(Appendix contd.)

Dr. John Sieburth, Graduate School of Oceanography, University of Rhode Island.

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Appendix III

1974 Conference: "The Fourth Food-Drugs from the Sea Conference;" University of Puerto Rico, Mayaguez - November 17-21, 1974.

Honorary Chairman: The Hon. Cruz A. Matos, Secretary of Natural Resources, Commonwealth of Puerto Rico, San Juan, Puerto Rico.

Co-Chairman: Dr. Maximo Cerame-Vivas, Department of Marine Science, University of Puerto Rico, Mayaguez.

Dr. George D. Ruggieri, Director, Osborn Laboratories of Marine Science, New York Zoological Society, Brooklyn, New York.

Coordinators:
(For MTS) Mr. Earl Herron, HERCON, Inc., Chairman, Marine Biological Resources Committee.

General Coordinator: Mr. George F. Greene, Jr., Oceanographic Liaison, Abbott Laboratories, North Chicago, Illinois.

Coordinator:
(Food Papers) Dr. Harold H. Webber, Groton Bioindustries, Groton, Mass.

Coordinator:
(Drug Papers) Dr. Leonard R. Worthen, College of Pharmacy, University of Rhode Island, Kingston, Rhode Island.

General Committee:
Dr. Heber Youngken, Jr., Dean, College of Pharmacy, University of Rhode Island.

Dr. Edward Miller, Asst. Medical Director, Hoffmann-LaRoche, Inc., Nutley, N.J.

Dr. Stanley Hall, Department of Chemistry, Rutgers University, Newark, N.J.

Dr. Lewis Krimen, Scientific Liaison, Abbott Laboratories, North Chicago, Illinois.

Local Arrangements:
Dr. Robert Middlebrook, University of Puerto Rico, School of Marine Sciences, Mayaguez, Puerto Rico.

Ms. Janet Eckerling, Department of Natural Resources, Commonwealth of Puerto Rico, San Juan, Puerto Rico.

Mr. Rudy Sundberg, Manager, Abbott Chemicals, Inc., Barceloneta, Puerto Rico.

Mr. Jose Rodriguez, Personnel Manager, Abbott Chemicals, Inc., Barceloneta, Puerto Rico.

Dr. Francisco A. Pagan-Font; Acting Director, Department of Marine Sciences, University of Puerto Rico, Mayaguez.

THE ECONOMICS OF UNCONVENTIONAL ENERGY RESOURCES

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ABSTRACT

It is suggested that optimal energy policy requires the determination of an economically efficient mix of all available energy sources. An efficient resource allocation requires that each energy resource be used in each feasible application up to the point where incremental benefits equal incremental costs.

This paper introduces a classification scheme which separates energy resources into two classes, based on fundamental differences in basic economic properties; these classes are conventional nonrenewable resources and unconventional inexhaustible resources. The former are generally exhaustible, with positive user costs; they are scarce and command positive prices; they have a well-developed technology, are produced and sold by oligopolists, and have substantial environmental impacts.

The latter are generally inexhaustible, with nonpositive user costs; they are free public goods, are not scarce, and require no prices to allocate them among competing uses; they possess a pre-development technology with the necessity of further research and development expenditures to render them economically viable; and their use appears to have relatively minor environmental impacts.

Decision environments of investment in solar space heating, solar cells, wind energy, tidal power, and energy from thermal gradients are discussed briefly to demonstrate some of the tradeoffs that exist between the advantages and disadvantages of specific applications of inexhaustible energy resources.

Existing markets fail to achieve the optimal resource allocation of the perfectly competitive model. The oligopolistic structure of the conventional energy industry results in excess profits, a lower than optimal output, and higher than optimal price, making substitute sources of energy appear economically feasible though they may not be feasible from a cost-of-extraction standpoint. On the other hand, market failures associated with environmental externalities, government subsidies to conventional energy sources, uncertain ability of firms to capture benefits of technical advances, and intergenerational equity considerations all indicate that current and projected energy resource mixes may be biased toward conventional nonrenewable resources. Corrective policy decisions for achieving a socially optimal energy mix will require quantitative analysis of the trade-offs involved.

INTRODUCTION

Conventional energy resources such as fossil fuels and uranium are extracted from finite stocks of ores. Currently there are many unconventional energy resources receiving serious attention for commercial applications; these resources are exterrestrial flows of energy which are virtually inexhaustible, such as solar energy (as radiant energy, wind, currents, or the ocean thermal gradient) and tidal energy.

This paper will consider the question of the optimal conjunctive use of these conventional and unconventional energy resources from the standpoint of economic efficiency.

In Part I a classification scheme is introduced which emphasizes the dichotomy between conventional nonrenewable resources and unconventional inexhaustible resources. The relative advantages and disadvantages of several specific applications of inexhaustible resources are discussed in Part II. In Part III some of the policy implications of issues raised in the preceding sections are addressed.

I. CLASSIFICATION OF ENERGY RESOURCES

In analyzing the problem of optimal conjunctive use of energy resources, it is convenient and useful to categorize the resources into two groups; these are nonrenewable or exhaustible resources on the one hand and inexhaustible resources on the other.

Exhaustible resources are those which are in finite supply; use of a unit of this type of resource in any time period for the extraction of usable energy precludes use in all future time periods. Because of the consumptive and irreversible nature of fuel applications of these resources, use imposes a cost into perpetuity; this user cost reflects essentially three things: a) the stream of foregone benefits that the resource unit could have earned in future use; b) the scarcity value of the resource; and c) the present value of having a unit of the resource in stock at the end of the planning horizon. Economic efficiency requires that a unit of an exhaustible resource be used today only if the net benefits from current use exceed the user cost.

Conventional energy resources such as fossil fuels or uranium are nonrenewable; positive user costs are associated with their use. Finite stocks of available energy are depleted by the extraction of internal energy from these minerals. Residuals or wastes from extraction are at a lower state of internal energy and generally have no further productive use or value and so require disposal, or are released into the environment in the process of energy extraction and become various forms of air and water pollution.

In contrast, unconventional energy resources such as the sun or the tides are inexhaustible flows of available energy. The amount of energy available in any time period is independent of use in previous time periods. The user costs of these inexhaustible resources cannot be positive.

Further, inexhaustible resources are essentially free public goods; they occur in such abundance that use by one individual does not affect the amount available to other individuals. No scarcity price is required to allocate the resource among competing uses as with conventional resources, which implies that the only costs associated with energy from renewable resources are the costs of complementary factors of production such as land, labor, and capital.

Relative scarcity of the resource itself is only part of the picture, then. Other resource inputs will always be required for the location, recovery, storage, processing, or transportation of the energy itself so that it is in usable form at final consumption sites. The costs of these complementary factor inputs are central to any attempt to estimate the magnitude of net benefits generated from a particular application of a specific resource.

The conventional energy industry is in general capital intensive; high sustained levels of investment are required to maintain or increase throughput of conventional fuels. The capital equipment necessary for all phases of energy production from the conventional fuels is founded on a solid and expanding technological base. An industry based on inexhaustible energy resources also will probably be capital intensive. Capital equipment used to make energy from these sources available for use must in most cases embody new and expensive technology; initial plants and processes may require substantial prior expenditures for research and development.

Conventional energy sources have often been responsible for substantial environmental spillover costs in numerous phases of production and consumption. Some familiar examples are the results of strip mining, refinery effluents, offshore oil spills, unsightly skylines and coastlines, power plant emissions and effluents, and of course vehicle exhaust emissions. In addition to purely localized or regional impacts, there are also possible effects of a much larger scale. The possibility exists, for example, that small-particle emissions may constitute a health hazard that cannot be prevented by current stack gas scrubbing technology, and increased levels of CO_2 in the atmosphere may lead to global climatic changes, with possible major consequences. There is also the question of land use policy associated with the siting of energy industry components, from deep water ports for supertankers in sensitive coastal zones, to on-site shale oil plants in the Rocky Mountains.

In contrast, inexhaustible energy sources produce no waste materials at all, due primarily to the fact that energy is not obtained by lowering the internal energy of minerals as in conventional sources. Though there may be thermal effluents associated with an application such as solar thermoelectric power plants, there would be no emissions or effluents of waste substances. Environmental impacts, it appears, would be confined to navigation hazards or the altering in subtle ways of natural environments and local ecologies.

In summary, the essential differences in the decision environments of investment in conventional energy resources and inexhaustible energy resources are the following. Conventional resources are finite and exhaustible, with associated positive user costs; they are scarce, and require positive market prices to allocate them among competing uses; they require complementary factor inputs and are produced with a highly developed technology; social costs including environmental costs are greater than private costs of production and consumption.

On the other hand, unconventional resources are inexhaustible, so have nonpositive user costs; they are free public goods so have zero prices; they have an emerging technological base with high initial costs and uncertain returns; they probably have minimal environmental impacts.

II. DECISION ENVIRONMENT OF SELECTED RESOURCE APPLICATIONS

Solar Space Heating/Cooling

Systems for using solar energy for space heating and cooling are well-documented.[1] Essentially the system absorbs heat with a selectively coated flat plate collector; the heat is transferred to a working fluid such as air or water and circulated through a storage medium which is thus heated. The heat is withdrawn as necessary to maintain the desired temperature. With some modification, the system may be used for space cooling as well.[2]

The system has several positive features. It makes use of an inexhaustible resource; user costs are avoided, and primary fuel costs are eliminated. The system emits no wastes and is perfectly non-polluting. Operating costs are minimal for periodic maintenance. The annual cost compares favorably to a conventional system cost which would include both a substantial capital cost and a fluctuating fuel charge. Figure 1 shows comparative "pre-Crisis" costs of several heating systems.

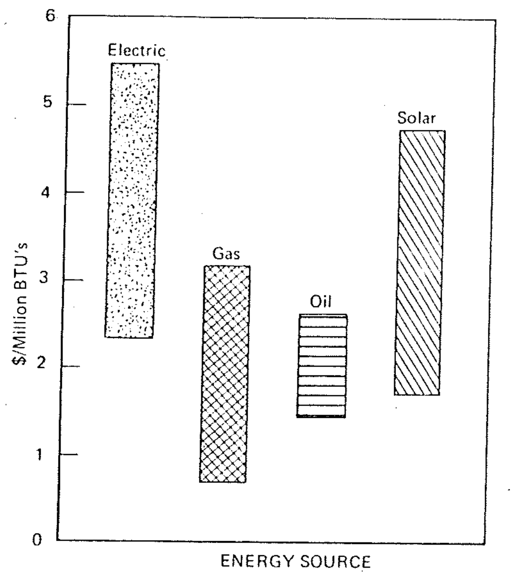

Figure 1. Cost Comparisons of Space Heating

Source: NSF/NASA Solar Energy Panel Report, "An Assessment of Solar Energy as a National Energy Resource," (College Park: University of Maryland Mechanical Engineering Department, 1972), as reproduced in P. E. Glaser and James C. Burke, "New Directions for Solar Energy Applications," (Boston: Arthur D. Little, Inc., 1973), p.10.

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[1] Farrington Daniels, Direct Use of the Sun's Energy, (New Haven: Yale University Press, 1964), Chapter 9.

[2] Interviews with Mr. Spencer Dickinson and Mr. William E. Smith of Solar Homes, Inc., Jamestown, Rhode Island, May 1974.

On the negative side, the system requires some secondary energy to power circulation pumps or fans. Reliability during extended periods of cloudiness requires either a full-scale backup climate control system or substantial reserve heat storage capacity. Some limitations are placed on design freedom of the architect in the interest of system efficiency, but in the future this is likely to affect future design of conventionally heated structures as well.

There could be a substantial peak-load problem placed on electric utilities if the system came into widespread use with electric power as the backup system. If adoption of solar heating on a large scale were to decrease total electricity consumed while at the same time demanding the existence of adequate capacity to meet the peak demand experienced in periods of adverse weather, unit rates for electricity would probably rise substantially. This follows from the tendency of utilities to use average-cost pricing, i.e., establishing rates to cover costs plus profit, where costs are largely fixed costs.

Because solar climate control is in its infancy, future component cost trends are highly uncertain; increased demand may force prices to rise beyond current projections, while technical advance and mass production economies may serve to lower costs quite dramatically. Thus the net benefits to society from a massive shift to solar heating (or cooling) from conventional systems are not amenable to assessment at present, except within broad bounds.

Solar Cells

It was implied above that electricity may be a poor choice for the power source used as a backup to the solar heating system. Conventional systems using fossil fuels on the premises, however, would also be undesirable because they would require another large capital expenditure for furnaces or burners. One possibility is to use a heat reservoir so large as to eliminate the need for a backup system. Another possibility is to produce electricity on-site, using solar heat engines, windmills, or solar cells.

Solar cells using light energy (photovoltaic cells) as a power source have been used extensively in the space program. Limited demand coupled with painstaking and expensive manufacturing procedures makes solar cells hundreds of times too expensive for widespread private use under current conditions. However, economies of scale in automated production together with advances in production technology could easily reduce costs enough for solar cells to be a competitive source of power.[3]

It is noted that silicon, the basic element in one type of solar cell, is among the most abundant elements on earth; the cells do not require intense sunlight to function, but work even under cloudy conditions; and they require no coolant medium as do thermal electric plants.

Unfortunately it is not known at how low a cost solar cells might eventually be produced. Another drawback is the requirement for electrical storage capacity for use during darkness. Advances in the technology of batteries, flywheels, and/or hydrogen production from water may alleviate this problem.

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[3] William R. Cherry, "Harnessing Solar Energy: The Potential," Astronautics and Aeronautics 11 (August 1973), p.34.

A particularly interesting solar cell application is a synchronous orbiting of satellites carrying vast arrays of solar cells, transmitting power via a microwave beam to Earth. Such a system would have the advantage of continuous sunlight undiminished by atmospheric effects; the cell array could be much smaller per kw of capacity than one on the ground. An operational space shuttle system could offer acceptable launching costs to make such a system competitive in the future. Environmental damage would be minimal. This system is receiving serious attention and could be providing some power by the end of the century.[4]

Wind Energy

Windmills are currently available for production of electricity on a small scale. Because of the high capital cost to the individual of the windmill, generator, converter, and batteries, their use as the primary source of power is contraindicated in areas where conventional energy sources are available. In areas not served by electric utilities, however, or as a supplement to other power systems in windy areas, it is conceivable that wind power may provide the most economical source of electricity.[5]

As with other inexhaustible sources, there is no fuel cost associated with wind power. Neither is there any effluent or emission of pollutants. But the stochastic nature of wind velocity will generally require supplemental energy, and this remains the main shortcoming of wind power.

Tidal Energy

Harnessing the energy in tidal movements is feasible only in a limited set of locations. Tidal ranges of the required order of magnitude occur only under a favorable combination of fairly high latitudes and conducive geography. Practical considerations require that structures to contain the water should be supplemented greatly by natural land formations.

Passamaquoddy Bay and Cobscook Bays, located in Maine and New Brunswick on the Bay of Fundy, where the greatest tidal ranges in the world are observed, are particularly well-suited to tidal power generation.[6] Extensive plans have been made for a 1 million kilowatt tidal power system at this site; a reassessment of this project incorporating contemporary cost figures and including all of the many indirect costs and benefits may be illuminating in view of the current prices of electricity in the Northeast.

Those few regions which possess characteristics favorable to the utilization of tidal power have potential benefits available to them from making full use of this inexhaustible resource; rigorous estimation of the costs and benefits of each potential project would seem to be in order wherever the tidal

[4]Peter E. Glaser, testimony in Space Shuttle Payloads, Hearings before the Committee on Aeronautical and Space Sciences, U. S. Senate, 93rd Congress, October 31, 1973, (Washington: U. S. Government Printing Office, 1973), pp. 11-62.

[5]Information provided by Solar Wind, Inc., East Holden, Maine.

[6]Stewart L. Udall, "The International Passamaquoddy Tidal Power Project and Upper Saint John Hydroelectric Power Development," (Washington: U. S. Department of the Interior, 1963), p. 13.

alternative seems feasible. Rising costs of conventional power and increasing energy demand are likely to make tidal systems an increasingly attractive supplement in some areas.

Environmental impacts of harnessing tidal power would be of an unusual nature and extremely difficult to quantify. A very large system could have a substantial impact on the marine ecosystem of the region. However, it was reported that the Passamaquoddy project would have no adverse effect on fish and wildlife; on the contrary, it was noted that power from the project would allow the elimination of many small and inefficient hydroelectric dams which currently block streams to the migration of anadromous fish, particularly the Atlantic salmon.[7]

Expected benefits of the "Quoddy" project included recreation and tourism benefits and flood control benefits as well as the value of power output. In addition, it was anticipated that the project would contribute to regional development of Maine's Washington County, which has historically been a target for area redevelopment due to low incomes and high unemployment.

Thermal Gradients

It is conceptually possible to derive useful energy wherever there is a temperature gradient. The concept was first applied to the ocean thermal gradient by Claude in 1929;[8] his experimental plant did work although equipment availability at that time and the small temperature difference at the site were such that the plant was never economically viable. Operationally, however, it clearly demonstrated that the temperature difference between warm surface waters and colder deep water could be used to generate power without conventional fuel. The principle could also be applied to temperature gradients between warm (cold) currents and the surrounding cold (warm) water. A particularly interesting feature of this system is that it could be used to produce a large amount of fresh water from sea water along with electric power.[9]

Technological problems with this approach are essentially ones of making systems more efficient. The limited temperature ranges allow efficiencies of only 1% or 2% with current technology.

The generator could be located ashore or offshore, feasibility being dependent on favorable shelf characteristics and water temperatures. The system produces no pollutants, but could conceivably have some adverse navigational effects. Effects on marine life would probably be slight, but should be investigated further.

POLICY IMPLICATIONS

Decision rules for the optimal conjunctive use of exhaustible and inexhaustible energy resources require that each re-

[7]Udall, p. 52.

[8]Georges Claude, "Power from the Tropical Seas," Mechanical Engineering 52 (December 1930).

[9]Donald F. Othmer and Oswald A. Roels, "Power, Fresh Water, and Food from Cold Deep Sea Water," Science 182 (12 October 1973).

source be used in each feasible application up to that point where the social benefit of the last unit used in each use is equal to the social cost of using that unit. Another way of expressing this concept is to say that each resource should be used in an application up to the point where the marginal net social benefit is equal to the marginal user cost.

The perfectly competitive market system is generally considered to produce an efficient resource allocation by the actions of a large number of individual producers and consumers as they respond to prices. No individual can affect the market price; the price is established through the interaction of total supply and total demand. This allows individual economic units to adjust the quantities they buy or sell to prevailing market prices so as to maximize their own benefits. In this way total benefits to society are a maximum, and each resource is used efficiently; i.e., only the highest-valued uses will be allocated units of the resource. The marginal use will be the one in which the net benefit of using the resource is zero, and the user just breaks even.

Government intervention in the markets for specific inputs or outputs is generally justified on the grounds that, left to itself, the market will fail to allocate resources in an economically efficient manner. There are several reasons for believing that energy markets will not function efficiently and will therefore not be conducive to an optimal set of resource allocations. If all of the associated market failures work in the same direction, either to an under-use or an over-use of a specific resource, then the direction of government policy would be quite clear, even though the magnitude of corrective action were to remain a difficult empirical question. In the case of energy resources, however, the situation is more complex.

On the one hand, it may be argued that existing markets will cause a too-rapid shift from conventional energy resources to inexhaustible resources. This is because of the oligopolistic nature of the existing energy market. Monopoly profits far in excess of production costs have led to a situation where the market prices of conventional fuels are so high that substitute forms of energy are beginning to appear attractive. This will lead to their adoption at a rate that is too high because the market price of conventional fuels is artificially high and includes rents to producing firms and nations.

On the other hand, there are a number of arguments to indicate that inexhaustible substitutes for conventional energy resources will be introduced too slowly.

First, there is a disparity between the social and private costs of production and consumption of conventional energy resources, which would be smaller for inexhaustible resources. The failure of firms to bear the costs of residuals disposal imposes a cost on society in the form of air pollution or water pollution. This disparity carries over into the consumption sector where motorists do not bear the costs of pollution created by their own vehicles, though they and the rest of society must bear the costs of related smog, traffic congestion, and noise. Because private costs are lower than social costs, producers tend to overproduce and consumers tend to overconsume conventional energy products relative to inexhaustible products; the market fails because it produces too much of the former and too little of the latter.

Second, entrepreneurs who would develop specific applications of inexhaustible resources must bid capital away from competing uses. The technological infancy of many applications

implies that substantial funding must be devoted to the development of commercially competitive systems. Private firms may be reluctant to undertake this investment either because of relatively high risk involved or because of uncertainty about being able to capture the benefits of an advance they have sponsored.

Third, certain applications of inexhaustible energy resources, such as the transmission of solar energy from collectors in space, are so large, so costly, and require development over such a long time horizon that private firms will be unwilling or unable to undertake them without government support. In this example, of course, government participation is essential for the orbiting of the stations; but precedent in the form of government subsidies such as the depletion allowance or the foreign tax credit, not to mention huge public expenditures on nuclear energy, would seem to demonstrate that firms might reasonably expect some public support of very large projects. Without it, of course, and in the face of continued support of conventional sources, allocation would be biased toward conventional sources.

Fourth, since future generations have no dollar votes in today's markets, except through the rate of time preference used to discount resource uses, it may be argued from the point of view of intergenerational equity that extractive resources are being overexploited. That is, since firms make extraction decisions based on the market rate of interest, and since there are reasons for supposing that the market rate is higher than the social rate of time preference, they will deplete their resource stocks too quickly.[10]

One may feel fairly comfortable with the conclusion that the allocation of energy resources is probably not optimal. The direction and magnitude of future policy aimed at generating an efficient mix of conventional and inexhaustible energy resources are not at all clear, however.

SUMMARY AND CONCLUSIONS

It has been suggested that the categorical differences between finite energy resources on the one hand and inexhaustible energy resources on the other hand are substantial. Several specific applications of inexhaustible resources have been described in order to exemplify the decision environment of investment in particular cases. Arguments have been presented which imply that existing markets cannot be relied upon to bring about an efficient allocation of energy resources; government intervention in the market may be justified if the resultant allocation of resources increases efficiency.

But what mix of conventional and inexhaustible energy resources is socially optimal today? How will the optimal mix change over time? These questions might be approached by a rigorous economic analysis of the complete set of available energy alternatives within a framework which explicitly recognizes the likely range and timing of technological advances. Such analysis must also include the quantification of many intangibles such as amenity benefits and costs associated with various energy sources and the question of intergenerational distribution; these are complex issues and their resolution is not likely to be free of subjective assumptions.

[10] Robert M. Solow, "The Economics of Resources or the Resources of Economics," American Economic Review: Papers and Proceedings 64 (May 1974), p. 8.

The important role of energy policy in shaping socioeconomic structure and behavior underscores the need for policy makers to be equipped with extensive information on the tradeoffs associated with various energy resource mixes if their actions are to result in an increase in social well-being.

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PROCESS FOR DETERMINING THE FEDERAL ROLE IN STIMULATING DEVELOPMENT OF OCEAN ENERGY TECHNOLOGIES

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ABSTRACT

This paper examines the economic and technical considerations which need to be taken into account when determining the type and scope of federal support for ocean energy technologies. It begins with assumptions concerning federal energy objectives and outlines the questions which need to be answered in designing a plan for government involvement in stimulating specific ocean technologies.

Briefly, energy supply/demand scenarios are mentioned and the state of each ocean energy technology is reviewed; but more importantly the need for accurate cost/benefit analyses of each technology, as compared with alternative new source technologies, is emphasized. For instance, how much energy can be expected from ocean current technologies, in what time frame, and at what cost? Do we know enough about the technical limitations and other impediments to development to estimate these costs and benefits? Such information is necessary for making trade-off decisions among alternative technical solutions to the energy dilemma. If following such a cost/benefit analysis we find that a certain degree of support for ocean energy can be profitably pursued, hopefully we can then determine how best to spend government resources to insure the development and full utilization of each such technology. This last step, determining the extent and type of government financial and technical involvement, is the primary focus of the paper.

Ocean technologies can be said to be at various stages along the innovation process line,[1] and different government mechanisms[2] for stimulating innovation are appropriate depending on, among other things, the stage of innovation, existing public/private involvement, and the risk or uncertainty of projects associated with each technology. Some attempt is made to isolate the characteristics of each ocean energy technology which must be considered in determining the kinds of government instruments best suited for stimulating innovation for that particular ocean energy system. A whole host of instruments will be mentioned[2] and the pros and cons of the more feasible will be presented as they pertain to the various energy technologies considered. Only with this kind of analysis will federal policy-makers be able to design a program best suited for stimulating those technologies which are able to make a significant contribution to our future energy economy.

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[1] Innovation is used in its traditional meaning of first (commercial) use of technology while innovation process refers to the activities from basic research through adoption by potential users of the technology. A simple linear model of the process of technological innovation proceeds:

Basic Research ⟶ Applied Research ⟶ Development ⟶ Innovation ⟶ Diffusion

[2] See Figure 1.