Paper #2-21

RESEARCH, DEVELOPMENT AND TECHNOLOGY TRANSFER

Prepared by the Technology Subgroup
of the
Operations & Environment Task Group

On September 15, 2011, The National Petroleum Council (NPC) in approving its report, *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Task Groups and/or Subgroups. These Topic and White Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic and White Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 57 such working documents used in the study analyses. Also included is a roster of the Subgroup that developed or submitted this paper. Appendix C of the final NPC report provides a complete list of the 57 Topic and White Papers and an abstract for each. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

Technology Subgroup		
Chair		
J. Daniel Arthur	Managing Partner	ALL Consulting
Assistant Chair		
H. William Hochheiser	Senior Energy and Environment Manager	ALL Consulting
Members		
Mark D. Bottrell	Manager – Field, Eastern Division	Chesapeake Energy Corporation
André Brown	Associate	W. L. Gore & Associates, Inc.
John Candler	Manager, Environmental Affairs	M-I SWACO
Lance Cole	Operations Manager	Petroleum Technology Transfer Council
David DeLaO	Manager, Drilling Engineering, Southern Division	Chesapeake Energy Corporation
Larry W. Dillon	Completions Manager, San Juan Business Unit	ConocoPhillips
Donald J. Drazan	Chief – Technical Assistance Section, Bureau of Oil and Gas Permitting and Management, Division of Mineral Resources, Department of Environmental Conservation	State of New York
Maurice B. Dusseault	Professor of Geological Engineering, Department of Earth & Environmental Sciences	University of Waterloo
Catherine P. Foerster	Commissioner	Alaska Oil & Gas Conservation Commission
Linda Goodwin	President	DOT Matrix Inc.
Edward Hanzlik	Senior Consultant, Petroleum Engineering, Heavy Oil & Unconventional Resources	Chevron Energy Technology Company
Ron Hyden	Technology Director, Production Enhancement	Halliburton Company

Jake Jacobs	Environment, Health and Safety Advisor	Encana Oil & Gas (USA) Inc.
Valerie A. Jochen	Technical Director, Production Unconventional Resources	Schlumberger
Bethany A. Kurz	Senior Research Manager, Energy & Environmental Research Center	University of North Dakota
Matthew E. Mantell	Senior Environmental Engineer	Chesapeake Energy Corporation
John P. Martin*	Senior Project Manager, Energy Resources R&D	New York State Energy Research and Development Authority
Dag Nummedal	Director, Colorado Energy Research Institute	Colorado School of Mines
Jerry R. Simmons	Executive Director	National Association of Royalty Owners
Steve Thomson	Manager, DeSoto Water Resources	Southwestern Energy Company
Denise A. Tuck	Global Manager, Chemical Compliance, Health, Safety and Environment	Halliburton Energy Services, Inc.
Mike Uretsky	Member, Board of Directors Executive Committee	Northern Wayne Property Owners Alliance
John A. Veil**	Manager, Water Policy Program, Argonne National Laboratory	U.S. Department of Energy
Donnie Wallis	Manager – Regulatory Affairs, Air Programs and Design	Chesapeake Energy Corporation
Chris R. Williams	Group Lead, Special Projects, Environment, Health and Safety	Encana Oil & Gas (USA) Inc.
Ad Hoc Member		
Douglas W. Morris	Director, Reserves and Production Division, Energy Information Administration	U.S. Department of Energy

* Individual has since retired but was employed by the specified company while participating in the study.

** Individual has since retired but was employed by the specified company while participating in the study.

Table of Contents

ABSTRACT

Research, product development and technology transfer comprise different stages in a continuum of progress based on growth of knowledge, improvement of capabilities and deployment of those capabilities to improve the quality of life. Technology development turns knowledge into actionable goods and services while technology transfer enables permeation of technology from its origins into a wide variety of applications. The ongoing and future importance of oil and gas (O&G) industrial progress requires well-planned and vigorous research and development (R&D) as well as effective technology transfers both to and from the O&G enterprises.

The US Department of Energy (DOE) invests more in basic and applied research than any federal agency other than the National Institutes of Health (NIH) and the National Science Foundation (NSF). But DOE investment in O&G-related R&D is almost entirely through the National Energy Technology Laboratory (NETL) which is the only national laboratory dedicated to fossil-fuel energy. Applied research is carried out by a combination of federal and business organizations, with business operating at twice the level of the federal government. Most O&G-related research is, in fact, funded privately by energy companies.

As a result of federal government legislation from 1980 through 2007, government-sponsored research, development and technology transfer has increasingly favored collaborations comprising consortia of government, academic, non-profit and industry researchers and technologists. As part of that trend, three main initiatives by the DOE have included (1) Energy Innovation Hubs, involving large numbers of distributed efforts but led by a central institution to integrate fundamental research through commercial technology deployment; (2) Energy Frontier Research Centers, comprising a few dozen senior investigators at multiple institutions and focused on fundamental research to overcome technology roadblocks; and (3) ARPA-E projects, based on small groups at single institutions who focus sharply on high-risk / high-return technologies of near-term payoff. However, none of those three initiatives have emphasized or substantially included O&G-related projects.

Technology deployment includes training of personnel to understand and effectively use new technologies in productive, commercial applications. Indeed, the technology-sociology theory of Charles Perrow holds that the inability of effective training to keep pace with complicated growth of advanced technologies is a contributor to “normal accidents” in all technology-dependent enterprises, including O&G. Even so, there currently is no clearinghouse of information to assess how effectively training is accomplished during the rollout of new technologies during O&G developments.

Accomplishing safe and environmentally sustainable O&G developments, as needed for the nation’s energy security during transition to renewable sources of energy, improvements must be made to better include O&G concerns in the nation’s overall R&D programs and priorities. Key findings and related recommendations are that:

- Funding is not well aligned with the critical role of O&G among balanced national priorities. The majority of the funds dedicated to hydrocarbon-based energy R&D are focused on carbon capture and sequestration (CCS) rather than on minimizing the

lifecycle footprint of O&G development. More attention is needed on sustainable production of petroleum and, especially, natural gas which is an abundant domestic resource.

- Consortia have become the dominant and most beneficial R&D performance platform. A formal infrastructure should be created to facilitate communication between organizations and projects involved in O&G-oriented R&D. Establish an Energy Frontier Research Center or Hub (Hub) that is focused on low-environmental-impact O&G exploration, processing and use.

- Communication of R&D progress on energy topics remains ineffective. The federal government could organize an annual Energy Research Summit, which brings together leading researchers working in fields having or having the potential on energy advances, including but not limited to researchers working in energy and in environmental, computer and social sciences

- Cross-over of other technology into O&G is under-appreciated. The communication gap should be addressed through the proposed Energy Research Summit or other equivalent clearinghouse.

- Effectiveness of training in O&G technology deployment is not well documented. The federal government should a make meaningful participation in setting standards for training in the industry. There should be an immediate effort to set standards for training in the O&G field, including content, trainee performance levels, along with company processes to monitor the level of the training effort.

INTRODUCTION

A. Oil &Gas Research: A Collaborative Endeavor

An energy policy meeting national security, economic and environmental goals must include a robust, ongoing research effort that includes the steps between basic research and its implementation. It must address the research engine, technology transfer, management support, the regulatory structure, and the government environment and thus all of these components are conceptually related to research and development (R&D). Moreover, it must recognize that the oil and gas industries (O&G) are part of the overall US industrial pictures, with some activities carried out by large multinational companies, and others by small entrepreneurs. The larger companies have a complex set of relationships with subsidiaries and 'partners' around the world and thus they are part of the bigger trend towards globalization of business and R&D. As such, any picture of research activities must at least take cognizance of those kinds of relationships.

The business community funds and performs the overwhelming portion of applications-oriented US research. As such, the picture is clouded by internal company relationships, inter-company agreements, intellectual property rights concerns, as well as a lack of both open disclosure of those efforts and the absence of a readily available picture of overall R&D efforts. The picture is further clouded by the fact that successful work in O&G R&D must involve collaborative partnerships among academic, government laboratory and private organizations. That collaborative, multi-lateral practice provides insights and expertise that would not likely be available under other unilateral pursuits. The collaborative practice merges the research and technology implementation activities in a positive sense by reducing or eliminating the competitive premise of the marketplace.

B. A Policy-Oriented Picture

The objective of this paper is to stimulate discussion regarding policy alternatives that can move the US national energy program forward. Certain choices had to be made in order to maintain this focus. The general sphere of 'research' is broad, covering everything from the various forms of research, to technology transfer efforts intended to disseminate innovations and facilitate successful implementation, to providing adequate training. These activities take place in many different venues, including the federal government, federally funded research and development centers, academic institutions and private companies. Some of those activities are viewed as proprietary by their performers. And finally, the data surrounding those activities are fragmented and frequently not publicly disclosed. Given that complex situation, this paper focuses on bigger pictures that may be addressed by energy policy. Where specific instances are mentioned, they are used solely as examples of the point being made, and no inferences should be made regarding their uniqueness; in most cases, other examples could equally well have been selected.

RESEARCH

A. Trends in R&D Investments

An examination of R&D in the US shows four clear trends that are important to our concern. In a macro sense, the US as a whole invests large amounts in R&D. As seen in Table 1, R&D expenditures rose from $288 billion in 2003 to $398 billion in 2008 (both measured in 2010 dollars). When R&D expenditures are stated relative to a country's gross national product (GNP), the US R&D is comparable with the equivalent measure for many other developed nations.

As seen in Table 1 and Figure 1, beginning in 1980 the business sector R&D expenditures exceeded those of the federal government (National Science Board, 2010). Most overall R&D funding is provided by industry, with the federal government playing a major role in basic research, and lesser roles a technology marches towards implementation. While the amount invested in research by the federal government is large in an overall sense, an increasing portion has been dedicated to defense-related activities. The amount that the federal government puts into energy research is small compared to its other expenditures. The federal government provides critical funds for basic research and for high-risk, high-payoff projects. And finally, much of the current research effort is carried out through consortia – a point that will be discussed more fully as part of a discussion about technology transfer.

Figure 1. Trends in R&D funding by government and industry (National Science Board, 2010).

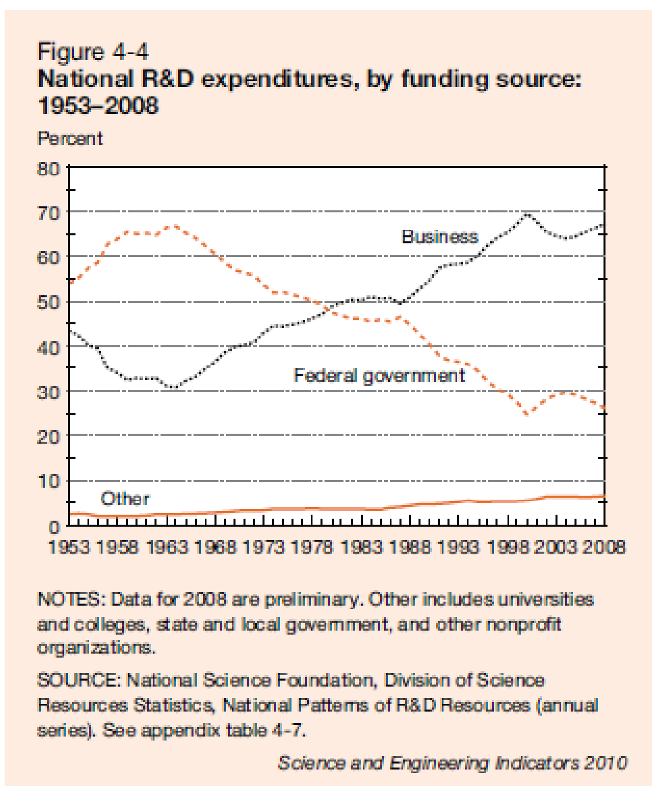


Table 1. US R&D expenditures by funding source (National Science Board, 2010). In the original source, all amounts were inflation-adjusted to either 2010 dollars ("Current") or 2000 dollars as shown.

Table 4-1
U.S. R&D expenditures, by performing sector and funding source: 2003–08

Sector	2003	2004	2005	2006	2007	2008
	Current $millions					
All performing sectors	288,324	299,201	322,104	347,046	372,527	397,616
Business	200,724	208,301	226,159	247,669	269,267	289,105
Federal government	35,005	35,632	37,716	38,926	39,897	41,741
Federal intramural[a]	22,752	22,844	24,470	25,556	25,858	27,000
FFRDCs	12,253	12,788	13,246	13,369	14,039	14,741
Industry-administered[b]	2,458	2,485	2,601	3,122	4,839	5,031
U&C-administered[b]	7,301	7,659	7,817	7,306	5,892	6,023
Nonprofit-administered	2,494	2,644	2,828	2,941	3,308	3,688
Universities and colleges	40,484	43,128	45,197	46,983	49,021	51,163
Other nonprofit	12,111	12,140	13,032	13,469	14,341	15,606
All funding sources	288,324	299,201	322,104	347,046	372,527	397,616
Business	186,174	191,376	207,826	227,254	246,927	267,847
Federal government	83,618	88,766	93,817	98,036	101,764	103,696
Universities and colleges	7,650	7,937	8,579	9,307	9,993	10,600
Nonfederal government	2,742	2,883	2,922	3,021	3,249	3,453
Other nonprofit	8,140	8,239	8,960	9,429	10,593	12,020
	Constant 2000 $millions					
All performing sectors	270,971	273,335	284,962	297,444	310,913	324,791
Business	188,643	190,294	200,081	212,271	224,732	236,155
Federal government	32,898	32,551	33,367	33,362	33,299	34,096
Federal intramural[a]	21,383	20,869	21,648	21,904	21,582	22,055
FFRDCs	11,516	11,682	11,719	11,459	11,717	12,042
Industry-administered[b]	2,310	2,270	2,301	2,676	4,039	4,109
U&C-administered[b]	6,861	6,997	6,916	6,262	4,918	4,920
Nonprofit-administered	2,344	2,415	2,502	2,521	2,761	3,012
Universities and colleges	38,047	39,400	39,986	40,268	40,913	41,792
Other nonprofit	11,382	11,090	11,529	11,544	11,969	12,748
All funding sources	270,971	273,335	284,962	297,444	310,913	324,791
Business	174,969	174,831	183,862	194,773	206,087	218,790
Federal government	78,585	81,092	82,999	84,024	84,933	84,704
Universities and colleges	7,190	7,251	7,589	7,977	8,341	8,658
Nonfederal government	2,577	2,634	2,585	2,589	2,711	2,821
Other nonprofit	7,650	7,527	7,926	8,081	8,841	9,818

FFRDC = federally funded research and development center; U&C = universities and colleges

[a]Includes expenditures of federal intramural R&D and costs associated with administering extramural R&D.
[b]In June 2006, Los Alamos National Laboratory (approximately $2 billion in annual R&D expenditures in recent years) became industry administered; previously, U&C administered. This shift is one reason for change in trends apparent in R&D expenditure figures between 2006 and 2007.

NOTES: Data for 2008 are preliminary. Data based on annual reports by performers except for nonprofit sector. Expenditure levels for academic and federal government performers are calendar-year approximations based on fiscal year data. For federal government expenditures, approximation equal to 75% of amount reported in same fiscal year plus 25% of amount reported in subsequent fiscal year. For academic expenditures, respective percentages are 50 and 50, because those fiscal years generally begin on 1 July instead of 1 October.

SOURCE: National Science Foundation, Division of Science Resources Statistics, National Patterns of R&D Resources (annual series). See appendix tables 4-3 and 4-7.

Science and Engineering Indicators 2010

The business sector funds most R&D (Fig. 2) and it uses most of the R&D funding (Fig. 3), including additional funds provided by the federal government (Fig. 4).

Figure 2. Trends in R&D investments by organizations (National Science Board, 2010).

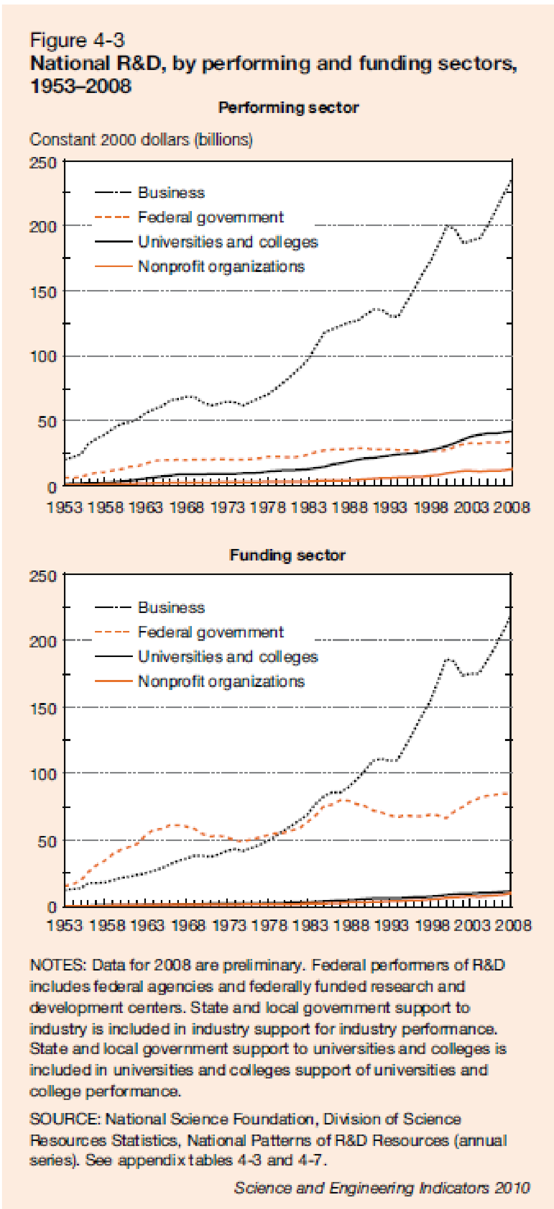


Figure 3. Proportions of total R&D investments spent by organizations from different economic sectors (National Science Board, 2010).

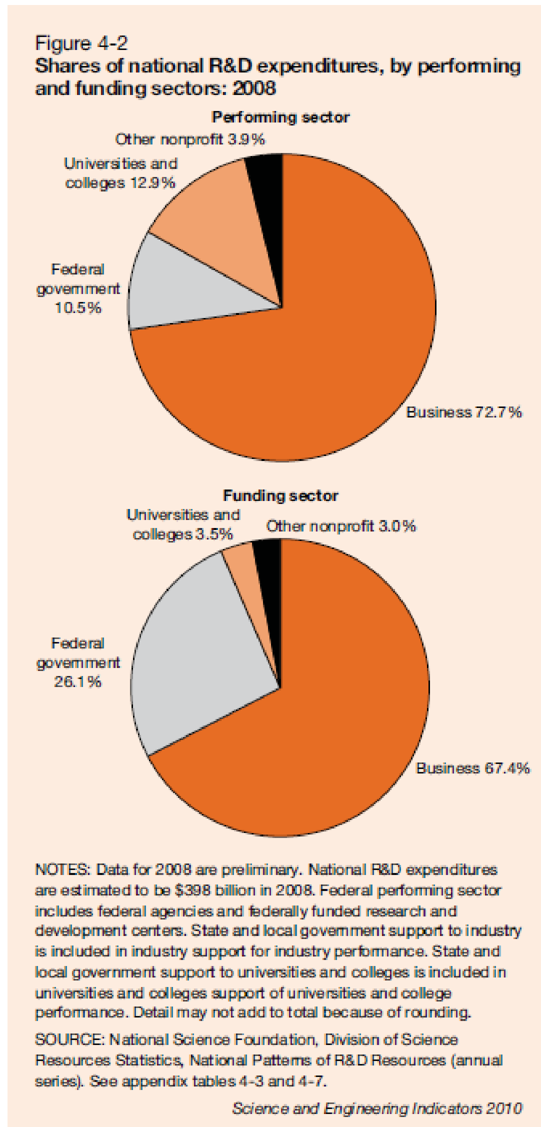
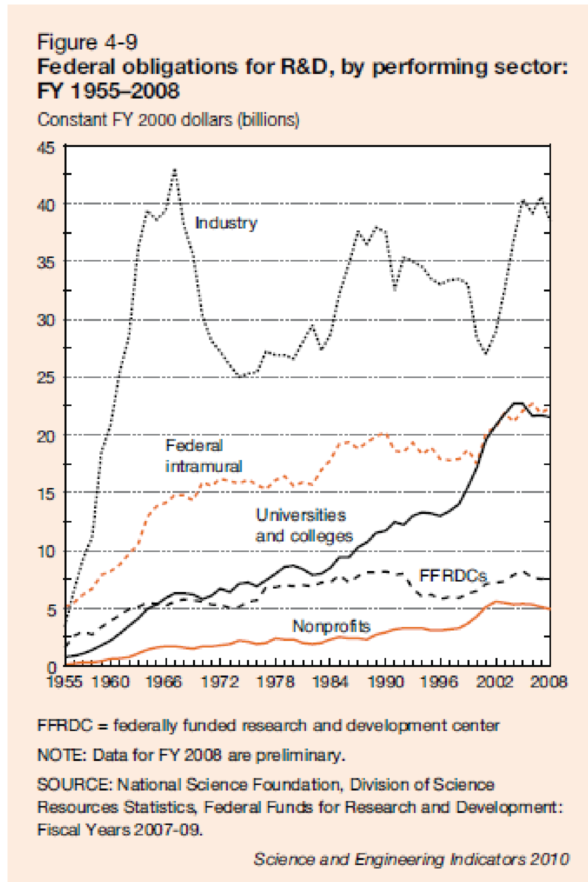


Figure 4. Federal government R&D funds as spent by organizations from different economic sectors (National Science Board, 2010).



B. US Government R&D

Basic research is carried out by a combination of the federal government and academic institutions. Business funding for basic research generally goes to an assortment of academic and not-for-profit institutions. Applied research is carried out by a combination of federal and business organizations, with business operating at twice the level of the federal government. Business funding for applied research stays largely within the business sector (but not necessarily within the same company providing the funding) while federal funding is divided between federal agencies and FFRDCs (Federally Funded Research and Development Centers (FFRDCs) that are denoted by the government as National Laboratories, including several under the umbrella of the US Department of Energy (DOE)[1].

The US approach to government funding of academic research is different from the approach followed in other economically advanced countries. Other countries provide block grants to academic institutions, leaving it up to the recipients to decide upon the allocation of the funds to departments and types of research. The US generally provides funding for specific, separately budgeted R&D projects supporting objectives of funding agencies. In some cases, states also may provide undesignated funds. Supporting arguments can be made for either the designated- or undesignated-funding approach. The non-US approach (undesignated funds) is administratively simpler but does not allow for tailoring according to topic or relative strengths of departments within a specific institution. The US approach (designated funds) requires more complex program management by the government but preserves flexibility in targeting funds to the best, peer-reviewed projects regardless of institutional affiliation.

[1] The National Laboratories under stewardship of DOE conduct research in a variety of scientific and technical fields. They include: Ames Laboratory, Argonne National Laboratory, Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Idaho National Engineering and Environmental Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, National Energy Technology Laboratory, National Renewable Energy Laboratory, New Brunswick Laboratory, Oak Ridge Laboratory, Pacific Northwest Laboratory, Princeton Plasma Physics Laboratory, Sandia National Laboratories, Savannah River National Laboratory, Stanford Linear Accelerator Center, and the Thomas Jefferson National Accelerator Facility.

Table 2. Single-year (2008) distribution of R&D funds among various enterprises and topical areas (National Science Board, 2010).

Table 4-2
U.S. R&D expenditures, by character of work, performing sector, and funding source: 2008

Sector	Total	Business	Federal government	Universities and colleges	Other nonprofit	Total expenditures (% distribution)
R&D	397,616	267,847	103,696	14,053	12,020	100.0
Business	289,105	263,310	25,795	*	*	72.7
Federal government	41,741	*	41,741	*	*	10.5
Federal intramural	27,000	*	27,000	*	*	6.8
FFRDCs	14,741	*	14,741	*	*	3.7
Industry-administered	5,031	*	5,031	*	*	1.3
U&C-administered	6,023	*	6,023	*	*	1.5
Nonprofit-administered	3,688	*	3,688	*	*	0.9
Universities and colleges	51,163	2,908	30,177	14,053	4,024	12.9
Other nonprofit organizations	15,606	1,629	5,982	*	7,995	3.9
Percent distribution by source	100.0	67.4	26.1	3.5	3.0	na
Basic research	69,146	12,222	39,379	10,188	7,357	100.0
Business	11,907	9,209	2,697	*	*	17.2
Federal government	10,189	*	10,189	*	*	14.7
Federal intramural	4,734	*	4,734	*	*	6.8
FFRDCs	5,455	*	5,455	*	*	7.9
Industry-administered	2,287	*	2,287	*	*	3.3
U&C-administered	1,736	*	1,736	*	*	2.5
Nonprofit-administered	1,432	*	1,432	*	*	2.1
Universities and colleges	38,822	2,108	23,608	10,188	2,918	56.1
Other nonprofit organizations	8,229	904	2,885	*	4,439	11.9
Percent distribution by source	100.0	17.7	57.0	14.7	10.6	na
Applied research	88,578	53,827	28,649	3,169	2,934	100.0
Business	61,437	52,758	8,679	*	*	69.4
Federal government	11,599	*	11,599	*	*	13.1
Federal intramural	7,573	*	7,573	*	*	8.5
FFRDCs	4,026	*	4,026	*	*	4.5
Industry-administered	1,067	*	1,067	*	*	1.2
U&C-administered	1,644	*	1,644	*	*	1.9
Nonprofit-administered	1,315	*	1,315	*	*	1.5
Universities and colleges	10,556	656	5,824	3,169	908	11.9
Other nonprofit organizations	4,985	413	2,546	*	2,026	5.6
Percent distribution by source	100.0	60.8	32.3	3.6	3.3	na
Development	239,891	201,798	35,669	696	1,729	100.0
Business	215,761	201,342	14,419	*	*	89.9
Federal government	19,953	*	19,953	*	*	8.3
Federal intramural	14,693	*	14,693	*	*	6.1
FFRDCs	5,260	*	5,260	*	*	2.2
Industry-administered	1,676	*	1,676	*	*	0.7
U&C-administered	2,643	*	2,643	*	*	1.1
Nonprofit-administered	941	*	941	*	*	0.4
Universities and colleges	1,785	144	746	696	199	0.7
Other nonprofit organizations	2,392	312	551	*	1,530	1.0
Percent distribution by source	100.0	84.1	14.9	0.3	0.7	na

* = small to negligible amount, included as part of funding provided by other sectors; na = not applicable

FFRDC = federally funded research and development center; U&C = universities and colleges

NOTES: Data for 2008 are preliminary. Federal intramural includes federal intramural R&D and costs associated with administering extramural R&D. Funding for FFRDC performance chiefly federal, but any nonfederal support included in federal figures. State and local government support to industry included in industry support for industry performance. State and local government support to universities and colleges ($3,453 million) included in universities and colleges support for universities and colleges performance.

SOURCE: National Science Foundation, Division of Science Resources Statistics, National Patterns of R&D Resources (annual series). See appendix tables 4-3 to 4-10.

Science and Engineering Indicators 2010

TECHNOLOGY DEVELOPMENT AND TRANSFER

A. Globalization of R&D into Technology

The purpose of research is to find new knowledge either to answer questions or to solve problems. In industry, including O&G, the ultimate value of research as part of R&D is to enable new or improved products and services, including commercial applications of technologies. In the global marketplace, technology transfer has become an integral part of efforts focused on moving goods and services around the world. The technology-transfer practices that have been long-standing in Europe now are becoming essential components in the strategy and activities of US multinational firms.

The most significant change that has taken place is the internationalization of R&D, with a shift away from cost reduction and localization to undertaking R&D relating to core competencies in international Centers of Excellence – no matter where they may be located. As part of that globalization, there is growing foreign expansion of R&D in the US – some by mergers and some by acquisitions.

There has been a vigorous growth of complex inter-company collaborative relationships – some domestic and some international. Citing work by Freeman (1991), Rycroft (2003) provides the following enumeration:

> Such collaborative agreements encompass a wide range of activities, including: joint ventures, research corporations (e.g., research pacts, joint development agreements), technology exchange agreements (e.g., technology sharing, cross-licensing, mutual second-sourcing), direct investment, minority/cross holding, customer-supplier and customer-user relationships, R&D contracts, one-directional technology flow agreements (e.g., licensing, second sourcing), manufacturing agreements, marketing agreements, or service agreements. The term "strategic alliance" is often used to describe cooperative arrangements that are more stable and long-term than these categories, or to encompass collaboration that extends over a series of projects (Rycroft, 2003).

Measures of foreign direct investment focus on capital movements and hence may be a good indication of growing technology internationalization. As pointed out by Rycroft (2003), those investments fall into two broad categories: (1) building wholly-owned facilities in the host country, (2) undertaking joint ventures, where business enterprises share ownership and control across borders; and (3) acquiring control of an existing enterprise in the host country. Implementation of those options serves as an indicator of the degrees of attractiveness found in relations with the host country.

A considerable amount of US company R&D is carried out by majority-owned foreign affiliates of those companies (Table 3) (National Science Board, 2010). Similarly, foreign multinationals carry out substantial amounts of R&D in the US (Table 4) (National Science Board, 2010).

Table 3. Single-year (2006) expenditures on US R&D as work performed outside the US by foreign affiliates of US companies (National Science Board, 2010). In the original source, all amounts were inflation-adjusted to 2010 dollars ("Current").

Table 4-20

R&D performed abroad by majority-owned foreign affiliates of U.S. parent companies, by selected NAICS industry of affiliate and country/region: 2006

(Millions of current U.S. dollars)

		Manufacturing						Nonmanufacturing	
Country/region	All industries	Total	Chemicals	Machinery	Computer and electronic products	Electrical equipment, appliances, and components	Transportation equipment	Information	Professional, technical, scientific services
All countries	28,484	23,638	6,166	1,128	4,874	651	8,342	1,014	2,688
Canada	2,503	1,766	759	37	260	14	587	271	415
Europe	18,628	15,635	3,882	830	1,976	503	6,460	374	1,790
Belgium	948	699	D	15	D	D	26	3	226
France	1,447	1,287	313	110	206	28	392	29	78
Germany	4,919	4,754	253	279	609	245	2,888	22	100
Ireland	848	538	234	0	225	4	5	204	D
Italy	689	587	274	84	21	42	86	*	84
Netherlands	486	426	184	26	35	D	D	8	38
Sweden	1,536	1,512	72	8	68	20	D	1	19
Switzerland	933	501	254	52	61	4	6	D	D
United Kingdom	5,378	4,296	1,412	200	632	71	1,582	77	862
Asia and Pacific	5,575	4,680	1,233	D	2,105	129	849	D	D
Australia	596	536	162	D	D	1	D	1	28
China	804	675	30	15	541	35	30	D	D
Hong Kong	105	47	D	0	16	D	0	4	50
India	310	106	8	13	D	*	20	D	108
Japan	1,739	1,560	893	10	397	D	92	111	16
Korea	729	704	34	15	201	D	D	D	1
Malaysia	249	248	3	*	241	1	0	0	*
Singapore	850	634	D	*	564	2	D	D	D
Latin America/OWH	865	811	242	50	27	6	419	*	20
Brazil	571	539	136	48	18	4	307	0	11
Middle East	847	693	29	D	506	0	0	D	D
Israel	846	693	29	D	506	0	0	D	D
Africa	65	53	21	1	0	*	26	2	*
South Africa	52	42	19	1	0	*	D	2	*

D = suppressed to avoid disclosure of confidential information; * = ≤ $500,000

NAICS = North American Industry Classification System; OWH = other Western Hemisphere

NOTES: Preliminary 2006 estimates for majority-owned (>50%) nonbank affiliates of nonbank U.S. parents by country of ultimate beneficial owner and industry of affiliate. Expenditures included for R&D conducted by foreign affiliates, whether for themselves or others under contract. Expenditures exclue for R&D conducted by others for affiliates under contract.

SOURCE: Bureau of Economic Analysis, Survey of U.S. Direct Investment Abroad (annual series), http://www.bea.gov/international/index.htm#omc, accessed 6 May 2009.

Science and Engineering Indicators 2010

Table 4. Single-year (2006) expenditures on foreign company R&D as work performed inside the US by US affiliates of foreign companies (National Science Board, 2010). In the original source, all amounts were inflation-adjusted to 2010 dollars ("Current").

Table 4-18
R&D performed by majority-owned affiliates of foreign companies in United States, by selected NAICS industry of affiliate and country/region: 2006
(Millions of current U.S. dollars)

Country/region	All industries	Manufacturing: Total	Manufacturing: Chemicals	Manufacturing: Machinery	Manufacturing: Computer and electronic products	Manufacturing: Electrical equipment	Manufacturing: Transportation equipment	Nonmanufacturing: Information	Nonmanufacturing: Professional, technical, scientific services
All countries	34,257	25,035	12,750	789	3,072	1,329	4,198	967	1,879
Canada	1,586	295	D	11	D	D	D	D	83 e
Europe	25,803	22,121	12,168	637	2,568	1,226	3,697	592	729
France	3,335	2,978	D	D	575	D	180 e	165	D
Germany	6,742	5,880	1,761	99	121	D	2,812	D	D
Netherlands	1,562	D	D	D	D	2	D	0	4
Switzerland	5,039	4,483	4,248	44	D	D	5	2	D
United Kingdom	6,801	6,357	3,836	45 e	1,682	28	491	D	110 e
Asia/Pacific	4,589	1,475	409	D	380	39 e	D	D	986
Japan	3,995	1,258	396	58	295	38 e	262	18 e	819
Latin America/OWH	D	920	2 e	D	D	D	4 e	3	D
Middle East	D	161	D	1	D	0	9	D	0
Africa	35	D	D	0	0	0	0	D	0

D = suppressed to avoid disclosure of confidential information; e = >50% of value for data cell estimated to account for data not reported by respondents

NAICS = North American Industry Classification System; OWH = other Western Hemisphere

NOTES: Preliminary 2006 estimates for majority-owned (>50%) nonbank affiliates of nonbank U.S. parents by country of ultimate beneficial owner and industry of affiliate. Expenditures included for R&D conducted by foreign affiliates, whether for themselves or others under contract. Expenditures excluded for R&D conducted by others for affiliates under contract.

SOURCE: Bureau of Economic Analysis, Survey of Foreign Direct Investment in the United States (annual series), http://www.bea.gov/international/index.htm#omc, accessed 6 May 2009.

Science and Engineering Indicators 2010

B. Progress Through Consortia

The most effective forms of technology transfer come when the parties actively work together, i.e., when their individual successes are based on satisfactory use of a technology.

There is a critical link between technology innovation, technology transfer and globalization. The nature of this linkage has changed significantly over time, evolving from a form of outsourcing focused on localization and cost saving, to a crucial part of the overall innovation process (Rycroft, 2003).

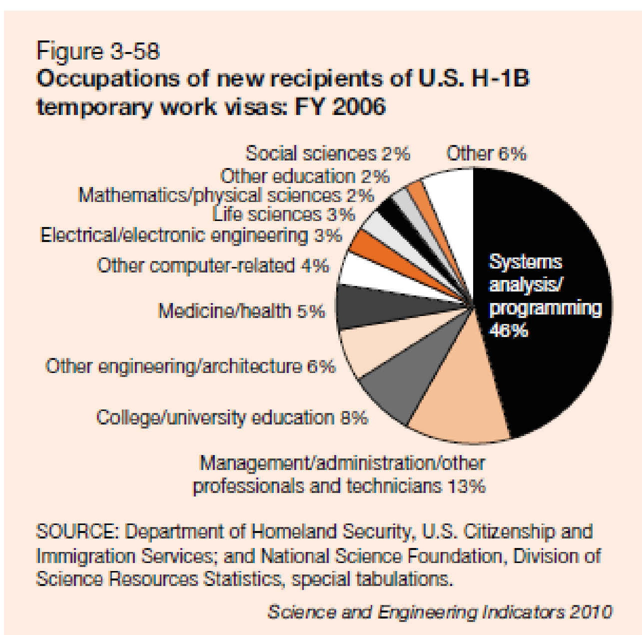
Rycroft (2003), in a paper focusing on indicators, points out that the work (and hence the indicators) focus on three related categories: technological exploitation (taking technological processes and products to international markets), technological generation (undertaking technology innovation in a host country), and technological collaboration (joining forces to innovate together). Those categories, by themselves, highlight the important dimensions of this process and reasons why they are essential to global energy companies. That categorization is elaborated upon more fully by Archibugi and Michie (1995).

Although international technology relationships are very important, there are no reliable indicators that accurately measure the level of that globalized effort. Efforts to measure value flows have traditionally focused on goods and services rather than intangibles. Much of the subject effort takes place on an intra-firm level, between parents and subsidiaries. Even if there are efforts to place monetary values on those activities, the resulting values are not arms-length transactions and they are influenced by many non-market factors. Alternative measures are used as surrogates, each with its own limitations.

Patents and patent disclosures are an indication of cases where the parties view the innovation as valuable and where the desirable form of protection is provided by securing international patents. Indexing technology progress by patents suffers from multiple deficiencies (Patel, 1995; Patel and Pavitt, 1997; Malerba and Orsenigo, 1996). Not all innovations are patented, since some firms feel that other mechanisms are more effective. Different technologies are patented at different rates. Patents ignore much of the software area, where some feel that adequate protection is provided by copyrights.

H-1B visas are an additional, although imperfect, indicator of science and engineering-based collaboration. The numbers of most types of temporary work visas issued to high-skilled workers has continued to increase. While 65,000 H-1B temporary work visas are authorized, there were 20,000 exemptions for students earning US masters degrees or doctorates and further exemptions for US academic and research institutions in their own hiring. Over two-thirds of the H-1B visas were used for science and technology visa recipients. More than half of all H-1B visa recipients were for India; Asian citizens made up three-quarters of all the H-1B recipients (National Science Board, 2010).

Figure 5. Single-year (US Fiscal Year 2006) H-1B visas issued by category of worker expertise (National Science Board, 2010).



The absence of good metrics can hinder the policy setting and management effort. Indeed, Anadon et al. (2010), in an analysis of US energy innovation, make a point of observing:

> It is imperative that all initiatives and institutions are required to consistently collect metrics on relevant outputs and outcomes and information about projects. This is essential to sustain public and political support, which will be necessary to ensure that the energy technology innovation effort enjoys the predictability and patience it needs. … Considerable thought is needed to design metrics that will drive effort in the right directions: with poor metrics, there is always a danger of managers focusing on meeting the metrics rather than the overall goal (Anadon et al., 2010).

Collaboration Pays Off. While technology transfer is often thought of as simply a tool for moving technologies out of the laboratory and towards implementation, in reality it is a process that also has many additional dimensions. It makes a given technology available to a wider number of people or firms; it provides feedback essential for fine turning; it provides a basis for collaboration; and it may be a source of revenue in and of itself. When looking at technology transfer, one must recognize that a large portion (perhaps most) transfers take place through informal mechanisms that may only be indirectly focused on technology transfer per se. Consider the following examples: papers in professional journals, reports from government laboratories regarding their work or work they are funding, physical proximity, market research and strategic planning exercises, patent searches, management, attendance at conferences, management consultants, contractors.

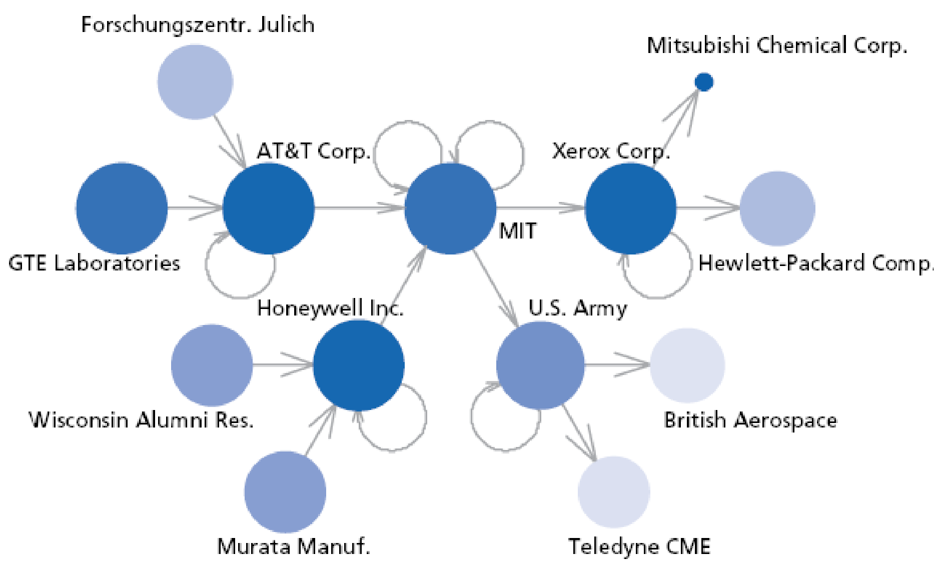
There is a trend towards increased collaboration in R&D and its use. Consortia bring together basic and applied researchers, users, and potential business partners. The consortium approach reflects the needs to bring diverse skills and resources to bear, as well as both explicit and implicit recognition of the role that such collaboration can play in moving technology innovation to use, and building economic relationships.

The research consortia and geographic proximity are by far the most interesting forms of informal technology transfer. The consortia provide a wide range of beneficial opportunities: academic/lab insights flow into industry; practical insights help to focus research and short circuit the process; access to test beds is facilitated by the shared collaboration; and new professionals receive training that will benefit them and the industry. Most significantly, there is not only essentially automatic transfer of knowledge between organizations, there is a spillover effect benefiting organizations that are not formal participants in the consortia. Intellectual property (IP) issues are not usually barriers to those collaborations since industry participants typically find that considerable adaptation is required within their respective companies before innovations can be fully utilized.

Consortia are clearly the basis for future collaborations. They form networks that facilitate transfers of knowledge and technologies. Using patents as a surrogate for measuring those collaborations, people working in collaborative projects become familiar with each other's work and tend to cross cite each other's work in patent applications (Cohen and Merrill, 2003). If you are part of a network because of collaborative projects or physical proximity, you have access to the resources of the network. If you are outside of the network you do not have the same access.

Consortia lend themselves to spillovers, i.e., the creation of knowledge in excess of that benefitting the immediate parties. Thus the formation of a strong technology center can contribute to the attraction of related industry with all of the associated research and economic benefits. The spillover effect can be seen, as one example, with the experience in the MIT Micro-Electro-Mechanical Systems (MEMS) effort to develop millimeter-scale sensors, actuators, and electronic components (Fig. 6).

Figure 6. Micro-Electro-Mechanical Systems (MEMS) consortium led by the Massachusetts Institute of Technology



Technology Transfer In. Discussions of technology frequently assume that there is a closed cycle in which advances progress logically from industry-based research to development to implementation. That oversimplified notion ignores potentially major sources of advances – advances in related fields, use of products or technologies from other fields, and off-the-shelf technologies. Recent advances in O&G, e.g., advances in analytics and visualization have helped formed the basis for 3-D seismic and subsalt imaging. Although it is difficult to put a monetary value on any individual topic, consider the following potential sources of O&G-relevant technologies:

- Computational Sciences

  - Analytics
  - Stimulation
  - Visualization
  - Imaging
  - Data Management
  - Search
  - Data Mining
  - Artificial intelligence
- Defense
  - Robotics
  - Visualization
  - Targeting
  - Communications networking
- Management – Human Resources
  - Project management
  - Training and certification
  - Team behavior

Gore-Tex® technology offers examples where new applications developed in topical areas far removed from the original purpose of the invention. Although Gore-Tex® is widely recognized as a durable, water-repellant, yet breathable fabric that is favored for manufacture of extreme-weather garments, its microporous membrane structure makes it applicable also to microchemical sampling and analysis. Surface geochemical techniques for hydrocarbon exploration historically have been challenged to preserve samples taken in the field until they could be analyzed later in laboratory settings. Problems included compositional degradation through loss of volatile components or though incorporation of extraneous gaseous components after removal from the original soil environment. The technology underlying Gore-Tex® now forms the basis for membranes that can be used to improve sample preservation both for hydrocarbon exploration and for environmental monitoring. Gore-Tex® membranes incorporated into sample containers can protect the adsorbent, and maintain the sample integrity by protecting it from soil, liquid water, and other site or ambient interferences (Hodny et al., 2009; Anderson, 2006).

An additional source of technology transfer comprises technology that already exists but is not in use. The internal R&D process in most companies brings new technologies to a point where the advance must be evaluated to determine whether working on it further is worthwhile from a business point of view – the costs of moving out of the laboratory into full implementation can be very expensive. Many advances get put on the shelf at that point – the economics do not work or needed supporting technologies do not exist or they are not sufficiently relevant to current corporate strategic plans. Once in awhile, one of those technologies surfaces as a full or partial solution of a problem. Such was the case with hydraulic fracturing. While the potential for using 'on the shelf' technologies exists, few companies have any formal mechanism for periodically reviewing the intellectual property inventories and determining its potential.

The need for and desirability of technology transfer to move things from the laboratory to commercialization have been formally recognized. "Nearly everywhere, however, decisions affecting the bulk of R&D expenditures are made by industry, thus removing achievement of such a target from direct government control. In the United States, industry funds about 67% of all R&D (National Science Board, 2010). Towards that end, the federal government has passed a number of acts explicitly designed to encourage research-related cooperation between organizations (including commercial organizations), and to facilitate transfers of federally-funded research into the private sector (Table 5).

Table 5. Legislation facilitating technology transfer (National Science Board, 2010).

Legislation	Key Provisions
Technology Innovation Act of 1980 (Stevenson-Wydler)	Established technology transfer as a federal government mission by directing federal labs to facilitate then transfer federally-owned and originated technology to nonfederal parties.
University and Small Business Patent Procedures Act of 1980 (Bayh-Dole)	Permitted small businesses, universities, and nonprofits to obtain titles to inventions developed with federal funds. Permitted government-owned and government-operated laboratories to grant exclusive patent rights to commercial organizations.
Small Business Innovation Development Act of 1982	Established SBIR program requiring federal agencies to set aside funds for small businesses to engage in R&D connected to agency's mission.
National Cooperative Research Act of 1984	Encouraged US firms to collaborate in generic pre-competitive research by establishing a rule of reason for evaluating antitrust implications of research joint ventures.
Patent and Trademark Clarification Act of 1984	Amended Stevenson-Wydler and Bayh-Dole Acts regarding use of patents and licenses to implement technology transfer.
Federal Technology Transfer Act of 1986	Enabled federal laboratories to enter cooperative research and development agreements (CRADAs) with outside parties and to negotiate licenses for patented inventions made at the laboratory.
Omnibus Trade and Competitiveness Act of 1988	Added to intellectual property protection. Directed attention to public-private cooperation on R&D, technology transfer, and commercialization. Established National Institute of Standards and Technology (NIST) Manufacturing Extension Partnership program.
National Competitiveness Technology Transfer Act of 1989	Expands use of CRADAs to include government-owned, contractor-operated federal laboratories. Increased nondisclosure provisions.
National Cooperative Research and Production Act of 1993	Relaxed restrictions on cooperative production activities, which enable research joint venture partners to work together in the application of technologies they jointly acquire.
National Technology Transfer and advancement Act of 1995	Amended Stevenson-Wydler to make CRADAs more attractive to federal laboratories, scientists and private industry.
Technology Transfer Commercialization Act of 2000	Broadened CRADA licensing authority to make agreements more attractive to private industry and increase the transfer of federal technology. Established procedures for performance reporting and monitoring by federal agencies on technology transfer activities.
America COMPETES Act of 2007 (American Creating Opportunities to Meaningfully Promote Excellence in Technology, Education and Sciences)	Increased investment in R&D, strengthened educational opportunities in science, technology, engineering and mathematics. Further developed the nation's innovation infrastructure. Established NIST's Technology Innovation Program. Called for a President's Council on Innovation and Competitiveness

The federal legislation summarized in Table 5 led to major steps within government agencies, all focused specifically on stimulating technology innovation, transfer and exploitation:

- Technology-related federal departments have technology transfer offices specifically charged with identifying technologies and facilitating their movement into the commercial sector.

- Cooperative research and development agreements (CRADAs) permit federal agencies and laboratories to work with private organizations on collaborative research, with the private organization having the ability to own the resulting intellectual property and the federal agency receiving a non-exclusive license for its use.

- Essentially all major universities have technology transfer offices focused on identifying, protecting and commercializing intellectual property, even where the underlying research was funded by the federal government (AUTM, 2011).

- The National Institute of Standards and Technology (NIST) Advanced Technology Program (now replaced by the Technology Innovation Program) provides funding and other assistance for high-risk, high-payoff innovations that would otherwise be too risky to attract venture capital (NIST, 2011).

- The Federal Laboratory Consortium (FLC) was organized in 1974 and formally chartered by the Federal Technology Transfer Act of 1986 to promote and strengthen technology transfer nationwide. Today, more than 250 federal laboratories and centers and their parent departments and agencies are FLC members (FLC, 2011). DOE national laboratories are members of the FLC consortium.

Figure 7 summarizes metrics that have been developed for evaluating progress of the US federal government programs with regard to technology transfer.

Figure 7. Technology transfer metrics for US federal government programs (National Science Board, 2010).

Federal Technology Transfer: Activities and Metrics

Federal technology transfer can take a variety of forms (FLC 2006), including the following:

- *Commercial transfer.* Movement of knowledge or technology is developed by a federal lab and transferred to private organizations in the commercial marketplace.
- *Scientific dissemination.* Publications, conference papers, and working papers are distributed, and other forms of data dissemination are employed.
- *Export of resources.* Federal lab personnel are made available to outside organizations with R&D needs through collaborative agreements or other service mechanisms.
- *Import of resources.* The federal lab brings in outside technology or expertise to enhance the lab's existing capabilities.
- *Dual use.* Technologies, products, or families of products with both commercial and federal applications are developed.

Most federal labs engage in all of these forms of technology transfer to some extent. The emphases and relative levels of each vary widely across the federal agencies, depending on the parent agency's mission, the lab's main areas of scientific and technological interest, typical clients, prevailing scientific/technical culture, and any special transfer authorities the agency may have been granted. For some agencies and their labs, the principal technology transfer thrust is patents, patent licenses, and material transfer agreements. Others emphasize traditional public dissemination of new scientific or technical knowledge and cooperative R&D relationships with outside organizations—with patenting and licensing activity taking place only when it is determined that private-sector investment in a new technology is needed to achieve development and commercialization goals.

Several metrics illustrate activities and agency priorities among three main classes of mechanisms. The *invention disclosure and patenting* category involves counts of invention disclosures filed (typically, an inventing scientist or engineer filing a written notice of the invention with the lab's technology transfer office), patent applications filed with the U.S. Patent and Trademark Office (or abroad), and patent awards received. The *licensing* category covers federal lab licensing of federal intellectual property, such as patents or copyrights, to outside parties to enable further development and commercialization, usually through the technology transfer office. For example, in recent years, DOE's government-owned, contractor-operated laboratories have increasingly used their special authority to transfer software technology through relatively quickly executed copyright license mechanisms. The third main category is *collaborative relationships for R&D*, including CRADAs.

Table 4-22
Federal laboratory technology transfer activity indicators, by selected U.S. agency: FY 2007

Technology transfer activity indicator	Total	DOD	HHS	DOE	NASA	USDA	DOC
Invention disclosures and patenting							
Inventions disclosed	4,486	838	447	1,575	1,268	126	32
Patent applications filed	1,824	597	261	693	105	114	7
Patents issued	1,406	425	379	441	93	37	4
Licensing							
All licenses, total active	10,347	460	1,418	5,842	1,883	339	217
Invention licenses	3,935	460	915	1,354	461	339	217
Other intellectual property licenses	6,405	0	460	4,488	1,422	0	0
Collaborative relationships for R&D							
CRADAs, total active	7,327	2,971	285	697	1	230	2,778
Traditional CRADAs	3,117	2,383	206	697	1	184	154
Other collaborative R&D relationships	9,445	0	0	0	2,666	4,084	2,695

CRADA = Cooperative Research and Development Agreement; DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; USDA = U.S. Department of Agriculture

NOTES: Other federal agencies not listed but included in total: Department of the Interior, Department of Transportation, Department of Veterans Affairs, and Environmental Protection Agency. Department of Homeland Security expected to provide technology transfer statistics starting in FY 2008. Invention licenses refers to inventions that are/could be patented. Other intellectual property refers to intellectual property protected through mechanisms other than a patent, e.g., copyright. Total active CRADAs refers to agreements executed under CRADA authority (15 U.S.C. 3710a). Traditional CRADAs are collaborative R&D partnerships between a federal laboratory and one or more nonfederal organizations. Federal agencies have varying authorities for other kinds of collaborative R&D relationships.

SOURCE: National Institute of Standards and Technology, Federal Laboratory Technology Transfer, Fiscal Year 2007, Summary Report to the President and the Congress, January 2009, http://patapsco.nist.gov/ts/220/external/index.htm, accessed 6 May 2009. See appendix table 4-43.

Science and Engineering Indicators 2010

C. Training

O&G activities are increasingly dependent upon the use of advanced technologies. It is thus essential that there be an adequate supply of workers that can understand the new technologies, along with their limitations and uses.

It is important that people working in an industry such as O&G will be adequately trained. This, in turn means that several conditions must be satisfied: (1) participants must have the proper skills needed to enter the courses; (2) the proper material must be contained in the courses; (3) the materials must be delivered in an appropriate and satisfactory manner; (4) there must be assurance that participants have an agreed-upon level of comprehension; and (5) there must be assurance that participants can use the new skills/knowledge on the job. Stated differently, there is a need for some form of certification at every stage of training.

The technology sociologist, Charles Perrow provided an excellent framework for understanding technology progress and related risks (Perrow, 1984). His thesis is very simple to understand:

- There is no such thing as a system that is totally risk-free. No matter how we work to reduce the likelihood of failure, there is always some (hopefully) minimal probability that some time, some place, there will be a failure. (Indeed, he calls them, “normal accidents”).

- Systems grow over time, adding more and more parts to the overall structure.

- Two things take place as these systems grow. First, the parts are generally connected together mechanically or electronically. From an engineering point of view, they are ‘tightly coupled’ and actions in one part rapidly impact other parts of the overall system. And second, as the system grows, it becomes more complex and less understandable by any one person or even a group of people.

- Shift now to the human aspects of this same process. Since there is no such thing as a totally reliable system, problems do take place. Perrow goes on to argue that people have a positive bias -- when faced with something that is ambiguous, they tend to interpret the event in a positive sense until there is clear evidence to the contrary. Rather than immediately sounding an emergency alarm, they ‘wait and see what is really going on.’ Moreover, this phenomenon is made worse because people think or are made to think that they have limited responsibility.

- The conclusion to Perrow’s thesis is that when there are problems, the early symptoms will probably be missed or ignored, and any reaction that takes place will be to the irrefutable problems caused by the spread of failures. Perrow’s conclusion is illustrated with case studies of Three Mile Island, Chernobyl, Space Shuttle *Challenger*, Exxon Valdez, the Iraq War and many other similar situations. There is no doubt that, if he were revising his book today, he would include the *Deepwater Horizon* incident..

After the *Deepwater Horizon* incident, which involved the Macondo well blowout and oil spill in the Gulf of Mexico in 2010, BP released the results of an internal study (BP, 2010)which identified a sequence of errors leading to the disaster.

- The annulus cement barrier did not isolate the hydrocarbons.
- The shoe track barriers did not isolate the hydrocarbons.
- The negative-pressure test was accepted although well integrity had not been established.
- Influx was not recognized until hydrocarbons were in the riser.
- Well-control response actions failed to regain control of the well.
- Diversion to the mud gas separator resulted in gas venting onto the rig.
- The fire and gas system did not prevent hydrocarbon ignition.
- The blowout preventer (BOP) emergency mode did not seal the well.

Through a review of rig audit findings and maintenance records, the investigative team found indications of potential weaknesses in the testing regime and maintenance management system for the BOP.

The team did not identify any single action or inaction that caused this accident. Rather a complex and interlinked series of mechanical failures, human judgments, engineering design, operations implementation and team interfaces came together to allow the initiation and escalation of the accident. Multiple companies, work teams and circumstances were involved over time.

The investigation team developed a series of recommendations to address each of the key findings. The recommendations were intended to enable prevention of similar accidents in the future, and in some cases, they addressed issues beyond the causal findings for this accident. The recommendations covered contractor oversight and assurances, risk assessment, well monitoring and well-control practices, integrity testing and BOP system maintenance, among other issues.

The conclusion of the BP investigation was, in effect, that the *Deepwater Horizon* disaster had all of the components of Perrow's 'normal accidents' – engineering failure, complexity, understandability and organizational failures. Most significantly, in this day and age, it adds an additional layer comprising a complex network of subcontractors.

The bottom line is that, no matter how we deal with the engineering and human errors (and we must), under normal circumstances, there can always be accidents.

Given the seriousness of human actions, one must look implement quality control, namely, certification, for the preparation and delivery of training programs for people dealing with O&G activities. Even so, certification is a difficult process. Training takes place in many different ways, including on-the-job training, reading manuals or taking formal courses. Over time, the training process per se has become more automated and more interactive. The field now includes webinars, DVDs and more recently, participation in simulations. While there is little industry-specific data regarding those approaches, the general training literature claims that the more interactive approaches are more effective in terms of retention, the ability to apply new skills and the ability of trainees to generalize knowledge to newly learned areas.

It is important to recognize also that training can take place in many different places, ranging from more traditional delivery locations – schools, internal courses, industrial conferences – to remotely delivered webinars as well as specialized facilities such as simulators. Examples of the latter are routinely found in the military, aircraft industry and nuclear utility industry.

RESEARCH AND DEVELOPMENT SPECIFIC TO ENERGY

A. Department of Energy (DOE) Placement in Federal R&D

The Department of Defense (DoD) gets the largest allocation of US Federal R&D funds, followed by the National Institutes of Health (NIH) and then DOE (Table 6, Fig. 8). A relatively small portion of the total federal R&D budget is allocated to energy-related research (National Science Board, 2010) and there are several significant characteristics that are important to O&G interests:

- After DoD, Health and Human Services (largely NIH) and NASA, DOE has the largest R&D budget in the federal government.

- DOE invests more in basic and applied research than any federal agency other than NIH and NSF.

- DOE invests more resources in FFRDCs than any other federal agency. FFRDCs get 66% of the DOE R&D budget and is partially explained by the need for specialized equipment and facilities that are only available at DOE labs and FFRDCs.

DOE is a major player in technology transfer activities such as those noted above.

B. DOE Core R&D Programs

The National Energy Technology Laboratory (NETL), which is part of DOE's national laboratory system, supports DOE's mission to advance the national, economic, and energy security of the United States (NETL, 2011). NETL implements a broad spectrum of energy and environmental R&D programs that emphasize domestic coal, natural gas, and oil to economically power our Nation's homes, industries, businesses, and transportation while protecting our environment and enhancing our energy independence.

Table 6. US Federal government R&D expenditures among agencies (National Science Board, 2010).

Table 4-7
Federal budget authority for R&D and R&D plant: FY 2008–10
(Millions of current dollars)

Performer/character of work	FY 2008 Actual	FY 2009 Enacted	FY 2009 ARRA[a]	FY 2010 Requested	Annual change (%)[b] 2008–09	Annual change (%)[b] 2009–10
All R&D, R&D facilities and equipment	143,746	147,065	18,335	147,620	2.3	0.4
DOD (military)	82,278	81,616	300	79,687	–0.8	–2.4
HHS	29,265	30,415	11,103	30,936	3.9	1.7
NIH	28,547	29,748	10,400	30,184	4.2	1.5
All other HHS R&D	718	667	703	752	–7.1	12.7
NASA	11,182	10,401	925	11,439	–7.0	10.0
DOE	9,807	10,621	2,446	10,740	8.3	1.1
NSF	4,580	4,857	2,900	5,312	6.0	9.4
USDA	2,336	2,421	176	2,272	3.6	–6.2
DOC	1,160	1,292	411	1,330	11.4	2.9
NOAA	625	700	1	644	12.0	–8.0
NIST	498	550	410	637	10.4	15.8
VA	960	1,020	0	1,160	6.3	13.7
DHS	995	1,096	0	1,125	10.2	2.6
DOT	875	913	0	939	4.3	2.8
DOI	683	692	74	730	1.3	5.5
USGS	586	611	74	649	4.3	6.2
EPA	551	580	0	619	5.3	6.7
ED	313	323	0	384	3.2	18.9
All other	761	818	0	947	7.5	15.8
Research	56,026	58,647	13,285	59,023	4.7	0.6
Basic	28,613	29,881	11,365	30,884	4.4	3.4
Applied	27,413	28,766	1,920	28,139	4.9	–2.2
Development	83,254	83,887	1,408	84,054	0.8	0.2
R&D facilities and equipment	4,466	4,531	3,642	4,543	1.5	0.3
Defense R&D	84,337	85,426	300	83,760	1.3	–2.0
Nondefense R&D	59,409	61,639	18,035	63,860	3.8	3.6
All R&D, R&D facilities and equipment (2000 constant $millions)	117,286	118,267	14,745	117,532	0.8	–0.6

ARRA = American Recovery and Reinvestment Act; DHS = Department of Homeland Security; DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; DOI = Department of the Interior; DOT = Department of Transportation; ED = Department of Education; EPA = Environmental Protection Agency; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NIST = National Institute of Standards and Technology; NOAA = National Oceanic and Atmospheric Administration; NSF = National Science Foundation; USDA = U.S. Department of Agriculture; USGS = U.S. Geological Survey; VA = Department of Veterans Affairs

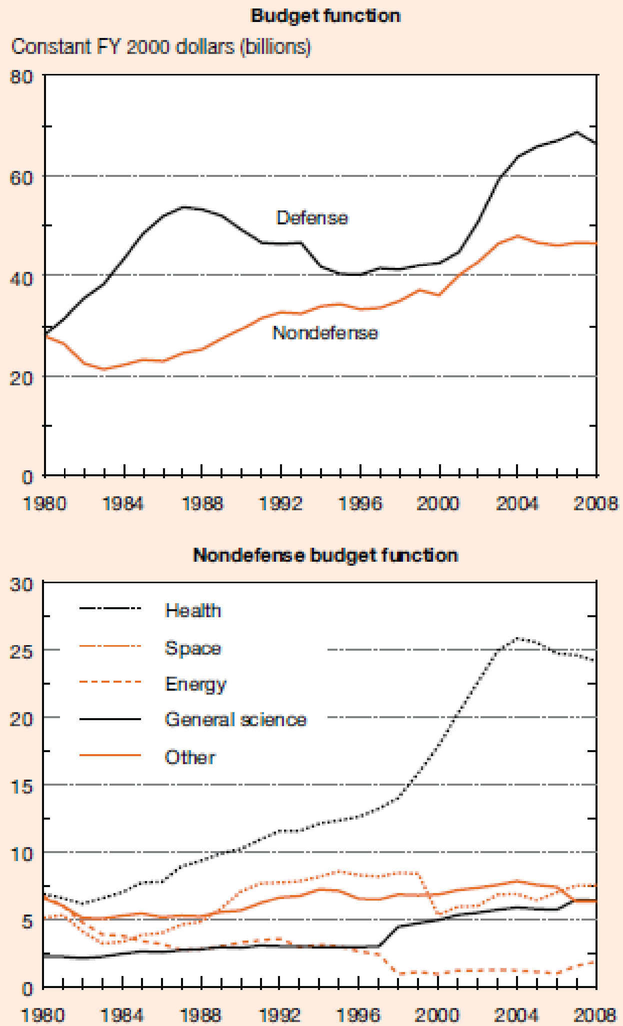
[a]Based on preliminary allocations of ARRA. These figures may change.
[b]Excludes appropriations from ARRA. Change is FY 2008 actual appropriations to FY 2009 enacted appropriations; FY 2009 enacted appropriations to FY 2010 requested appropriations.

SOURCES: Office of Management and Budget, Budget of the United States Government for Fiscal Year 2010, 7 May 2009; and Office of Science and Technology Policy, Executive Office of the President, Federal R&D, Technology, and STEM Education in the 2010 Budget, 7 May 2009.

Science and Engineering Indicators 2010

Figure 8. Proportions and trends of US Federal R&D expenditures by agency (National Science Board, 2010).

Figure 4-7
Federal R&D budget authority, by budget function: FY 1980–2008

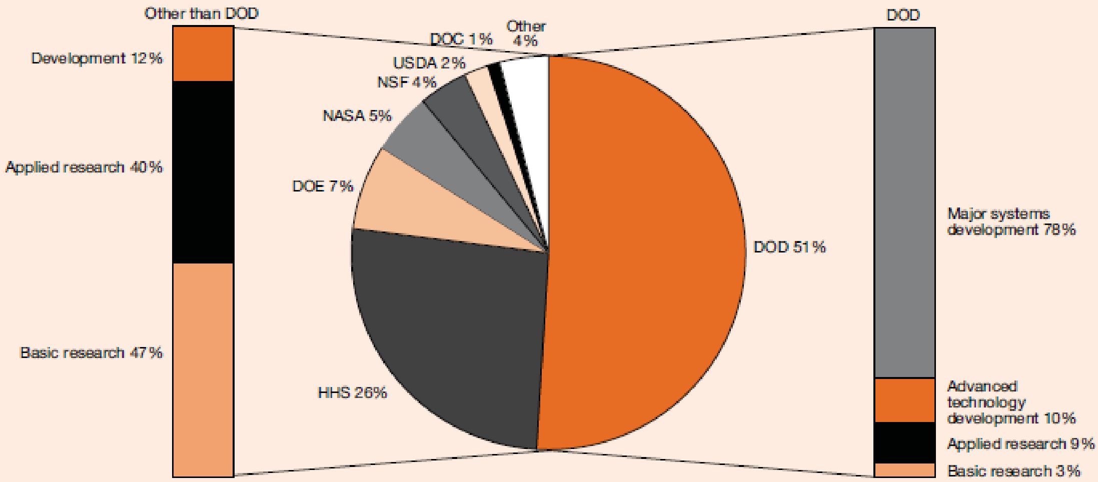


NOTES: Figures for FY 2008 are preliminary. Other includes all nondefense functions not separately graphed, such as agriculture and transportation. 1998 increase in general science and decrease in energy, and 2000 decrease in space were results of reclassification.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Federal R&D Funding by Budget Function: Fiscal Years 2007–09. See appendix table 4-17.

Science and Engineering Indicators 2010

Figure 4-8
Projected federal obligations for R&D, by agency and character of work: FY 2008



DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = Department of Agriculture

NOTE: Detail may not add to total because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Statistics, Federal Funds for Research and Development: Fiscal Years 2007–09. See appendix table 4-30.

Science and Engineering Indicators 2010

Table 4-8
Federal obligations for research and development, by agency and character of work: FY 2008
(Millions of current dollars)

Agency	Obligations for total R&D	Basic research	Applied research	Development	Basic research (%)	Applied research (%)	Development (%)
All federal government	114,625	27,559	27,538	59,528	24.0	24.0	51.9
DOD	58,676	1,510	5,345	51,821	2.6	9.1	88.3
HHS	29,657	15,989	13,594	74	53.9	45.8	0.2
DOE	8,212	3,243	2,917	2,052	39.5	35.5	25.0
NASA	6,243	1,298	829	4,117	20.8	13.3	65.9
NSF	4,031	3,692	340	0	91.6	8.4	0.0
USDA	2,357	990	1,197	170	42.0	50.8	7.2
DOC	1,062	108	861	93	10.2	81.1	8.8
DOT	885	3	638	245	0.3	72.0	27.7
DHS	847	191	77	579	22.5	9.1	68.3
DOI	625	43	513	68	6.9	82.1	10.9
EPA	557	97	379	81	17.4	68.1	14.5
VA	480	211	246	23	44.0	51.2	4.8
ED	325	4	202	119	1.3	62.0	36.7
Smithsonian Institution	148	148	0	0	100.0	0.0	0.0
AID	138	6	132	0	4.1	95.9	0.0
All other	382	26	270	86	6.9	70.6	22.5

AID = Agency for International Development; DHS = Department of Homeland Security; DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; DOI = Department of the Interior; DOT = Department of Transportation; ED = Department of Education; EPA = Environmental Protection Agency; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = U.S. Department of Agriculture; VA = Department of Veterans Affairs

NOTES: Table lists all agencies with R&D obligations greater than $100 million in FY 2008. Figures for FY 2008 are preliminary.

SOURCE: NSF, Division of Science Resources Statistics, Federal Funds for Research and Development: Fiscal Years 2007–09.

Science and Engineering Indicators 2010

.

.

Table 4-7
Federal budget authority for R&D and R&D plant: FY 2008–10
(Millions of current dollars)

Performer/character of work	FY 2008 Actual	FY 2009 Enacted	FY 2009 ARRA[a]	FY 2010 Requested	Annual change (%)[b] 2008–09	Annual change (%)[b] 2009–10
All R&D, R&D facilities and equipment	143,746	147,065	18,335	147,620	2.3	0.4
DOD (military)	82,278	81,616	300	79,687	–0.8	–2.4
HHS	29,265	30,415	11,103	30,936	3.9	1.7
NIH	28,547	29,748	10,400	30,184	4.2	1.5
All other HHS R&D	718	667	703	752	–7.1	12.7
NASA	11,182	10,401	925	11,439	–7.0	10.0
DOE	9,807	10,621	2,446	10,740	8.3	1.1
NSF	4,580	4,857	2,900	5,312	6.0	9.4
USDA	2,336	2,421	176	2,272	3.6	–6.2
DOC	1,160	1,292	411	1,330	11.4	2.9
NOAA	625	700	1	644	12.0	–8.0
NIST	498	550	410	637	10.4	15.8
VA	960	1,020	0	1,160	6.3	13.7
DHS	995	1,096	0	1,125	10.2	2.6
DOT	875	913	0	939	4.3	2.8
DOI	683	692	74	730	1.3	5.5
USGS	586	611	74	649	4.3	6.2
EPA	551	580	0	619	5.3	6.7
ED	313	323	0	384	3.2	18.9
All other	761	818	0	947	7.5	15.8
Research	56,026	58,647	13,285	59,023	4.7	0.6
Basic	28,613	29,881	11,365	30,884	4.4	3.4
Applied	27,413	28,766	1,920	28,139	4.9	–2.2
Development	83,254	83,887	1,408	84,054	0.8	0.2
R&D facilities and equipment	4,466	4,531	3,642	4,543	1.5	0.3
Defense R&D	84,337	85,426	300	83,760	1.3	–2.0
Nondefense R&D	59,409	61,639	18,035	63,860	3.8	3.6
All R&D, R&D facilities and equipment (2000 constant $millions)	117,286	118,267	14,745	117,532	0.8	–0.6

ARRA = American Recovery and Reinvestment Act; DHS = Department of Homeland Security; DOC = Department of Commerce; DOD = Department of Defense; DOE = Department of Energy; DOI = Department of the Interior; DOT = Department of Transportation; ED = Department of Education; EPA = Environmental Protection Agency; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NIST = National Institute of Standards and Technology; NOAA = National Oceanic and Atmospheric Administration; NSF = National Science Foundation; USDA = U.S. Department of Agriculture; USGS = U.S. Geological Survey; VA = Department of Veterans Affairs

[a]Based on preliminary allocations of ARRA. These figures may change.
[b]Excludes appropriations from ARRA. Change is FY 2008 actual appropriations to FY 2009 enacted appropriations; FY 2009 enacted appropriations to FY 2010 requested appropriations.

SOURCES: Office of Management and Budget, Budget of the United States Government for Fiscal Year 2010, 7 May 2009; and Office of Science and Technology Policy, Executive Office of the President, Federal R&D, Technology, and STEM Education in the 2010 Budget, 7 May 2009.

Science and Engineering Indicators 2010

NETL has expertise in coal, natural gas, and oil technologies, contract and project management, analysis of energy systems, and international energy issues.

In addition to research conducted onsite, NETL's project portfolio includes R&D conducted through partnerships, cooperative research and development agreements, financial assistance, and contractual arrangements with universities and the private sector. Together, those efforts focus a wealth of scientific and engineering talent on creating commercially viable solutions to national energy and environmental problems

NETL is a major component in the US energy research picture. It is the only DOE national lab dedicated to fossil energy and its research encompasses fundamental science through technology demonstrations. As such, it is a strategic center for research in natural gas and oil. It has a long history of successes that include:

- Development of electromagnetic telemetry (the need for non-wireline, non-mud-based communication in air-filled, horizontal or high-angle wellbores; problems with drill-pipe-conveyed and hybrid-wireline alternatives).
- Development of wired drill pipe (addressed a need for high data rate communications allowing high-resolution downhole drilling information to inform decisions in real time).
- Development of fracture mapping (absence of a method for measuring the length and orientation of a propped hydraulic fracture).
- Focus on activities carried out in collaboration with commercial enterprises and resulted in commercial applications.

DOE disclosed, applied for and received more patents than any other federal agency. It executed more invention and intellectual property licenses than any other federal agency. While it is a major participant in CRADAs, it is involved in significantly fewer than DoD and the Department of Commerce.

C. DOE Special Initiatives

Initiatives taken by DOE build upon the role of the federal government in basic research, the need for collaboration and the need to facilitate movement of relevant research from the laboratory to practical use. DOE's efforts are illustrated by three initiatives with unique characteristics and roles of each of the three new energy R&D modalities:

1. Energy Innovation Hubs will each comprise a large set of investigators spanning science, engineering, and policy disciplines focused on a single, critical national need identified by the DOE. Top talent drawn from the full spectrum of R&D performers -universities, private industry, non-profits, and government laboratories - will drive each Hub to become a world-leading R&D center in its topical area. Each Hub's management structure must allow empowered scientist-managers to execute quick decisions to shape

the course of research. With robust links to industry, the highly integrated Hubs will bridge the gap between basic scientific breakthroughs and industrial commercialization. Initial awards will be openly competed among R&D performers and are for $22 million in the first year and $25 million in years two through five, for a maximum of $122 million over the five-year term, subject to Congressional appropriations.

2. Energy Frontier Research Centers advance fundamental science relevant to real-world energy systems. Each focuses on the long-term basic research needed to overcome roadblocks to revolutionary energy technologies in a particular area. They are mostly multi-institutional centers composed of a self-assembled group of investigators, often spanning several science and engineering disciplines. This research is both "grand challenge" and "use inspired" fundamental science motivated by the need to solve a specific problem, such as energy storage, photoconversion, CO_2 sequestration, etc. The choice of topics was at the discretion of the applicants in response to a funding opportunity announcement (FOA) that solicited broadly across grand challenge and use inspired science. The funding range is $2-5 million per year per project.

3. ARPA-E supports research that is of potentially very high commercial impact but is deemed too risky for industrial investments. ARPA-E follows the Defense Advanced Research Projects Agency (DARPA) highly entrepreneurial approach to mission-oriented R&D by funding scientists and technologists (sometimes by forging and nurturing partnerships of its own design) to accelerate an immature energy technology with exceptional potential beyond the risk barriers that prevent its translation from the bench to the marketplace. ARPA-E will not fund discovery science nor will it support incremental improvements to current technologies. Its federal program managers take a "hands on" approach to managing the activities of R&D performers. The funding range per project may be as low as $500,000 or as high as $10 million. Projects will be selected on their potential to make rapid progress towards commercialization and will not be extended without demonstrable progress in a 2-3 year timeframe.

Table 7 provides additional comparisons and contrasts.

Table 7. Characteristics and roles of each of the three new energy DOE R&D modalities

Attribute	**Energy Innovation Hubs**	**Energy Frontier Research Centers**	**ARPA-E Projects**
Investigators and their institutions	Large set of investigators spanning multiple science and engineering disciplines and possibly including other non-science areas such as energy policy, economics, and market analysis. May be led by Labs or universities, nonprofit organizations or private firms. The model is the three existing Office of Science Bio-energy Research Centers.	Self-assembled group of ~12-20 senior investigators. May be led by DOE laboratories or universities. About two thirds of 46 EFRCs are led by universities.	Single investigator, small group, or small teams.
Central vs. distributed locations	Lead institution must provide a central location and strong scientific leadership. There must be a culture of empowered central research management.	Mostly multi-institutional centers, but with a clearly defined lead institution responsible for management.	Variable depending on project.
Diversity of disciplines per award	Many	Several	Few
Period of award and management	5 years. Managed by Offices across DOE. A Board of Advisors consisting of senior leadership will coordinate across DOE.	5 years. Managed by the Basic Energy Sciences program in the DOE Office of Science.	1-3 years. Managed by ARPA-E, which reports to the Secretary of Energy.
Award Amount	~$22 million in the first year with up to $10 million for infrastructure start-up; ~$25 million per year in subsequent years.	$ 2-5 million per year	$ 0.5-10 million per year
Core motivation	Integrate from fundamental research through potential commercialization. The breadth and emphasis of activities will be influenced by the nature of the Hub. Some Hubs may place a greater emphasis on basic and applied research, while others may focus more on technology development. DOE determines the topical areas of the Hubs and FOAs are topic-specific.	Fundamental research with a link to new energy technologies or technology roadblocks. The investigators proposed the subject matter from among a large set of scientific grand challenges and energy-relevant topics identified in and the FOA.	High-risk translational research driven by the potential for significant commercial impact in the near-term. In general, DOE determines the topics of interest, except for the initial FOA, which was broad-based.

Using the Energy Innovation Hubs as an example, the Department of Energy planned to establish the following three Energy Innovation Hubs in FY 2010:

- Fuels from Sunlight
- Efficient Energy Building Systems Design
- Modeling and Simulation for Nuclear Reactors (DOE, 2011b).

Each Hub research focus area was selected based on the following considerations:

- The focus area represents a significant grand challenge where major advances are likely to have a material impact on energy production or usage, greenhouse gas emissions, and economic growth.
- Although the scientific community may have addressed the focus area for decades through research at the individual-investigator or group level, a large-scale coordinated, multidisciplinary, systems-level approach is needed to accelerate the pace of discovery and innovation to realize efficiency, manufacturability, deployment, and utilization of new energy solutions.

DOE established 46 Energy Frontier Research Centers (DOE, 2011a). Those Centers involve 54 academic institutions, 13 national laboratories, 5 independent research institutions and 1 business laboratory. Most Centers involve 3-5 organizations. Among those centers, only two appear to be dealing with issues closely related to O&G:

- Center for Frontiers of Subsurface Energy Security, led by The University of Texas at Austin (CFSES, 2011).
- Center for Catalytic Hydrocarbon Functionalization, led by The University of Virginia (CCHF, 2011).

There are no Hubs currently focused on the transition from the current fossil-based environment mix to alternative platforms that have been suggested. This omission leaves open the possibility that we will develop new platforms and have insufficient guidance regarding efficient and effective steps for getting there.

D. External Policy Inputs

The Energy Technology Innovation Policy Group in the Belfer Center of the Harvard Kennedy School analyzed US energy policies (Anadon et al., 2009). Their work produced the following recommendations related to O&G developments and interests:

1. Increase the Department of Energy (DOE) budget for energy research, development, and demonstration to $6,060 million in FY2010 (from $4,173 million in FR 2008).
    a. Of this amount, they recommend that $1,500 million be allocated to basic energy sciences and $1,700 million to fossil energy, with the remainder divided between electric transmission and distribution, energy efficiency, renewable energy, hydrogen, nuclear fission and nuclear fusion.
    b. The major portion of the fossil energy recommendation relates to carbon capture and storage (CCS).
2. Develop, publish and implement a comprehensive US energy innovation strategy.

3. Strengthen DOE’s capacity to manage an expanded, integrated federal energy R&D and demonstration enterprise.
4. Create mechanisms for managing both demonstration projects and high-risk, high potential R&D.
5. Encourage expanded private-sector investment in energy innovation.
6. Strengthen international cooperation in energy research.
7. Target and better coordinate incentives for large-scale deployment of energy technologies.

FINDINGS AND RECOMMENDATIONS

A. Findings on the Current State of R&D for O&G Development

<u>Funding is not Well Aligned with the Critical Role of O&G among Balanced National Priorities</u>. Federal funding for domestic energy-related research is low and there is a very small segment of the research funds directed towards oil and gas R&D. The low level of O&G-targeted R&D is not consistent with the fact domestic natural gas is viewed as an essential element in yielding short-term environmental benefits while moving towards a more environmentally benign energy portfolio. The majority of the funds dedicated to hydrocarbon-based energy R&D are focused on carbon capture and sequestration (CCS) rather than on minimizing the lifecycle footprint of O&G development.

An R&D portfolio focused on innovatively moving from the current energy mix to a mix more environmentally benign is critical at this time. The current project mix emphasizes renewable energy without adequate attention to a hydrocarbon-enabled transitional path to a renewable future.

Projects currently funded in the energy arena do not generally give explicit consideration to the important role of technology developments in related disciplines. Many of the current exploratory and development tools are the direct result of advances made in the computational sciences. Current problems facing oil and gas development have the common social science issues, such as risk perception, analysis and management, training, and certifications.

The majority of R&D that is relevant to O&G has been outsourced to private industry. That approach shifts the funding to projects with short-term commercial payoffs and makes funding levels excessively dependant on commercial economic forecasts and company profits rather than long-term national strategic objectives. R&D funds could be used to support the unique role of natural gas as a more environmentally benign available energy resource that is a strong complement to renewable energy resources. The R&D necessary to continue to drive a smaller lifecycle footprint would be accelerated if conducted at a federal level rather than by a single company. Federal funding for R&D links well to responsible federal land management due to the amount of gas development that occurs on federal lands.

Consortia Have Become the Dominant and Most Beneficial R&D Performance Platforms. Much of the current research taking place is done by a consortium of DOE, national labs, academic institutions and industry. This is essential from a financial point of view, improves the quality of the research, and accelerates transfer of research results into practical implementation. It is essential that this mix of implementers and the role played by the consortia be encouraged and managed. Technology transfer must be an important part of any research considerations. There is strong evidence that public-private consortia have benefits extending beyond a specific research area and stimulate economic growth in the areas surrounding the research labs (feeder companies and spin-offs and housing for partner organizations).

Communication of R&D Progress on Energy Topics Remains Ineffective. Much of the communication regarding energy-related research is taking place in a fragmented manner, for example at conferences, academic publications, professional publications, and industry or academic meetings. That fragmentation makes it difficult to identify and harness diverse sets of experts and research results. There is no central depository or index to research taking place in or being funded by the federal government.

Cross-Over of Other Technology into O&G is Under-Appreciated. Many advances have their origins in disciplines other than energy, per se. As an example, many of the current O&G practices would not be possible in the absence of advances that are more commonly thought of as the computational sciences, e.g., data management, pattern recognition, visualization and simulation. To date, there has been little explicit focus on research potential provided by new social media, web-based video and webinars.

Effectiveness of Training in O&G Technology Deployment is not Well Documented. It is difficult to determine the magnitude of training effort that takes place within the O&G industry. Most training takes place within companies, in professional divisions of universities, from private training companies, or on an ad hoc basis within conferences. Data are lacking for the overall O&G training effort (expenditures, man-hours), methods of delivery, or locations. It must be assumed that where the data exist, they are company-specific and maintained within individual company records.

It is difficult to determine whether the training that takes place focuses on needed areas, is timely, and is delivered adequately. There is no clearing house within which there might be a catalog of courses and delivery methods.

It is not possible to formulate any judgments regarding the skill levels of trainees. Data are lacking for evaluations of the training taking place. It must be assumed that at least some deliverers have evaluations at the ends of the courses. Those evaluation tools are not themselves evaluated, nor is there any record of trainee performance during a course.

B. Recommendations for Alternative R&D Approaches

The following is an alternative approach to funding R&D:

1. Federal funding of energy R&D could be increased for projects that are not subject to short-term economic and political cycles.

2. Federal funding of natural gas R&D related to minimizing the lifecycle footprint could be increased to recognize the key role of natural gas as a bridge fuel to a more renewable-energy-based society.

Funding commitments longer than 5 years (a current federal milestone), and with effective immunity from sentiment linked to seasonal or annual cycles of commodity behavior (a common public and political reaction), likely are necessary to solve the more difficult technology problems that have the longer-term benefits. For example, year-to-year volatility in oil and gasoline prices, should not be the standard by which O&G-related R&D is commenced or canceled. A long-term vision must prevail for accomplishing energy security and lifecycle reduction.

Natural gas is generally recognized as an important bridge in moving towards other fuel sources. Movement in that direction requires careful balancing of the potentials provided by new resources such as shale and deep gas, technologies such as hydraulic fracturing, environmental and regulatory concerns. No single company can justify undertaking all aspects of the necessary research. Security would be improved by decreasing the need for LNG imports. And finally, the federal government owns a lot of the resource and would be a major beneficiary of funds coming from its safe production.

DOE R&D initiatives should be revised to include more O&G involvement as follows:

- Continue to support ARPA-E with focus on high-risk and high-but assure that the ARPA-E includes research that addresses natural gas capabilities as a bridge to a renewable energy future.

- Establish an Energy Frontier Research Center or Hub (Hub) that is focused on low-environmental-impact O&G exploration, processing and use. Establishing a Hub will attract related labs, academic-research organizations and industry and will provide a critical mass of resources with considerable benefits from related fields, the economy and states. The combination of benefits should create the potential for utilizing diverse funding sources and for shifting on-going support to other organizations.

- Initiate a demonstration project to focus on mixed-source electric generation (coal, oil, natural gas, solar, wind, and nuclear) electric generation. The proposed project will identify issues, technologies and strategies for building upon both existing approaches and those being developed to move closer towards a low lifecycle environmental footprint energy portfolio.

- Identify, evaluate, communicate and present mitigation of risks associated with the use of energy alternatives. That holistic risk dialog can be accomplished with collaboration of energy researchers, environmental scientists, industry representatives, insurance risk experts, and representation of state and local governments.

Consortia and partnerships can be usefully improved by growing links between public-private research organizations working on energy innovations, research, and development. Particular emphasis could be placed on management and oversight, assuring consistency with a national energy strategy, assuring consistency within and between organizations, and providing guidelines addressing when public-private partnerships are the most effective form of relationship (as opposed, for example, to “work for hire” contracts).

A formal infrastructure should be created to facilitate communication between organizations and projects involved in O&G-oriented R&D. That relatively inexpensive effort could greatly enhance sourcing of assistance and sharing efforts, experiences and results. It has the potential to provide process-related research data, reduce duplication, facilitate technology transfer, and aid policy formulation and management. Most significantly, the technical tools already exist, e.g., the Internet, database management, data mining, social networks. The private sector organizations can take full responsibility for infrastructure development and management.

The federal government could organize an annual Energy Research Summit, which brings together leading researchers working in fields including but not limited to energy and in environmental, computer and social sciences. The annual WWW Conference is one example of such an effort although in a very different discipline.

Incorporate research and use of new media, behavioral sciences and organization behavior into research projects, thus adding efficiency to the research process and facilitating successful implementation of results

The federal government should make meaningful participation in setting standards for training in the industry. There should be an immediate effort to set standards for training in the O&G field. (The focus here is intentionally on ‘standards’ rather than specifics. Individual companies and circumstances may mandate different approaches and/or delivery systems. Nevertheless, the seriousness of O&G activities and public attention mandate that steps are taken to provide added assurance that the activities are carried out satisfactorily.) This effort should address content, trainee performance levels, along with company processes to monitor the level of the training effort.

.

REFERENCES

Anadon, L.D., Bunn, M., Jones, C., and Narayanamurti, V. (2010). U.S. Public Energy Innovation Institutions and Mechanisms: Status & Deficiencies. Harvard University, January 14, 2010, 8 p. http://belfercenter.ksg.harvard.edu/files/US-Public-Energy-Innovation-Institutions-and-Mechanisms.pdf

Anadon, L.D., Gallagher, K.S., Bunn, M., and Jones, C. (2009). Tackling U.S. Energy Challenges and Opportunities: Preliminary Policy Recommendations for Enhancing Energy Innovation in The United States. Energy Research, Development, Demonstration & Deployment Policy Project, Energy Technology Innovation Policy Group Harvard University, February 2009, 36 p. http://belfercenter.ksg.harvard.edu/files/ERD3_Energy_Report_Final.pdf

Anderson, H.S. (2006). Amplified Geochemical Imaging: An Enhanced View to Optimize Outcomes. European Association of Geoscientists & Engineers. *First Break, 24(8)*, p. 77-81. http://fb.eage.org/content.php?id=27070

Archibugi, D. and Michie, J. (1995). The Globalization of Technology: A New Taxonomy. *Cambridge Journal of Economics 19(1)*, p. 121-140.

AUTM (2011). Association of University Technology Managers. http://www.autm.net/

BP (2010). *Deepwater Horizon* Accident Investigation Report. BP Plc., September 8, 2010. 192 p. http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/incident_response/STAGING/local_assets/downloads_pdfs/Deepwater_Horizon_Accident_Investigation_Report.pdf

CCHF (2011). The Center for Catalytic Hydrocarbon Functionalization. College and Graduate School of Arts & Sciences, University of Virginia. http://artsandsciences.virginia.edu/cchf/

CFSES (2011). Center for Frontiers of Subsurface Energy Security. Center for Petroleum and Geosystems Engineering, The University of Texas at Austin. http://www.utcfses.org/

Cohen W. M. and Merrill S. A. (eds.) (2003) *Patents in the Knowledge-Based Economy*. National Research Council. ISBN: 978-0-309-08636-3, 352 p. http://www.nap.edu/catalog.php?record_id=10770

DOE (2011a). Energy Frontier Research Centers. US Department of Energy. http://www.er.doe.gov/bes/EFRC/index.html

DOE (2011b) Energy Innovation Hubs Q&A. US Department of Energy. http://www.energy.gov/hubs/qanda.htm

FLC (2011). About the FLC. Federal Laboratory Consortium for Technology Transfer. http://www.federallabs.org/home/about/

Freeman, C. (1991). Networks of Innovators: A Synthesis of Research Issues. *Research Policy 20(5)*, p. 499-514.

Hodny J. W., Whetzel J. E. Jr. and Anderson H. S. II (2009) Quantitative Passive Soil Gas and Air Sampling in Vapor Intrusion Investigations. Air & Waste Management Association, February 13, 209, 19 p. http://secure.awma.org/presentations/VaporIntrusion09/Papers/5-Hodny.pdf

Malerba, F. and Orsenigo, J. (1996). Schumpeterian Patterns of Innovation are Technology Specific. *Research Policy, 25(3),* p. 451-478. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V77-3VV58P9-B&_user=10&_coverDate=05%2F31%2F1996&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_searchStrId=1746253025&_rerunOrigin=scholar.google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=a138bff4c12da76a4e4a50992a6ea142&searchtype=a

National Science Board (2010). *Science and Engineering Indicators 2010*. NSB 10-01, National Science Foundation, Arlington VA. 566 p. http://www.nsf.gov/statistics/seind10/pdf/seind10.pdf

NETL (2011) About NETL. National Energy Technology Laboratory, US Department of Energy. http://www.netl.doe.gov/about/index.html

NIST (2011). Technology Innovation Program. National Institute of Standards and Technology, US Department of Commerce. http://www.nist.gov/tip/

Patel, P. (1995). Localised Production of Technology for Global Markets. *Cambridge Journal of Economics 19(1),* p. 144-153. http://cje.oxfordjournals.org/content/19/1/141.abstract

Patel, P. and Pavitt, K. (1997). The Technological Competencies of the World's Largest Firms: Complex and Path-Dependent, But Not Much Variety. *Research Policy, 26(2)*, p. 142-143. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V77-3SX28W2-1&_user=10&_coverDate=05%2F31%2F1997&_rdoc=1&_fmt=high&_orig=gateway&_origin=gateway&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=ad583f3aacd2ff4ed24fd002e61ce509&searchtype=a

Perrow, C. (1984). *Normal Accidents: Living with High-Risk Technologies*. Basic Books, New York. 386 p. ISBN 0-691-00412-9. http://books.google.com/books?id=VC5hYoMw4N0C&dq=Perrow,+C.+(1984).+Normal+Accidents:+Living+with+High-Risk+Technologies&lr=&sitesec=reviews

Rycroft, R.. (2003). Technology-Based Globalization Indicators: The Centrality of Innovation Network Data. *Technology in Society, 25(3)*, p. 299-317. http://www.mendeley.com/research/technologybased-globalization-indicators-centrality-innovation-network-data/