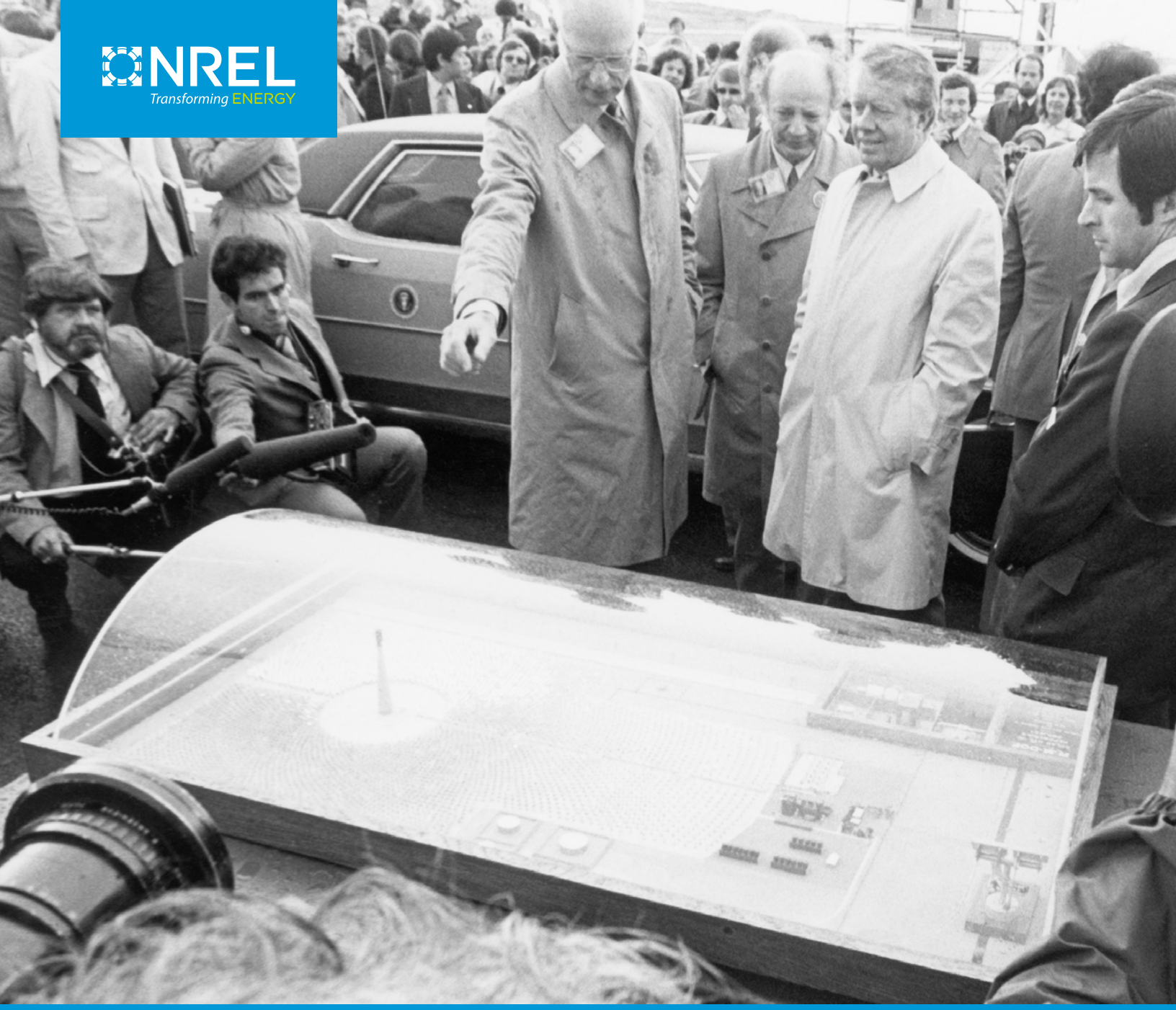
NREL
Transforming ENERGY



Creating the National Renewable Energy Laboratory:

Implications for New National Energy Research Institutes

Foreword

Many people from multiple organizations were instrumental for the information in this publication and getting it published. From NREL, thanks to Kim Adams for providing background material on NREL and for making this document part of the NREL history; to Brian Morris for providing the staffing and budget data; and to Gian Porro, Andrea Watson, Ron Benioff, and David Palchak for their review and comments.

In addition to the dozens of people interviewed over the past decade, the author offers very special thanks to colleagues and collaborators at many energy institutes around the world and their continuing work to develop their own research institutes. The author would also like to specifically recognize Joan Adams, Adrian Roberts, and Bobi Garrett for providing essential input and support based on their experiences leading and advising new and established research institutes across the globe. Thanks also for the thoughtful review comments from Jerad Ford (Commonwealth Scientific and Industrial Research Organisation, Australia); Thomas Roos, Clinton Carter-Brown, and colleagues (Council for Scientific and Industrial Research, South Africa); and Pankaj Batra (Central Electricity Authority, India).

This publication is part of a series that aims to inform understanding of the U.S. national laboratory complex as well as its history and impact. These include: The National Renewable Energy Laboratory History: 1977–2016 and What Are Federally Funded Research and Development Centers?"

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Front cover photo: President Jimmy Carter visits SERI (Solar Energy Research Institute), which would later become NREL. May 1978. *Photo by Dana Moran, NREL, 14616*

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SERI researcher. Raghu Bhattacharya, uses a simple, yet effective electrodeposition process to coat wires, silver sheets, and nickel ribbons with superconducting thin film materials, part of SERI's foundational and applied research into new energy materials. *Photo by Warren Gretz, NREL, 00075.*

Introduction

National energy research institutes increase innovation and grow economies. Yet, creating new research and development (R&D) capacity is a complex, nonlinear, noncommercial, multidecade process. Government decision makers and planners designing a new national energy research and development institute frequently benchmark established global institutes and set ambitious short-term objectives for their nascent organizations.

The history of the design and development of the National Renewable Energy Laboratory (NREL) in the United States illustrates how the plans for a new institute can be realized and evolve over four decades. This history summarizes the process of planning and developing NREL as a new research institute to meet its mandated mission, including creating a research agenda and plans for R&D management, human resources, financial sustainability, and facilities.

The NREL origin story, informed by the development of similar institutions around the world, also reveals generalized principles useful for decision makers across the globe who are designing their own research institute, which are described in this report, including:

- Start with a clear and enduring mission, then build a research agenda to meet that mission
- Learn from other organizations and adapt to local context
- Expect decades of development time to reach objectives
- Plan for flexibility and resilience in the mission, research, and operations
- Achieve sustained commitment from primary sponsors and stakeholders
- Develop highly talented and diverse human capital.

Campbell Stokes sunshine recorder, which are not in general use any more, but it's an interesting historical instrument. It records sunshine by burning a trace on a daily paper log that can then be measured in length to quantify daily sunshine. Designed in the late 1800s, data from such devices have been used to build historical databases for solar resource assessment worldwide. *Photo by NREL, 19742.*

Context: National Energy Research

Since the early 1900s, the concept of research has transitioned from the individual scientist and assistants working in their own small lab to large-scale industrial and national research facilities with hundreds to thousands of scientists. Nikola Tesla and Thomas Edison are examples of early energy research with individual labs and small teams testing new technologies that they brought to the rapidly growing electricity market. Fast forward 150 years to institutions such as NREL with 3,000 employees and a dozen laboratory buildings, yet still with the same goal of bringing clean energy technologies to the market. This transition in how research is conducted was driven in part by the expanding scale of industrial and global problems, requiring large expensive equipment and cross-disciplinary teams; yet, it also reflects the increasing strength of national governments and the economic value they perceive in basic and applied research at a national scale. Nearly all high-economy countries currently support large-scale research and development (R&D) facilities. Emerging economies often target the creation of research capacity within their countries as essential to their transition to a knowledge-based economy, benchmarking their ambitions against large institutes established in other countries decades earlier, including NREL.

However, the current success of existing large national-scale research facilities obscures the struggles they faced in their creation and development. New research and development institutes are created, grow, and evolve within a broader national innovation system, which includes responding to changing politics, policies, and priorities. New research institutes are also influenced by internal factors such as their strategies, structures, and organizational capabilities (including physical facilities and equipment, human capacity and skills, and management systems). Most become established over decades, surviving political turnovers, economic downturns, funding gyrations, management disruptions, insufficient human capital, changing mission priorities, and other hurdles. When planning and managing a new research institute, it is essential to understand the potential dynamic shifts that can affect research organizations and how other institutes survived and eventually thrive through them.

Thus, it is important to document the history of the creation of NREL to understand its current successful national research role and culture as well as define its future research as part of a research continuum from its original mission. History studies can also aid in the design and development of other new institutions by national-level decision makers. This report describes the development of NREL from its origin through its first four decades. Then, it summarizes fundamentals of research operations and key principles of planning a new research institute derived from the experiences of NREL and other successful energy research institutes over time as they transitioned from startup to steady state and the external and internal factors influencing their various stages of development.

Establishment of the National Renewable Energy Laboratory

Like many successful energy research institutes, NREL history illustrates the nonlinear pathway a national energy research institute might take from initiation to the present. NREL is one of 17 U.S. Department of Energy (DOE) national laboratories. It emerged from the 1970s energy crisis and a renewed interest in energy independence at the time. The details for the following summary come from primary documents (referenced below) and interviews conducted by the authors as well as those done for the NREL history study.[1] This report identifies the key success principles of laboratory creation, as a complement to the documentation of the NREL history.

In 1974, the U.S. Congress established the Solar Energy Research Institute (SERI) by national mandate.[2] An independent expert committee organized by the National Research Council (NRC) designed and planned SERI, releasing their strategy for establishing SERI in November 1975.[3] After an open competition to choose the location and managing organization, SERI was officially launched in July 1977.[4] In 1991, SERI become NREL, expanding its mission space beyond solar energy.

SERI and NREL survived numerous political upheavals, national economic crises, dramatic changes in the energy technology and market landscape, and significant increases and decreases in U.S. government funding, ultimately growing a comprehensive portfolio of clean energy and energy efficiency research. The following describes five major planning components for SERI and NREL and how they changed over its four decades of development.

[1] Adams, Kimberly, Editor. National Renewable Energy Laboratory History: 1977–2016. BK-6A42-84180, 2022.
[2] Solar Energy Research, Development and Demonstration Act of 1974, Public Law 93-473, October 26, 1974.
[3] Assembly of Mathematical and Physical Sciences, National Research Council, *Establishment of a Solar Energy Research Institute* (Washington, D.C.: Academy of Sciences, 1975). https://www.nap.edu/catalog/13356/establishment-of-a-solar-energy-research-institute.
[4] SERI, *SERI: The First Year* (Golden, CO: Solar Energy Research Institute, December 1978), SERI/SP-11-142, https://www.nrel.gov/docs/legosti/old/142.pdf.
[5] DOE also rebid SERI about 10 years earlier, but the 1998 rebid resulted in management changes (Midwest Research Institute brought in partners for the first time) as a result of a changing research strategies from DOE and the growing influence of renewable energy in the market.

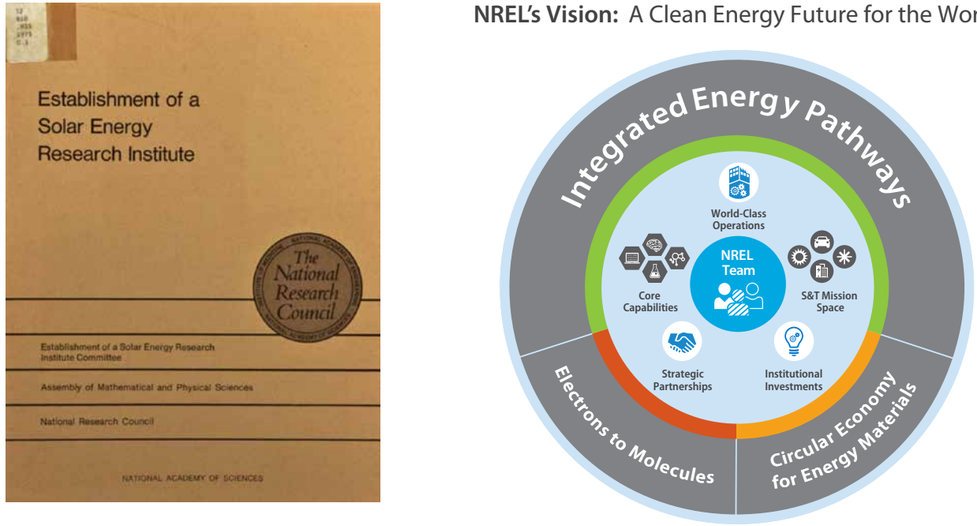


Figure 1. Cover of SERI founding strategy (1975) (left) and NREL's current critical research areas (2021) (right)

Research Agenda

The original strategy from the NRC defined a brief but clear research agenda for SERI, including three research goals:

1. Improving technical and analysis tools for solar energy and related fields
2. Providing sound assessments of status and options of policy for solar energy
3. Facilitating in a collaborative, educational, and supportive role the widespread introduction of solar energy when it is economically sound.

"Solar" energy was broadly defined and included solar heat, solar electric, wind power, ocean thermal gradients, biomass, storage, conversion, and transmission, as well as environmental assessment. The research scope ranged from basic research through manufacturing research and technology transfer. There was also a strong focus on systems modeling, policy analysis, and economics.

Notably, NREL continues to have a mission well aligned with its founding research agenda, growing its development into new renewable energy technologies and expanding its systems focus (see Figure 1). Even some of its newest program areas—electrons to molecules and circular economy—can draw a line back to the initial SERI research agenda. While at times this singular mission (that is succinctly stated in both the original and current name of the institute) may have left SERI/NREL vulnerable to policy shifts, it has also served as foundation of a clear unifying mission for staff and stakeholders.

R&D Management Plan

SERI was designed from the start to be a government-owned lab operated by a contractor. Soon after the NRC released its strategy report, an open competition was announced in 1976 to select both a location and an operating organization. In March 1977, after receiving more than a dozen bidders, the contract was awarded to Midwest Research Institute for a site in Golden, Colorado, just west of Denver. The strategy report recommended a review of the SERI management and mission "in 20 years or so," and right on time, in 1998,[5] DOE rebid the contract to realign the institute to have more market impact; Midwest Research Institute teamed with Battelle Memorial Institute to win the contract again. The management structure of private operations with government oversight has been retained. Multidecadal review and realignment has seemed to strike a balance between stability and adaptability.

A key NRC recommendation was that the research be managed centrally, not in distributed centers. The NRC noted national renewable energy research capacity in 1977 was insufficient to divide renewable energy research among institutes and locations. Small field sites were recommended to access specific resources or climates, but the NRC recommended most of SERI be in a central location as a single institute.

NREL continues to maintain and grow its primary campus and, to a large extent, use field sites for core functions based on their geography. Post-2020, NREL is adapting this approach as staff become more able to work remotely yet still engage meaningfully virtually; this approach might

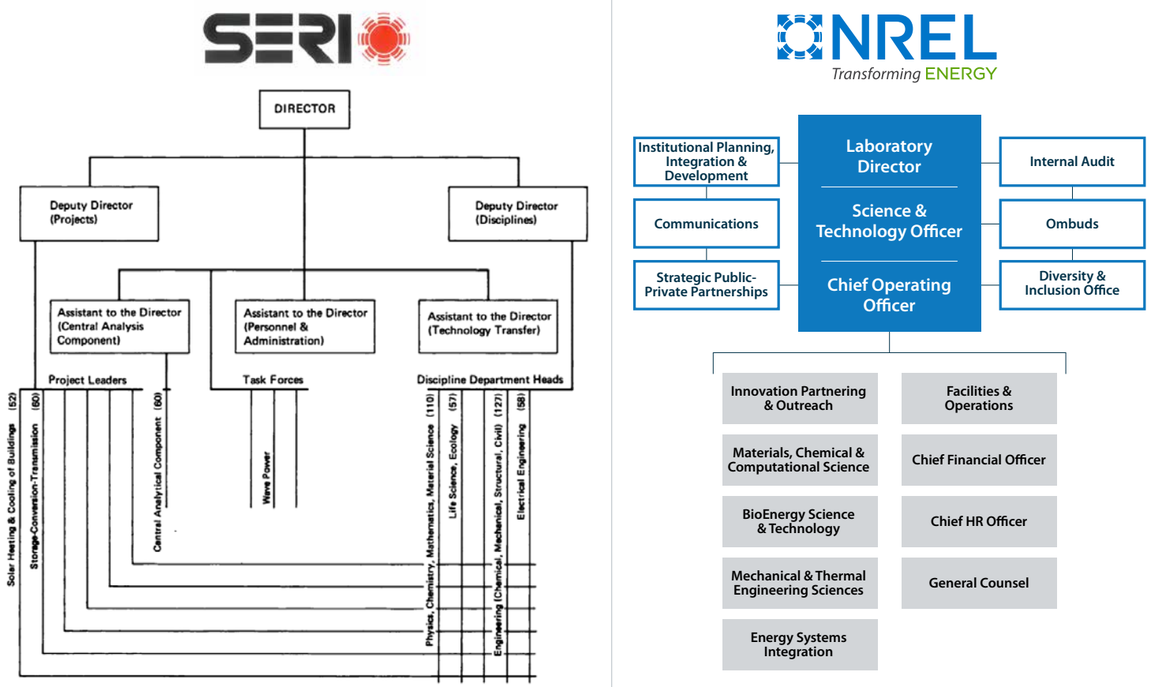


Figure 2. Proposed SERI research structure (1975) and NREL's current organization chart (2021)
Note the flat structure of the operations and research components, which are a blend of disciplines and technology-focused programs.

enable retention of skilled researchers who wish to live elsewhere in the country.

A second key R&D management recommendation of the NRC was staff should be organized in a matrix of various semipermanent disciplines, similar to a university, and programs; such an organization enables staff to work on time-limited projects and teams to change as appropriate. This structure has been partially retained at NREL, but the projects and disciplines have merged into R&D directorates focused on both technologies and related disciplines, with analysis merged into systems integration (see Figure 2). The organizational structure evolved over time as NREL grew, but the general concept of matrixing staff from across different parts of the institute to work on time-limited projects has been retained.

Initial operations included management of both an intramural and an extramural research program. SERI and NREL both had flexibility in designing and implementing research programs, with the extramural program being largely targeted to industry to catalyze the development of a U.S. renewable energy industry. NREL technical staff engaged directly with subcontractors in the technical work to impart knowledge and ensure the success of the outcome. This close partnership through subcontracted work was the primary mechanism for technology transfer in the first decades. Often these were small startup companies in the early stages of the renewable energy market. As DOE grew (it was created a few months after SERI), it took over management of most of the extramural programs and expanded participation to other national laboratories and universities. In the 1990s and 2000s, as the renewable energy industry matured, NREL's external engagement reversed, and it received (instead of provided) industry funding to conduct collaborative research. After 1998 and again with a 2008 rebid, (1) the focus on commercialization of technologies across the renewable energy and energy efficiency spectrum increased, and (2) the emphasis on systems integration, particularly focusing on electricity grid research, grew.

Human Resources Plan

The NRC's original strategy report proposed rapid growth of SERI starting with management and analysis while experimental facilities were being built. Full operations were expected by the third year with an estimated 630 professionals (scientists, engineers, economists, and lawyers) in a total laboratory population of 1,430. The NRC recommended 20% of professional staff be filled by people on leave from universities, government labs, or industry and by fellowships or term appointments and postdocs, with some remaining "in place" while research facilities were being built. While the strategy included this diversity of background, there were no explicit staff diversity goals for SERI/NREL until much later. Renewable energy being a new field did attract more women than traditional energy fields at the time.

The first laboratory director was an employee of the Midwest Research Institute, the operating contractor, which also provided early management support. The first director's initial focus was on bringing on technical and operating talent. Figure 3 shows the full-time staff levels for SERI and NREL starting from year of inception.

Staffing levels can serve as an indicator of the overall strength of an organization over time. Like many new research institutes, SERI and NREL did not grow steadily; rather, they experienced a strong start in the first four years and then a 50% budget cut in Year 5 that resulted in more than a quarter of the staff being laid off, followed by a decade of steady decline. The strategic plan that called for 1,430 staff by Year 3 instead took 33 years to achieve. Illustrative of early staffing difficulties, SERI experienced multiple short-term directors in its early years for various reasons, both personal and political. Three staffing peaks followed the initial decline: in the early 1990s when SERI became NREL; in the mid-2000s because of a general government stimulus in response to a global recession; and in the late 2010s from increased interest in renewables and concern about climate change. Three of the four peaks were followed by periods of contraction that were part a pattern where staffing would nearly double and then drop by about 20%, and the pattern would then repeat over several decades.

Several human-resource approaches were later implemented to help soften changes like these. First, interns and postdocs enabled research without long-term hiring commitments. In the case of the stimulus funds in the mid-2000s that were known to be short term, NREL hired contractors and term-limited employees, which resulted in a large staff increase from 2008 to 2011 that was followed by a slow release of those employees as the funds were spent on buildings and equipment. Finally, though it is not explicitly encouraged, NREL staff who leave to take positions with universities, DOE, or industry often return to the laboratory with new knowledge when growth is anticipated.

2,859 Staff on board at 9/30/2020: 2,491 (87%) employees, 368 (13%) contract staff, 0 (0%) construction

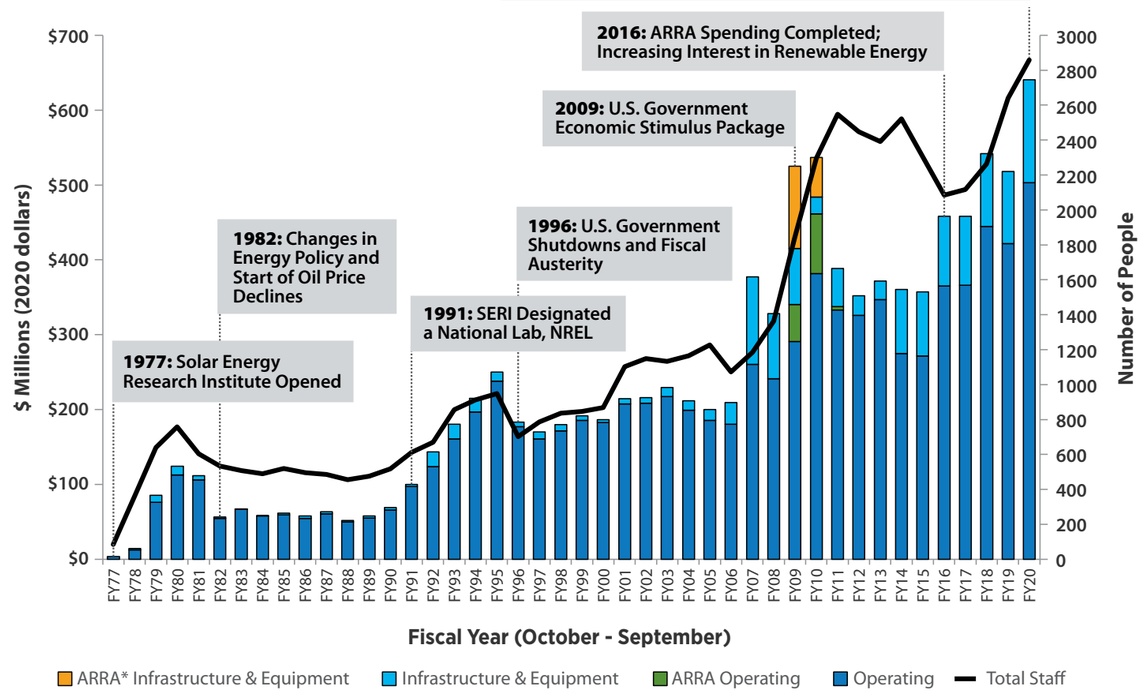


Figure 3. SERI and NREL staffing and budget from inception (1977) to 2020
ARRA = American Recovery and Reinvestment Act of 2009

Financial Sustainability Plan

SERI and NREL evolved through political and economic upheavals that significantly impacted financial sustainability. Initial funding was from a single agency (DOE) within the national government. This sole dependence on DOE tied SERI's and NREL's financial health to DOE's budget priorities and the political priorities of the active presidential administration and the legislature. This dependence sometimes resulted in dramatic funding decreases and increases, as seen in Figure 3, including a 50% budget cut in Year 5 resulting from a change in the presidential administration and associated priorities. This first loss of funding nearly ended SERI, but it was saved by the director at the time, who worked to assemble a diverse set of supporters from both political parties as well as local elected officials and industry stakeholders. He also moved SERI from the advocacy approach of the previous director to a focus on objective R&D.

A second 25% budget cut in 1996 resulted from overall government shutdowns and austerity measures that affected all national laboratories. And in 2006, a new administration's energy plan initially focused on conventional energy and aimed to cut NREL's budget by 30%–50%. However, after stakeholder meetings around the country yielded significant turnout and overwhelming support for renewable energy, the administration reversed its position and announced a new energy initiative at NREL, with a near doubling of the budget.

In 2009, when a government stimulus package was announced, NREL management recognized it would represent a short-term source of funds. However, in the preceding few years, they had created a comprehensive campus facilities design that identified capital investments to enable the research mission (as part of a facilities plan, described in the next section). So, when stimulus funds were available, the laboratory management sought and received funds to construct new buildings and infrastructure using contractors. This kept operating budgets steady to avoid major staffing disruptions while allowing for major capability investment.

Most recently, NREL has sought to diversify its funding sources beyond DOE, receiving a growing percentage from other sources, with modest success; it still depends on its primary DOE sponsor for over 70% of its funding. New contracting mechanisms to receive funds from nonprofit foundations and the private sector were agreed on with DOE. Ultimately, financial sustainability depends on gaining the trust and confidence of customers for delivering relevant results, maintaining political acumen, building stakeholder support for the mission, preparing projects that can be ready when funds are available, and diversifying funding sources.

Facilities Plan

The NRC's original strategy specifically called for a single centralized location with small field stations so that the limited resources could be efficiently deployed to multiple programs. The criteria for the location were an "intellectual atmosphere" (in today's terms, an innovation ecosystem) with good communication and transportation, desirable places to live for recruiting staff and families, nearby universities for continuing education, industry in relevant areas, access to skilled technical support personnel, high solar insolation and other renewable resources, land availability and local support, and access to conference facilities.

The western part of Denver, Colorado, was selected based on these criteria, and the state of Colorado donated the land the laboratory occupies. NREL continues to recruit staff based on its location near the mountains, medium-sized metropolitan culture, nearby universities, clean industries, large airport, and sunny skies. The importance of location selection of a new research institute should not be underestimated and can have a long-lasting impact on institutional success, from recruitment to campus expansions.

SERI started in nearby leased offices with the intention to rapidly build out its own facilities on the donated lands. It first built solar research laboratories on its new site. However, NREL did not fully move out of leased offices into its own space on campus until about 35 years later, when a combination of advanced campus planning and short-term government stimulus-related funding enabled construction of new office, research, and amenities space (see previous section). This move to owned space was significantly slower than expected, and was realized only through persistence and planning by staff and management and growing support for the mission by local, state, and national decisoinmakers. Figure 4 shows the slow progression of the main campus over 40 years.

Field facilities for wind technology testing required certain wind conditions and more space than was available at the main campus, so the laboratory acquired an existing wind test facility north of the main campus in 1984. In 2020, facilities for cold climate housing research were acquired from an existing institute in the state of Alaska. Also, NREL maintains an office in Washington, D.C., for direct engagement with DOE headquarters and other national government sponsors.

Essential to a new research institute are both quick access to first research facilities to accomplish early mission success and a phased vision of the larger set of facilities over time as the research agenda and funding expands. A research institute should strategically anticipate, evaluate, and plan new sites and facilities to be prepared to take advantage of unexpected opportunities.

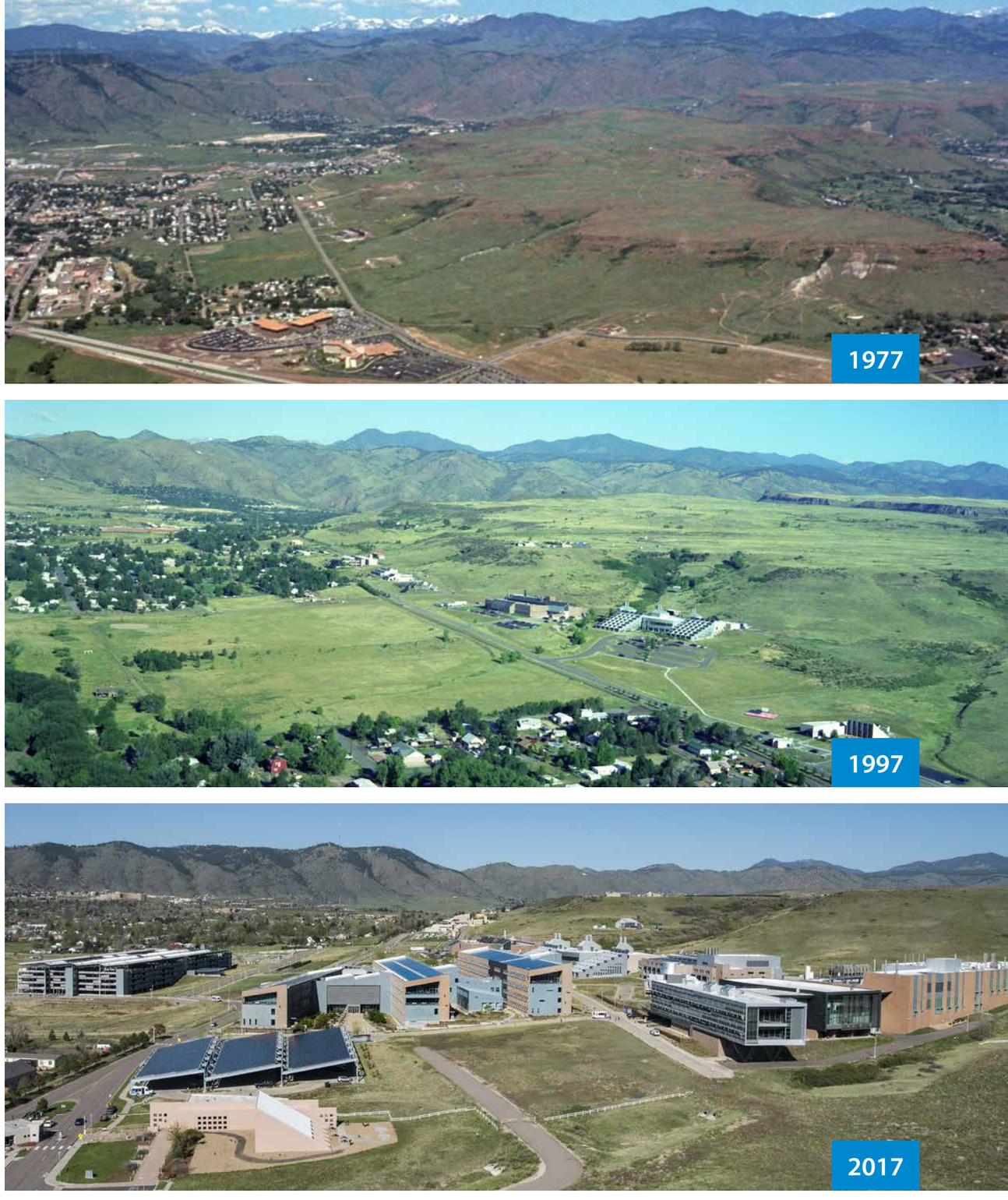


Figure 4. SERI campus in 1977 and the main NREL campus in 1997 and 2017. *Photo by Warren Gretz, 1977, NREL, 15450; 1997 photo by Mike Linenberger, NREL, 03057; 2017 photo by Dennis Schroeder, NREL, 44761*

Fundamentals of R&D Institute Operations

Based on the history of NREL and similar energy research institutions, generalized fundamentals operating a new institute can be identified. Large scientific research institute operations consist of a complex set of activities with research at the center, as illustrated in Figure 5. The research may include development of new technologies; applied integration of technologies into larger systems;

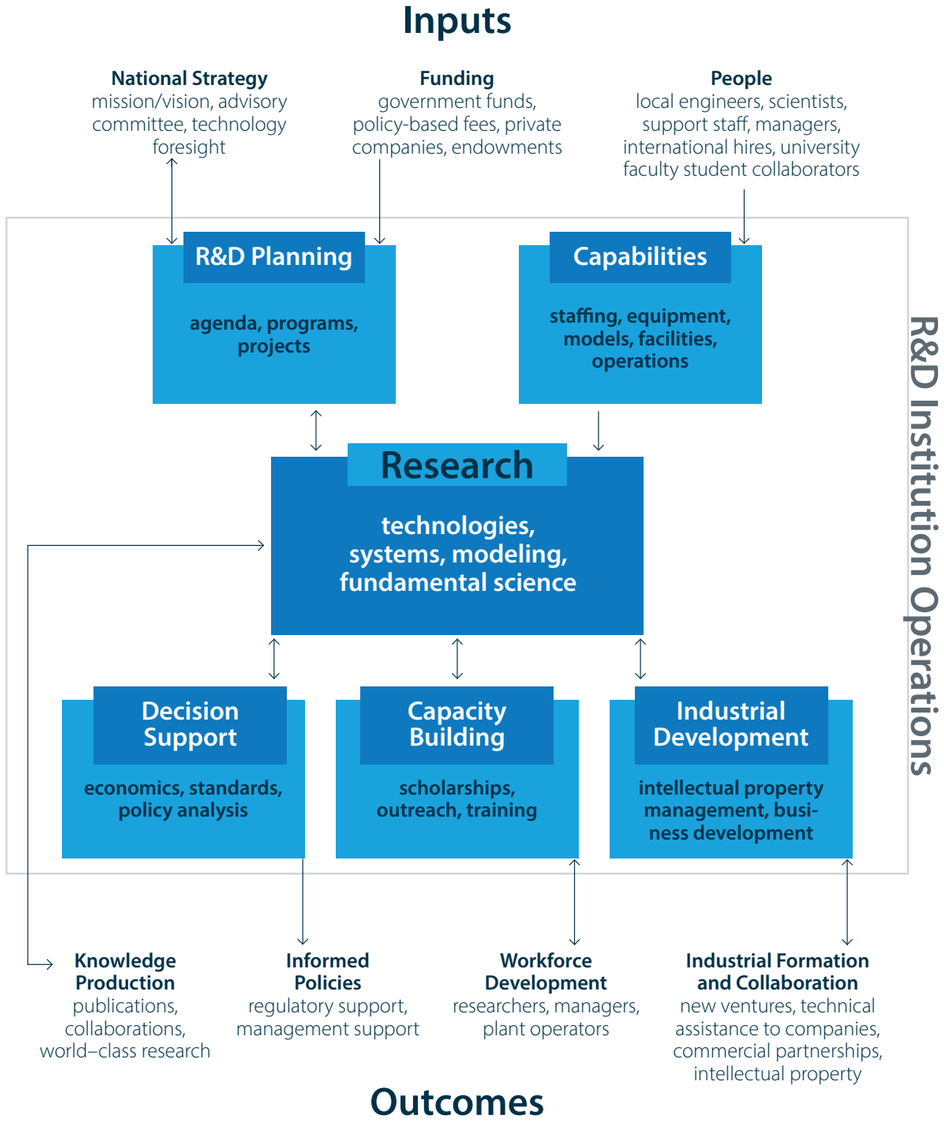


Figure 5. Fundamental aspects of R&D operations

A researcher installs instrumentation at SERI's first resource assessment tower on top of South Table Mountain, circa 1980. *Photo by Warren Gretz, NREL, 00468.*

modeling and computing; and basic fundamental science in chemistry, physics, biology, geoscience, and math. R&D planning is documented in an R&D agenda and conducted through programs and projects. R&D requires high-quality capabilities of expert staff, research equipment, models (including data), and facilities, supported by an operations infrastructure.

Research institutes require and are influenced and supported by external inputs. Research plans are aligned to national strategies that feed a clear and compelling mission and vision of the organization. Research institutes frequently receive input from external advisory committees or boards of directors that guide institutional development strategy and planned research areas, supported by technology foresight analysis. Funding can come from multiple sources—frequently from governments but also from policy-based fees, private companies, or endowments—and should be incorporated into a business model for the research institute. For successful innovation, the people in the research institute are highly talented and diverse, including local and international hires and partnerships with universities for specialty faculty under joint appointments and for graduate and postdoctoral students who become part of the research pipeline.

In addition to research, research institutes also fulfill other fundamental programmatic functions. Their expertise provides decision support through techno-economic analysis, development of technology performance standards, and analysis of policy options. They can build the technical capacity of a country or region through educational scholarships; outreach and technical assistance on science-based solutions to societal challenges; and training for the private sector, decision makers, and students. Research institutes are also a key part of an industrial development ecosystem, creating intellectual property that can be licensed and supporting business and industry by de-risking early-stage research and hosting shared user facilities that enable companies to develop and test new technologies.

The outcomes from research institutes include:

- Knowledge production outputs such as publications and collaborations that advance scientific progress
- Enabling of informed policies through data and analysis that are important for the design of new regulations, managing research programs, improving economies, and other functions of government that have far-reaching effects
- Skilled workforce development for research, technology management, and operations of facilities
- Industry formation and collaboration through the development of technologies and research that enables the launch of new products and new companies by the private sector.

Outcome metrics should all link directly to the operations and research. Government investment in research institute infrastructure and programs means government decision makers typically define the major thrust areas and outcome metrics, working in collaboration with research managers and with input from industrial and societal needs. Successful research institutes respond to government and stakeholder demands with objective and independent research results and outcomes. As public entities, the scientific outcomes should generally be communicated and disseminated to a wide variety of stakeholders and the public.

Existing successful research institutes have developed and refined their operating fundamentals over decades. When a country or an organization decides to develop a new research institute, they need to take multiple simultaneous actions to define, plan, and achieve near-term successes for each of these outcomes. The research institute development process can be overwhelming and complex, especially because the establishment, growth, and evolution of national research institutes are driven by each country's unique needs, resources, cultures, and policies.

SERI's Karen Dukehart works on fluid dynamics. Used for NREL's 20th anniversary. *Photo by Warren Gretz, NREL, 00597*

Research and Institutional Strategic Planning: Five Key Components

Research and institutional strategic planning are essential to successfully launching the research institute development process. While the mission and mandate typically come from the founding and sponsoring government or organizations, the strategy is typically developed by research leaders with input from external stakeholders and experts. To sustain the relevance of an institute over time, it is also essential to revisit the strategy as the external context evolves and the institute advances from startup to maturation and periodically during steady state.

A research institute strategy consists of five components that all ultimately contribute to fulfilling the research institute's mandate and mission, as illustrated in Figure 6. After the mandate and mission, the first among these is the research agenda, although the components all overlap and intersect in their development.

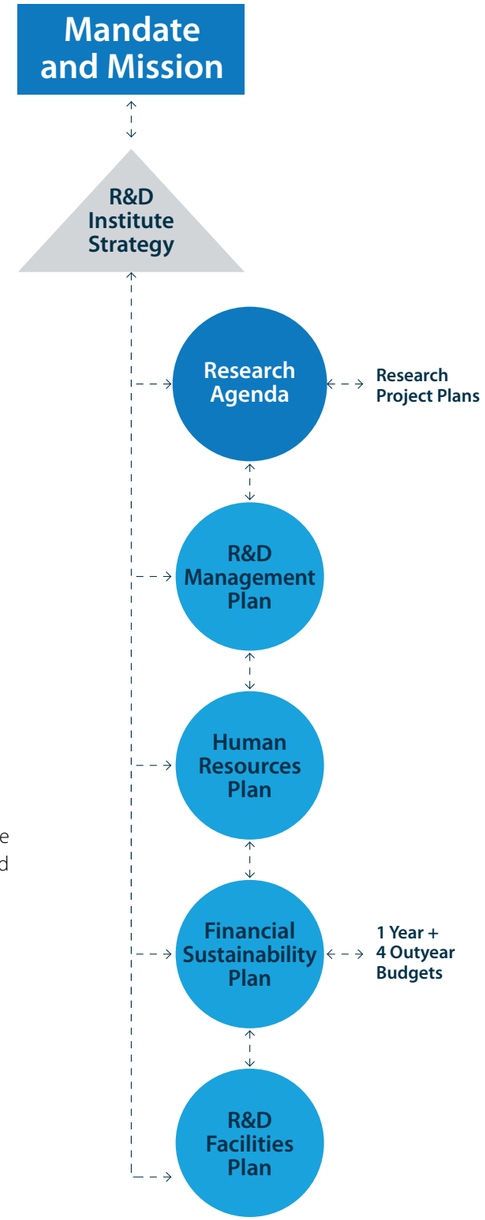


Figure 6. Planning components for designing a new research and development institute

A researcher reviews results from a spectral photometer measuring electro optical properties of electrochromatic device. *Photo by Warren Gretz, NREL, 04490.*

Research Agenda

The research agenda defines the near-term and long-term research focus areas and programs that will fulfill the mandate and mission of the research institute, as illustrated in Figure 7. Research focus areas have long-term strategic research objectives and represent core areas of research. Each focus area has multiple research programs seeking to meet mid-term critical outcomes. Individual projects and their deliverables are nested in each program. The research agenda provides significant details on specific R&D programs so that research leaderships can select projects and design future research capabilities.

Care should be taken to prioritize early focus areas on the core research needed to meet the mission and plan to build on and expand them in 5–10 years. Trying to build too many programs at once often dilutes resources and slows progress. The research agenda should detail the prioritized projects that will yield near-term successes and begin the collection of long-term data sets.

The types of research activities considered for the research agenda should be comprehensive and appropriate to the mandate and mission, including:

- Laboratory-based research, such as bench-level experiments, materials development, and prototyping
- Field studies, such as resource assessment and monitoring, characterization and modeling, and human and environmental health impact evaluations
- Computational and quantitative assessment, such as model development, modeling and simulation, systems analysis and design, and demographics and behavioral and communication studies
- Advanced technology development and engineering, such as technology testing and evaluation, demonstrations at engineering and pilot scale, and scale-up of innovations.

Relevant technology statuses and trends—including those of policies, energy resources, technology research needs, and market—influence the initial selection of the research focus areas and the ongoing development of research programs and projects. Existing and potential resources and capabilities—including those from partnerships as well as available research technologies, expected financial resources, and accessible human capacity—should also be inputs to the selection of research focus areas.

The research agenda leads to the identification of resource allocations and needs for funding, staffing, equipment, and facilities, which are defined in the other planning components (which are described next). The timeline of program implementation of the research agenda can be iterative in cases where resource planning identifies a funding or capability gap, which can be addressed by new resources or delaying the outcomes of the programs in the research agenda. The objectives and outcomes in the research agenda should be specific enough to be linked to the performance management of the research institute and incorporated in the R&D management plan. Priority should be given to foundational programs that require time to develop with dependencies of future programs (e.g., long-term natural resource monitoring) and to those programs that can demonstrate near-term success with existing or easily developed capabilities. Over time, research programs should be designed to build on each other with integrated performance measurement toward the common mission that is transparent to staff, sponsors, and stakeholders.

Once the research agenda is defined or at least outlined, the other four planning components support the planned research. These can be developed concurrently, and they should inform each other. All four should consider the external context of the research institute—specifically national, political, and societal objectives—as well as the innovation ecosystem of universities, other research institutes, technology startups, and private industry.

R&D Management Plan

The R&D management plan defines how the research in the agenda will be conducted. At an early stage, the plan defines principles and approaches that over time will ultimately be codified into policies and procedures. The R&D management plan starts with defining research culture principles, such as mission-driven or basic research, matrixed or independent teams, management or employee-driven initiatives, public-facing or proprietary projects, and open access or protected intellectual property. Though a working culture will emerge based on early leadership and staff, formally defining these principles upfront guides the course of its development. The research culture defined both formally and informally at the start of a research institute will persist through the decades, thus careful early consideration of its principles is essential.

Roles and responsibilities of the institute and its potential partners define which research will be conducted in-house and which will be done with partners or externally, based on the local innovation ecosystem. Core capabilities need to be defined and nurtured, with a willingness to engage partners to help develop capabilities or bring in noncore skills. Careful selection of strategic partners is essential early on and should remain constant over the following years. Engagement with partners can include management agreements, joint appointments and research, student hires, and subcontracts. Performance metrics for R&D at the institutional and project level include both outputs (e.g., numbers of staff, patents, and publications) and outcomes (e.g., uptake of research findings into new technologies or policies). Specific plans for individual projects will align with the concepts defined in the overall R&D management plan.

Human Resources Plan

The human resources plan defines the staff development and the organizational structure of the research institute needed to facilitate research. Highly qualified and dedicated staff are the most important asset of a successful research institute. The researchers' technical expertise that is needed for each stage of the research agenda should be well defined, as should how those researchers can be accessed (e.g., hiring and developing in-house, senior strategic hires, joint appointments, or contractors). Developing the human resources plan means reaching consensus on (1) an approach to acquiring or developing human capabilities where gaps exist and (2) whether to develop the capabilities within the country over time and/or recruit international expert hires. The decision about the approach taken should aim to optimize meeting both research goals and societal objectives. Human diversity in background, nationality, education, and experience often yields creativity in thought and approaches to research. The human resources plan should include policies on staff training, development, and education in both technical research topics and research management. Education can be brought in-house, or staff can be supported externally at universities or through applied rotations at partner institutes. The human resources plan should support multiyear development of the specialized knowledge needed to advance to the research agenda over time.

The human resources plan should also define the organizational structure—which can be based on either capabilities or programs—and it should include the research support functions. The definition of the structure

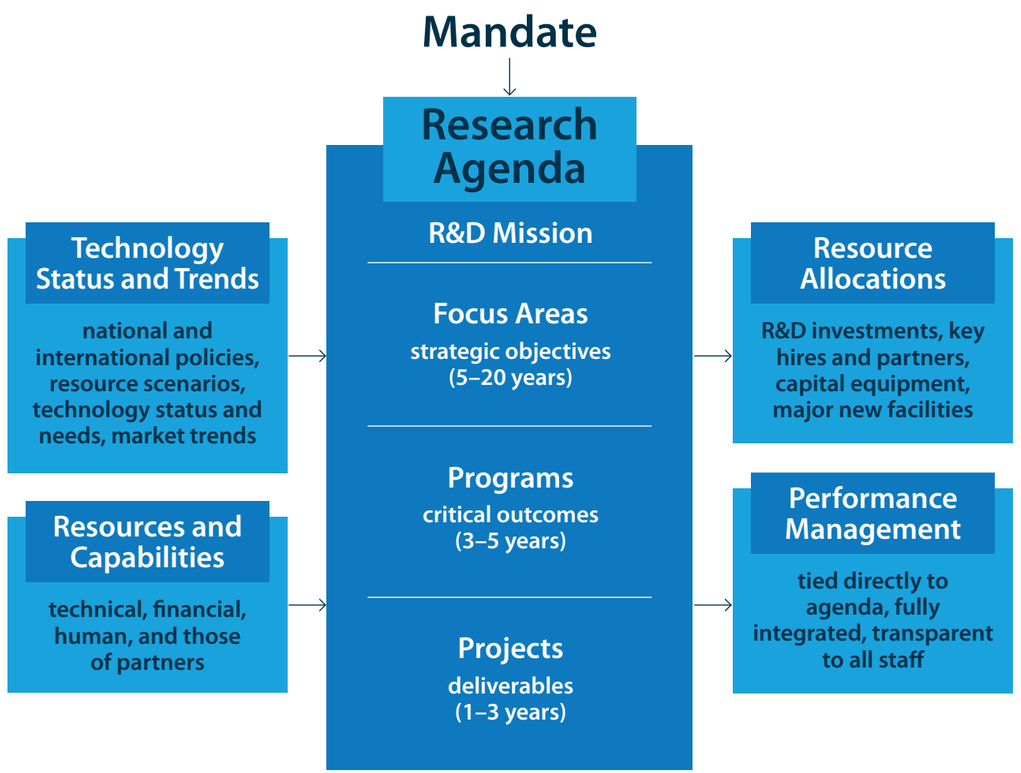


Figure 7. Components of the research agenda

should include both how it will start and how it might change over time as the research institute grows from a few dozen people to hundreds and then thousands; doing so will enable the research institute to balance the growth of research, management, and operations staff as needed to continue to meet its mission. The plan for growth should allow for a healthy turnover or rotation of staff into the private sector or government to refresh the talent base and develop connections with key stakeholders.

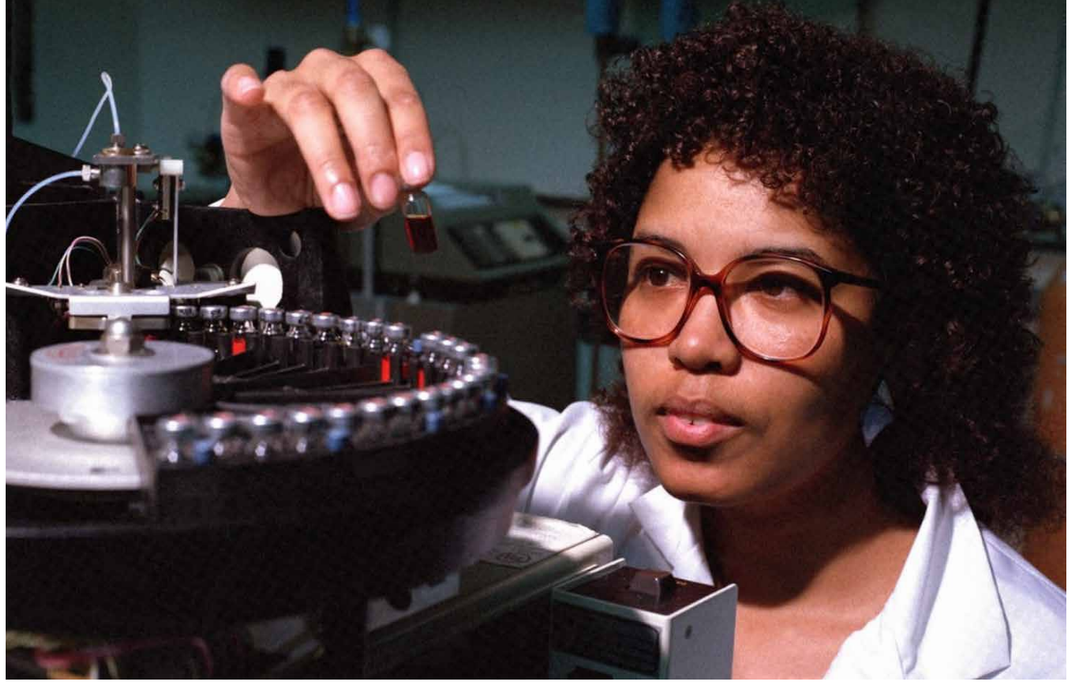
Financial Sustainability Plan

The financial sustainability plan, or business plan, defines the approach for funding the research institute over time. Many research institutes start with initial funding from government or a sponsor but then need to define a sustaining business model. Over time, most research institutes continue to receive a significant portion of their funding from the government or their initial sponsor, but alternative models have worked, including those based on memberships, fees, and endowments, which in turn affect the type of research conducted. The financial sustainability plan should objectively define the approach to sustainable funding without undue optimism, and it should plan for significant variability over time. Operationally, the research institute should establish an annual budget with a four-year budget projection to facilitate facility planning, hiring, and business development that reflects the priorities identified in the research agenda.

R&D Facilities Plan

The R&D facilities plan defines the buildings and equipment needed for the planned research. Given the large capital costs in the startup phase, the plan may need to address how it will gain access to partner facilities and how it will establish capabilities that can be rapidly developed in leased buildings. Near-term emphasis should be on the equipment needed to develop long-term data sets, which should be secured early so the data can be collected over time. Another early emphasis should be on facilities and equipment that enable staff training and early publications and results. Additionally, the facilities plan defines whether the research institute will be centralized on a campus, distributed across several campuses, or be virtual at partner sites. The design of facilities should enable the type of culture that is defined in the R&D management plan. Construction of the facilities—and access to them—should align closely with the timeline of the research agenda and be phased over decades, and they should both target near-term successes and anticipate longer-term plans for when capital funding can be secured.

Ben Rushe of DOE tours SERI labs and Interim Test Site.
Photo by Warren Gretz, NREL, 04499



Fannie Posey Eddy conducts biomass analysis as part of SERI's capabilities to develop biomass as a renewable resource.
Photo by Warren Gretz, NREL, 05436

Key Principles for Establishing a National Energy Research Institute

Decision makers and planners using the history and approaches described here when establishing a new national energy research institute may consider several key principles derived from experience and benchmarking of the historical development of research institutes across the world.

Start with a clear and enduring mission and then build a research agenda to meet that mission.

The process described in this report starts with a clear research mission that should be specific and enduring even as markets, governments, and customers change. The research agenda and then the other planning components of the research institute should all contribute to the mission.

Apply equal focus to developing effective business systems as well as research programs, because streamlined contracting, human resources, facility operations, procurement, and communications will have equally important impacts on the research institute's success and enabling research as the research itself.

A researcher checks this SERI remote meteorological tower linked from South Table Mountain to a lab in Building 16 via radio telemetry--a computer in the lab recorded information about solar radiation and surface weather--the system was powered by a PV array.
Photo by Warren Gretz, NREL, 00609

Learn from others and adapt to local context.

Learning about best practices for managing and operating a similar research organization might reduce the time and cost required to establish a new research institute. Benchmarking other research institutes has the added benefit of engaging with potential partners and defining a distinctive mission to avoid duplication. However, the information gathered should be carefully adapted to the local context, including the innovation ecosystem, political system, and cultural values. Ideally, local staff with external input should lead the benchmarking activities.

- *Benchmarking other research institutes* is important when planning, designing, and developing a new research institute. The selection of research institutes to benchmark should be based on specific criteria that are tailored to the mission of the new institute. Examples of selection criteria include alignment with mission and potential business model, similar policy or political context, cultural affiliation, and a general diversity of institutes to explore options.
- *Embrace robust collaborations and partnerships* through and beyond the initial learning from others. Effective interactions with collaborators and stakeholders can lead to new approaches and innovation within a research institute's local context, as well as to long-term stakeholder support. These broad relationships also provide context for the trends in markets and technologies that inform strategy development.

Expect decades of development time to reach objectives.

Many organizations successfully built, revitalized, and sustain their innovation institutions. However, benchmarking established research institutes gives the perception that they achieved their success rapidly, linearly, and completely, when the actual building stage of a research institute can typically take 30–40 years. Both the short and long term should be considered, as institutes evolve from startup through maturation and full operations, often through periods of surges and stagnation.

- *Aim for early and visible successes* while planning for a larger agenda over decades. Doing so enables a new research institute to establish its core mission and prove it has functional operations and can conduct valuable research. Such successes become invaluable when financial, political, or management disruptions inevitably arise.
- *Build the research institute strategically over the long term*, consistently growing capabilities, resources, and research programs over decades to achieve a consistent and compelling mission. Aim for excellence of a core set of capabilities that expand, and then be willing to retire or transition capabilities or programs that no longer have significant impact.

Plan for flexibility and resilience in the mission, research, and operations.

All established research institutes have successfully negotiated their way through major disruptions, including significant funding cuts, overly rapid growth, organizational rivalries, policy reversals, leadership transitions, neglect and stagnation, accidents, and missed opportunities. Those that have survived were able to adapt through flexible business models, a culture of resilient staff dedicated to an enduring mission, and visionary leaders able to build and leverage relationships with stakeholders and prepare for unexpected opportunities.

- *Design flexibility and resilience into the mission, research, and operations* to respond to changes in government, funding, and innovations, even if the exact disruptions are difficult to predict.
- *Adopt a mission-driven outcome-based management approach* in order to adapt strategy, structure, and organizational capabilities to both changing national innovation systems and more abrupt existential changes.

Achieve sustained commitment from primary sponsors and stakeholders.

Nearly every national research institute has significant government support via policies and funding to build its research enterprise and complementary industries. In some cases, the primary sponsor could be a private individual or organization through an endowment or a membership fee-based model. No matter the initial funding source, sustained commitment from a primary sponsor enables the highest likelihood of success, unlike "seed funds" that expect a transition to a completely new set of sponsors in a short time frame.

- *Leverage funds through cost-share collaborations and supplement them with a diverse portfolio of sponsors* yet recognize that self-sufficient operation is difficult to achieve and few research institutes have become independent from their initial primary sponsor.
- *Build and actively maintain stakeholder support across sectors*, including the industries relevant to the mission, policymakers regardless of political affiliation, current and former employees, and local and regional communities. Such support is critical early in the development and during times of change for a research institute.
- *Communicate programs and research outcomes broadly but objectively*. Commitment can be further developed when a broad range of stakeholders know what the research institute is doing. Research objectivity should be maintained but still include engaged communications to amplify research findings at a national and ultimately global scale.

Develop highly talented and diverse human capital.

Most research institutes have initial difficulties hiring and developing human skills and capacity. However, these difficulties can be overcome through education/scholarships, hires of international experts, staff exchanges, and partnerships with industry and universities. Indeed, successful research institutes have an objective to contribute to their country's overall economic development and skilled workforce over various timeframes that can then feed back into their own workforce.

- *Create an operational and workplace culture that supports, rewards, and recognizes innovation* and that will also attract and retain skilled researchers. Though enticing a top researcher with a high salary and expensive equipment might be expedient, a workplace culture that truly supports research will be more enduring. Create a place where researchers will want to work and select a location where they and their families will want to live.
- *Embrace diversity of staff and partners as a means for innovation and capacity building.* The development of a new research institute means finding and developing new capabilities by looking outward beyond organizational and geopolitical boundaries for those committed to the scientific mission.

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