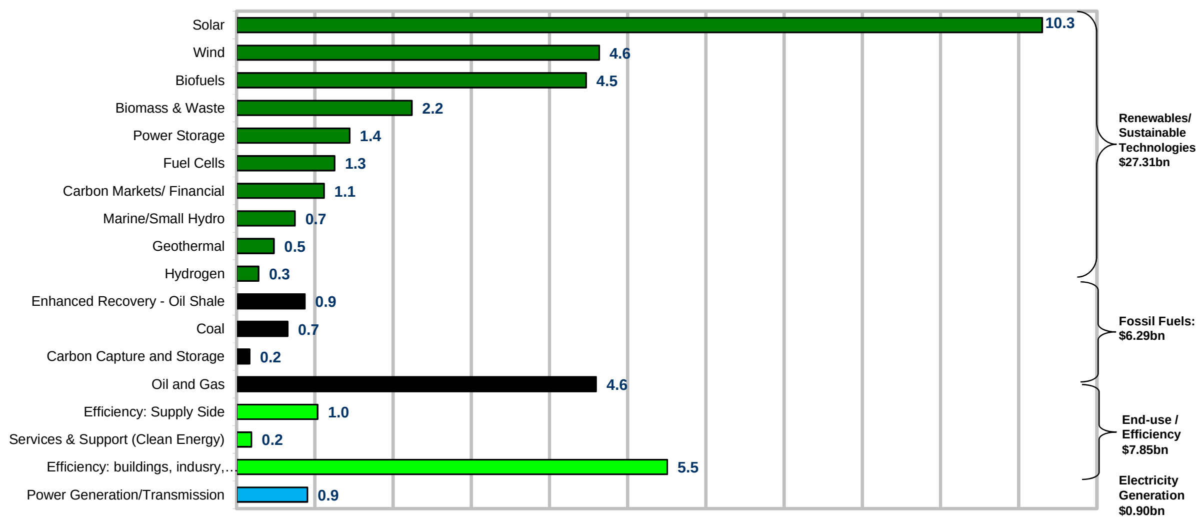

FIGURE 5. VENTURE CAPITAL / PRIVATE EQUITY INVESTMENTS (US2008$ BILLION) IN ENERGY TECHNOLOGIES (2002-2008). NOTES: 'BIOFUELS' EXCLUDES INVESTMENTS IN BRAZILIAN ETHANOL COMPANIES. SOURCES: O'ROURKE, 2009; BLOOMBERG NEW ENERGY FINANCE DATABASE, COURTESY OF ERD3 PROJECT HARVARD (NEF/SEFI, 2009); THOMSON REUTERS VENTUREXPERT DATA BASETHOMSON FINANCIAL, 2009).

Figure 5 shows that the majority of energy investments made by VC/PE investors are in to sustainable energy (particularly renewable power generation) and end-use efficiency technologies. Solar is the dominant technology class capturing some 30% of the global total over the 2002-2008 period and growing particularly rapidly from 2005 in terms of both numbers of transactions and total amounts invested. End-use efficiency, including smart energy metering in buildings, demand response software systems, high efficiency lighting, and so on, also grew markedly in this period.

4 DIFFUSION INVESTMENTS

'Diffusion' investments into mature commercial energy technologies are not collected systematically. Modelling studies, as well as limited survey data, allow estimates of capital investments in energy supply technologies, but analogous data for energy end-use investments are almost entirely lacking. A companion case study on end-use investments aims to provide a plausible first order estimate to address this data gap and to provide a comparator for the estimates of energy supply investments reviewed here.

4.1 Diffusion Investments in Energy Supply Technologies

Data on energy supply investments are typically based on limited surveys or model estimates which combine statistical data and/or estimates of capacity additions with average technology-specific investment costs. Modelling studies have been available since the mid-1990s from the research community (e.g., Nakicenovic et al., 1998; Nakicenovic and Rogner, 1996; Riahi et al., 2007) as well as in the work of the IEA, particularly the World Energy Investment Outlook (IEA, 2003), but also in the Energy Technology Perspectives series (IEA, 2006; 2008a) and the World Energy Outlook series (e.g., IEA, 2008b; 2009b). These latter reports include unique survey data on energy supply investments particularly in the oil and gas industry.

A common feature and drawback of almost all modelling studies is that energy supply investments are not reported for their reference or base year values, but instead as cumulative totals over the model projection horizon (typically 30 years). This makes an assessment of current investment levels and allocations difficult, and a robust comparison among different modelling studies almost impossible. Here we draw heavily on the only modelling study that has disclosed its base year energy investment values (Riahi et al., 2007), and compare this with the surveys reported in the IEA's World Energy Outlook series (IEA, 2006; 2008b; 2009b). The Riahi et al. (2007) estimates are based on capacity additions and price levels in 2000 as the reference year, expressed in US1990$ and converted here to a common US2005$ basis using the US GDP deflator although price levels remain in year 2000 terms. (Energy technology price escalation after 2000 is a feature observed for almost all energy supply technologies, but technology-specific price deflators are not available, hence reported prices and inferred investment numbers refer to year 2000 levels). As the energy sector has seen significant price escalation since 2004 (particularly for oil and gas), these Riahi et al. (2007) estimates can be considered a lower bound, and the IEA estimates an upper bound (see Table 3).

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TABLE 3. ESTIMATES OF DIFFUSION INVESTMENTS (US2005$ BILLION) IN ENERGY SUPPLY TECHNOLOGIES. NOTES: T&D = TRANSPORT AND DISTRIBUTION OF ELECTRICITY. SOURCES: LOW ESTIMATES FROM RIAHI ET AL., 2007; HIGH ESTIMATES FROM IEA (2006; 2008B; 2009B). SEE TEXT FOR DETAILS.

INVESTMENTS (US$2005 BILLION) IN ENERGY SUPPLY TECHNOLOGIES		**LOW ESTIMATE (prices & activity in 2000)**	**HIGH ESTIMATE (prices & activity in 2005-2007)**
FUELS - UPSTREAM:			
	Exploration fossil fuels	n.a.	40
	Extraction fossil fuels	180	180-360
FUELS - DOWNSTREAM: [1]		n.a.	100-140
	Synfuels, fossil	1	7
	Biofuels	20	n.a.
	Other	20	n.a.
TOTAL FUELS		**>220**	**300-550** [2]
POWER GENERATION:			
	Fossil	110	n.a.
	Non-fossil	100	n.a.
	Total (Fossil + non-fossil)	210	220-300
	T&D	>>70	?-230-?
TOTAL POWER GENERATION		**>500**	**450-520** [3]
TOTAL ENERGY SUPPLY		***>720***	***750-840*** [3]

Table notes: [1] Includes refining, pipelines, etc. [2] Minimum excludes exploration; maximum includes exploration. [3] Minimum - maxima range is not additive from sub-component min-max range.

Despite differences in estimated investments per technology class, the available data shown in Table 3 suggest a likely order of magnitude range of annual energy supply investments from around US$700 billion (2005$) up to some US$840 billion in 2007/2008. Investments are dominated by electricity generation and transport and distribution (T&D) which total around US$500 billion. Fossil fuel supply investments, particularly upstream (i.e., exploration and production), account for US$250-400 billion, mostly for oil and gas. The renewable energy technologies that featured prominently in market formation investments are thus minor players under the market conditions characterizing current diffusion investments. Liquid and gaseous biofuels account for US$20 billion (included in the lower bound of fuel investments), including US$8 billion for Brazilian ethanol (UNEP/SEFI/NEF, 2009). Large-scale hydropower make up less than 17% of current energy supply investments (<US$100 billion for annual capacity additions of between 25-30 GW).

Major uncertainties include the accounting for oil and gas exploration activities (at some US$40 billion). Some companies categorise these as R,D&D activity for future oil/gas reserves. On this basis, oil and gas exploration would represent the single largest type of R,D&D spending across the energy sector as a whole.

Uncertainties also exist for electricity transport and distribution (T&D) infrastructure investments for which only modelling study data are available and estimates differ by about a factor of three. The IEA (IEA, 2008b) projection of average annual electricity T&D infrastructure investments of US$230 billion over the period 2007 - 2015 appears extremely high, and is comparable to current investments in electricity generation capacity. It is also interesting to note that no studies report actual data for current investments in nuclear energy (even though nuclear capacity additions feature prominently in many projections). According to IEA (2002; 2009b), installed nuclear capacity expanded by 20 GW between 1999 and 2007. IEA (2008b) reports an increase from 358 to 376 GW between 2000 and 2006, which yields an average annual net increase in nuclear capacity of between 2-3 GW, mostly in Asia where investment costs are comparatively modest at an estimated 1500-2500 $/kW. This suggests current investments of between US$3-7.5 billion/year for nuclear reactors, which makes this the only technology in which R,D&D investments *exceed* diffusion investments.

Evidence regarding the time trend of energy supply investments is scarce. An intriguing empirical finding from the US shows a significant decline in energy supply investments as a share of sector revenues for electricity generation in the second half of the twentieth century (see Figure 6). The declining share of revenues reinvested in capital stock in the US electricity sector suggest a substantial thinning of resources available for capital turnover and diffusion of new technologies as a twin result of slowing demand growth and energy sector deregulation and liberalization. It remains unclear if this trend is a specific phenomenon of the US or IEA countries, but it certainly emphasises the importance of comprehensive time series data on energy sector investments to support decision making.

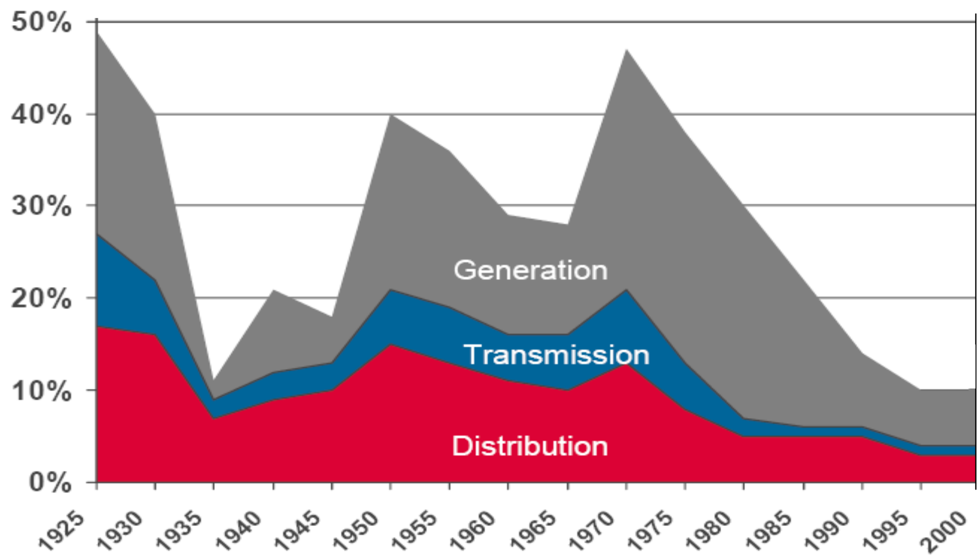

FIGURE 6. DECLINING INVESTMENTS AS A SHARE OF REVENUES IN THE US ELECTRICITY SECTOR (1925-2000). SOURCE: MODIFIED FROM EPRI, 2003.

This assessment of diffusion investments has focused on the global level for the simple reason that regionally disaggregated investment data are lacking. Modelling studies suggest that energy supply investments in the year 2000 were distributed about 60:40 between developed and developing economies (using the Annex I and non-Annex I definitions of the United Nations Framework Convention on Climate Change). Short-term projections (e.g., to 2030 by IEA, 2009b) suggest roughly a 50:50 split in the energy supply investment needs of Annex I and non-Annex I countries, for a global total of cumulative energy supply investments from 2008 to 2030 of some US$25 trillion (2008$).

4.2 Diffusion Investments in Energy End-use Technologies

The distributed, decentralised nature of investments in end-use technologies by households and firms, and their conventional classification as consumer expenditures rather than investments, explains the absence of energy end-use investment estimates in the literature. Compounding these data challenges are definitional problems. Even defining what constitutes an energy end-use technology is difficult. In the case of a new building, for example, the system boundary might be drawn around the heating and air conditioning systems, or more broadly to include the building envelope and structures that contribute to the demand for heat or cooling. Indeed, the entire building may be considered an end-use technology. Some modeling studies include incremental energy end-use technology investments associated with energy efficiency improvements over a reference scenario (e.g., IEA, 2009b). Apart from introducing additional definitional ambiguities (i.e., what constitutes incremental investments), the modeling is invariably partial, omitting certain technologies, and treating others inconsistently. More commonly, modeling studies deal with energy end-use investments either by 'assuming away' missing data through exogenous (policy-independent) energy efficiency trends.

These data issues and challenges are discussed in more detail in a companion case study which presents a global, bottom-up estimate of total investment costs in energy end-use technologies. This case study uses volume data (production, delivery, sales, and installations) and cost estimates to approximate total investment costs in 2005 both for end-use technologies (broadly defined) and their specific energy-using components (narrowly defined). Here, we summarise these estimates to provide a comparator for the energy supply investments presented above. We recommend the reader to the companion case study for all details of method and data (see also Wilson and Grubler, 2011).

Investments in 2005 in end-use technologies (broadly defined) are estimated to be in the order of US$1 - 3.5 trillion. Investments in the energy-using components of these end-use technologies (narrowly defined) is in the order of US$0.1 - 0.7 trillion. These investment ranges particularly at the upper end should be treated as underestimates, as many end-use technologies were omitted from the analysis. We therefore suggest a range of annual end-use investments to be conservatively in the order of US$0.3 - 4.0 trillion. This compares with the range of annual energy supply investments in the order of US$0.7 trillion.

Although the two ranges span the same orders of magnitude, the upper bound of end-use investments is four times higher than its energy supply equivalent. Interestingly, this result aligns with the IEA's estimation that demand-side investment needs exceed supply-side investment needs by a factor of 4 to 5 in climate policy scenarios (IEA, 2008a). Disaggregating the data by region shows that approximately two-thirds of the end-use investments in 2005 are in Annex I countries; the remaining one-third are in developing economies.

5 CONCLUSIONS

In this case study, we have compiled disparate data on R,D&D and market formation investments, on diffusion investments in energy supply technologies, and integrated these with novel datasets on R,D&D investments in BRIMCS countries, and on diffusion investments in end-use technologies. The result is a synthetic snapshot of the financial resources mobilised globally as investments in to the energy technology innovation system, distinguishing both the stage of the innovation lifecycle (R,D&D, market formation, diffusion) and the type of technology (upstream, downstream, power generation, T&D, end-use).

From this picture summarised in Table **1**, certain key findings emerge.

First, the scale of resource mobilization increases across successive innovation stages, from R,D&D (~$50 billion), to market formation (~$150 billion), to the dominant diffusion stage (>$1000 billion). If large-scale technological change is on the agenda, changes in the diffusion environment and associated incentives for technology adoption and diffusion – e.g., through changes in relative prices – will be essential *in addition to* the resources invested in developing improved technologies in the earlier innovation stages.

Second, the structure of current energy investments is highly asymmetrical. End-use technologies dominate diffusion investments but are strongly under-represented in earlier innovation investments (based on available data). The comparatively large support for energy supply technologies such as fossil fuels and nuclear energy in R,D&D is therefore brought into sharper relief, and is mismatched with the challenges facing the energy system from energy access to energy security and climate change mitigation, all of which call for vastly improved energy end-use efficiency.

Third, six major emerging economies – Brazil, the Russian Federation, India, Mexico, China, and South Africa, known collectively as 'BRIMCS' countries – now account for a significant proportion of global energy innovation investments. However, significant regional imbalances, particularly in the support for energy R,D&D, persist. The increasing globalization of energy innovation in general, and of energy technology R,D&D in particular, suggests that new mechanisms for international technology cooperation and coordination might be needed, including appropriate institutional (re)designs beyond the limited existing membership and scope of the IEA.

Finally, it is clear that there are formidable data problems associated with assessing energy technology innovation, pointing to important areas of future research and renewed initiatives to provide better technology-specific data. Institutions to collect and share these data at both national and international levels are also needed.

6 FURTHER READING

The Riahi et al., 2007 study is noteworthy for its reporting of base year investment data, and should be read as a contrasting approach to the IEA World Energy Outlook studies (IEA, 2008b; 2009b).

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