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NASA Net Zero Energy Buildings Roadmap

Shanti Pless, Jennifer Scheib, Paul Torcellini, Bob Hendron, and Michelle Slovensky

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Technical Report
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October 2014

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Executive Summary

To prepare for the time-phased net zero energy buildings (NZEBs) requirement for new federal buildings starting in 2020, set forth in Executive Order (EO) 13514, NASA requested that the National Renewable Energy Laboratory (NREL) develop a roadmap for NASA's compliance. NASA detailed a Statement of Work that requested information on strategic, organizational, and tactical aspects of net zero energy buildings.

This roadmap presents a high-level approach to NZEB planning, design, construction, and operations, based on NREL's firsthand experience procuring NZEBs, and based on NREL and other industry research on NZEB feasibility.

The strategic approach to NZEBs starts with an interpretation of the EO language relating to NZEBs. Specifically, this roadmap defines an NZEB acquisition process as one that first sets an aggressive energy use intensity goal for the building in project planning. It then meets the reduced demand goal through energy efficiency approaches and technologies. Lastly, it adds renewable energy in a prioritized manner, using building-associated, emission-free sources first, to offset the annual conventional energy use required at the building. The NZEB process extends through the life of the building, requiring a balance of energy use and production in each fiscal year.

The roadmap continues by identifying the most important organizational changes that will have to take place at NASA for the agency to successfully adopt the NZEB process: (1) identify or create energy performance assurance capability to act as the conduit for information and critical eye for NZEB topics within the agency and during the course of individual projects; and (2) effect culture change at the building level, which includes engaging occupants and facility staff to take ownership of the skills required to achieve an NZEB goal.

The organizational and tactical approaches to NZEBs as presented in this roadmap are intertwined: the organizational approach categorizes the unique elements of NZEB construction that are required in every NZEB; the tactical approach lists all specific actions and associated metrics that make up the organizational categories. It is unlikely that any project will use all tactics. Combined, the organizational and tactical sections of the roadmap present a high-level how-to approach to NZEBs, focused at the project level. Key attributes of the approach are that it:

- Starts from NASA's current efforts in high performance building design and construction, and extends from the trajectory of current federal building performance requirements.
- Addresses EO 13514 NZEB language as a building-by-building goal, which requires project teams to overcome barriers but also allows ownership of the benefits.
- Identifies a set of 57 tactics (or skills) that NASA will need if it is to achieve the NZEB requirement.
- Presents a pathway for NASA facilities staff to become proficient or experts (trains others) in one or a handful of high performance building systems.
- Proposes an approach for selecting tactics and a timeline for vetting all tactics, resulting in NASA standard NZEB planning, design, construction, and operation by 2030.

The roadmap concludes by identifying the risks that could prevent NASA from becoming proficient in NZEB new construction by 2030 and prioritizes the steps for implementing the roadmap.

Acronyms

CP	Capstone proficiency
DBIA	Design Build Institute of America
EO	Executive Order
EUI	Energy use intensity
GSHP	Ground source heat pump
HVAC	Heating, ventilation, and air conditioning
LEED	Leadership in Energy and Environmental Design
MEL	Miscellaneous electric load
NBI	New Buildings Institute
NREL	National Renewable Energy Laboratory
NZEB	Net zero energy building
NZER	Net zero energy ready
O&M	Operations and maintenance
OP	Organizational proficiency
PER	Preliminary Engineering Report
POE	Post Occupancy Evaluation
PPL	Plug and process load
PV	Photovoltaic
RE	Renewable energy
REC	Renewable energy certificates
RFP	Request for Proposals
SHW	Solar hot water
SSPP	Strategic Sustainability Performance Plan
T&D	Transmission and distribution
TLCC	Total life cycle cost
USGBC	US Green Building Council

Table of Contents

List of Figures

List of Tables

1 Introduction and Background

Beginning in 2020, all new federal buildings must be designed to achieve net zero energy building (NZEB) performance by 2030, in accordance with Executive Order (EO) 13514, titled "Federal Leadership in Environmental, Energy, and Economic Performance." NASA is supportive of this target, and has decided to establish short-, medium-, and long-term objectives that will ultimately enable the agency to achieve the requirements. NASA has established several high-level targets in its Strategic Sustainability Performance Plan (SSPP), and has demonstrated a commitment to high performance buildings through a series of demonstration projects. However, an integrated plan tailored to NASA's needs, with clear objectives, definitions, roles, and timetables, has not yet been established by NASA leadership and embraced by all Centers and communities of practice.

As part of an ongoing collaboration between NASA and the National Renewable Energy Laboratory (NREL), NASA asked NREL to assist with this process by developing a multitiered roadmap that would leverage NREL's experience overcoming technical and market barriers to net zero energy buildings (NZEBs) through recent campus projects and energy-efficient buildings research, and adapt that experience to NASA's specific challenges. The objectives are to:

- Establish a clear interpretation of EO 13514 sections that are related to the federal NZEBs strategic goal that NASA can adopt and apply.
- Identify a series of time-phased incremental organizational objectives and proficiencies that are necessary to achieve the strategic goal.
- Describe specific tactics that NASA should implement in pursuing the organizational objectives.

NASA intends to use the roadmap to inform the NASA Construction of Facilities 5-year plan decision-making process, and to share with other federal agencies that are developing their own long-term plans to meet the EO 13514 requirements. The roadmap draws from NASA current resources, which include:

- The 2013 Introduction to Sustainable Facilities presentations
- The 2013 Construction of Facilities Management presentations
- Site-specific climate risk handouts and workshop summaries
- The 2012 Energy Management Report summary
- Post Occupancy Evaluation (POE) reports
- The 2010 Renewable Energy Assessment report.

The roadmap builds on NASA's current sustainable building procurement processes so the organizational and tactical pieces of the roadmap can begin at current practice. To engage a variety of NASA communities of practice such as facilities engineering, operations and maintenance (O&M), real property/master planning, environmental, energy management, and procurement, NREL:

- Led an after-action review video- and teleconference with a variety of NASA Centers and communities of practice during a site visit to Kennedy Space Center to set a baseline for current building practice.
- Presented the initial roadmap outline and held a question-and-answer session at the face-to-face Energy Efficiency Panel meeting.
- Visited Ames Research Center during the POE, to extract lessons learned from a recent NASA high performance building.
- Presented a draft of the roadmap via video- and teleconference to a variety of Centers and communities of practice and held a subsequent formal NASA review period.
- Considered the needs, recommendations, and concerns expressed by the communities of practice.

2 Strategic Approach

The strategic approach to NZEBs recommended for NASA is rooted in an interpretation of the relevant requirements of EO 13514, titled "Federal Leadership in Environmental, Energy, and Economic Performance," and application of these requirements to NASA's building portfolio and new construction planned over the next decade and beyond. To give a premise for the NZEB interpretation, the general policy language is first presented. As stated, the purpose of EO 13514 is to:

> "*... establish an integrated strategy towards sustainability in the Federal Government and to make reduction of greenhouse gas emissions a priority for Federal agencies ...*" (Preamble)

Recommended Interpretation: Reduction of greenhouse gas emissions is an overarching goal of EO 13514. The integrated strategy referenced is detailed as follows:

> "*... Federal agencies shall increase energy efficiency; measure, report, and reduce their greenhouse gas emissions from direct and indirect activities; conserve and protect water resources through efficiency, reuse, and stormwater management; eliminate waste, recycle, and prevent pollution; leverage agency acquisitions to foster markets for sustainable technologies and environmentally preferable materials, products, and services; design, construct, maintain, and operate high performance sustainable buildings in sustainable locations; strengthen the vitality and livability of the communities in which Federal facilities are located; and inform Federal employees about and involve them in the achievement of these goals. …*" (Section 1. Policy.)

Recommended Interpretation: The overarching goal given in the preamble will be achieved by implementing an array of strategies. Each strategy given in the EO Policy section can be mapped to a directive in the Goals section. These strategies are intertwined in their contribution to meeting the goal of greenhouse gas emissions reduction; thus, several directives in EO 13514 are cited in this roadmap. The focus of this roadmap, though, is on section (g)(i), which calls for NZEB design and operation of new buildings, and maps to, "design, construct, maintain, and operate high performance sustainable buildings" in the previous citation. The term "buildings" applies to NASA real property asset class 540 Buildings, but does not apply to NASA real property asset class 515 Other Structures & Facilities. However, projects for new structures could benefit from incorporating elements of NZEB practices, and certain structures may present opportunities for net zero or even net positive energy operation, such as vehicle parking structures.

2.1 Value of Net Zero Energy Buildings

Before interpreting the high performance building- and NZEB-specific requirements of EO 13514, this section discusses the value of the NZEB goal. NZEBs, and the construction and O&M thereof, can provide value to many stakeholders within the NASA family and to society as a whole. Some of these benefits will be realized directly through the performance of buildings; others will result from the knowledge, experience, and technical advances associated with NASA's leadership in constructing innovative high performance buildings.

2.1.1 Benefits to NASA

The most obvious direct benefit for NASA to invest in NZEBs will be dramatically reduced—or even zero—utility costs for a new building. If NZEBs can be achieved cost effectively, achievement of the 100% NZEB goal for new buildings (and not required but suggested implementation of some of the NZEB approaches in major renovations) will also have a positive effect on overall expenditures for the agency, freeing up funds for activities that are more directly related to the core mission.

2.1.1.1 Cost Savings Potential and Approach

Recent research has demonstrated that NZEBs can be cost effective when planned, managed, and verified using innovative, performance-based procurement approach and integrated design. For example, the NREL Research Support Facility, a large office building in Golden, Colorado, was procured using a typical construction budget for the area. Although limited data are available for NZEB construction costs, a recent study by the New Buildings Institute (NBI 2012) presents:

- A limited set of case studies suggesting that NZEBs can be procured with a 0%–10% premium on typical construction costs.
- Energy and cost modeling results showing the potential for NZEB payback periods of 12–15 years.

Based on NREL's experience and results from the NBI case studies, the lower bounds of initial capital cost premium are possible when a project team:

- Selects energy efficiency as a project priority, trading off cost investment in architectural elements that do not impact or assist in energy performance.
- Integrates simple and passive efficiency solutions, with an emphasis on envelope optimization.
- Downsizes or eliminates heating, ventilation, and air conditioning (HVAC) equipment based on passive envelope design.
- Maximizes the use of modular and repeatable design solutions.
- Specifies readily available and tested technology and focuses on the implementation details.
- Implements experimental solutions only when necessary for NZEBs and incorporates the appropriate system experts onto the project team.
- Incorporates a continuous value engineering process as part of the integrated design effort that allows cost tradeoffs between design disciplines.
- Engages experienced key subcontractors early in the design process.
- Evaluates and prepares for soft costs such as added time to review energy modeling reports and research the operation of new systems; over time, as NASA becomes proficient in NZEB acquisition and operation, the added soft costs will be reduced.

Anecdotally, operating costs can be reduced when simple and passive solutions are used. Examples such as high thermal mass, aggressive insulation, reduced lighting power density, and overhangs controlling solar load have low maintenance costs, long life cycles, and high probability of performing as expected. Use of such systems can reduce O&M costs, leading to potentially significant cumulative cost savings over a 40-year life cycle cost analysis period (specified by the National Energy Conservation Policy Act as modified by the Energy Independence and Security Act of 2007, Section 441), given the simple payback period shown possible by the NBI case studies.

2.1.1.2 Additional Benefits

The potential for cost-effective NZEBs is real, but success will require a rigorous decision-making process for each new project, as well as internal research, tracking, and communicating of each attempt. Once successful, though, the energy cost savings provided through reduced energy are likely to be complemented by valuable nonenergy benefits. The following benefits can be difficult or impossible to quantify monetarily, and are therefore often omitted from financial analysis:

- Fewer work orders generated by occupant comfort complaints, and lower absentee rate and staff turnover, assuming use of energy efficiency approaches that engage occupants by allowing them to control systems such as electric lighting and natural ventilation as needed
- Less overtime for maintenance staff, reduced backlog of preventive and reactive maintenance items, assuming simple and passive energy efficiency systems are used
- Greater thermal comfort, improved indoor air quality, and better lighting quality, assuming passive design solutions give all occupants access to glare-free daylight, natural ventilation, and adequately zoned thermal systems
- Flexibility to accommodate future changes to building occupancy and activities, assuming lighting and HVAC systems are zoned to account for variable occupancy so that systems can be set back or shut down when unoccupied
- Public relations value for improved sustainability
- Reduced environmental impact of operations, specifically greenhouse gas emissions, which can lead to compliance with: (1) the EO 13514 emission reduction requirement discussed in Section 2.2.1.1 and (2) local cap and trade or other environmental attribute programs
- Potential to contribute toward Center energy security and resiliency improvements.

NASA's commitment to NZEBs will also help the agency to:

- Develop and demonstrate innovative project delivery approaches that other agencies or the private sector can adopt.
- Advance energy efficiency and distributed renewable energy (RE) technologies.
- Improve methods for integrated design.
- Reduce the costs of energy-efficient products and equipment as demand exceeds a threshold level for manufacturing efficiency and competition increases.
- Train leaders who can motivate other federal agencies and the private sector to take action.

2.1.2 Benefits to Society

In line with EO 13514, national efforts to increase the feasibility and cost effectiveness of NZEBs are driven by several important societal benefits associated with reduced energy use:

- Reduced dependence on finite fossil fuels
- Greater energy independence
- Reduced greenhouse gas emissions that lead to climate change
- Improved livability in the surrounding community
- Reduced pollution from coal-burning power plants
- Reduced need for expensive nuclear power plants, with associated nuclear waste disposal challenges
- Job creation.

2.2 Application of Executive Order 13514

Moving forward from the value proposition of NZEBs inherent in EO 13514 and supported by industry research, the following sections cite relevant EO 13514 language. First, relevant goals in the EO 13514 are interpreted and connected to NZEB concepts and then the specific NZEB definitions are discussed.

2.2.1 Net Zero Energy Building Supporting Goals in EO 13514

The following subsections cite EO 13514 goals that relate to NZEB acquisition, design, and operations.

2.2.1.1 Greenhouse Gas Emissions

The first specific goal of EO 13514 is to:

> "*… establish and report to the Chair of the Council on Environmental Quality (CEQ Chair) and the Director of the Office of Management and Budget (OMB Director) a percentage reduction target for agency-wide reductions of scope 1 and 2 greenhouse gas emissions in absolute terms by fiscal year 2020, relative to a fiscal year 2008 baseline of the agency's scope 1 and 2 greenhouse gas emissions. … In establishing the target, the agency head shall consider reductions associated with: (i) reducing energy intensity in agency buildings; (ii) increasing agency use of renewable energy and implementing renewable energy generation projects on agency property …*" (Sec. 2. Goals for Agencies. (a))

Recommended Interpretation: NASA was required to set targets by January 2010 for reductions in greenhouse gas emissions. Emphasis was added to building energy use as a path toward the greenhouse gas emission reduction target by requiring an associated energy intensity reduction sub target. EO 13514 did not augment agency-level energy intensity reduction requirements established in the National Energy Conservation Policy Act as modified by the Energy Independence and Security Act of 2007. The current energy intensity targets are relative to a 2003 baseline and ratchet down each year, ending in a 30% reduction in 2015. The EO 13514 greenhouse gas reduction target should be met by September 2020. NASA should continue the energy intensity reduction trajectory between 2015 and 2020, aligning with NZEB performance, which is likely to be specified in future federal guidance. The roadmap, though, does not focus on agency-level energy intensity goals; rather, it focuses on building-level, demand-side energy use intensity (EUI) goals.

2.2.1.2 Net Zero Energy Buildings

The NZEB directive of EO 13514 is to:

> "*... implement high performance sustainable Federal building design, construction, operation and management, maintenance, and deconstruction including by: (i) beginning in 2020 and thereafter, ensuring that all new Federal buildings that enter the planning process are designed to achieve zero-net-energy by 2030 …*" (Sec. 2. Goals for Agencies. (g)(i))

Recommended Interpretation: This section requires that all new NASA buildings (federal new construction) be designed to reach net zero energy starting in 2020. It does not necessarily require that all new NASA buildings constructed after 2020 be an NZEB immediately. Buildings in the planning, design, or construction phase before 2020 appear to be exempt. Even for buildings entering the planning process after 2020, RE sources can be added over time, ultimately reaching net zero energy by 2030, although NASA should attempt to complete NZEB projects as soon as possible, as suggested by the tactic selection plan in Table 3-3. More importantly, we recommend that this section be interpreted as requiring net zero energy to be met at the individual building level. The language does not clearly require that buildings achieve net zero energy based on metering or utility bills but we recommend that NASA embrace NZEBs as an objective target demonstrated by actual performance after the building is occupied, and not simply as a design goal. Furthermore, we recommend that NASA apply the tactics given in the roadmap to major renovation projects to increase the rate at which NZEB processes and skill sets are built up within the agency, and to realize the stated potential benefits more broadly across the Centers.

2.2.1.3 Sustainable Building Design

The remaining goal citations in this section relate to general sustainability, focused on the built environment.

> "*… (ii) ensuring that all new construction, major renovation, or repair and alteration of Federal buildings complies with the Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings (Guiding Principles); (iii) ensuring that at least 15 percent of the agency's existing buildings (above 5,000 gross square feet) and building leases (above 5,000 gross square feet) meet the Guiding Principles by fiscal year 2015 and that the agency makes annual progress toward 100-percent conformance with the Guiding Principles for its building inventory …*" (Sec. 2. Goals for Agencies. (g)(ii-iii))

Recommended Interpretation: The Guiding Principles currently apply to all NASA new construction projects, requiring 30% less energy use relative to ASHRAE Standard 90.1-2007. Furthermore, the energy efficiency design performance standards for new Federal commercial buildings (10 CFR 433) require designs beginning July 9, 2014, meet ASHRAE 90.1-2010 and achieve at least 30% better than ASHRAE 90.1-2010 if life-cycle cost-effective. This requirement is independent of RE. For net zero energy ready (NZER) preparedness, NASA should target 50% less energy use relative to an ASHRAE Standard 90.1-2010 baseline for all buildings entering planning in 2020.

By the end of the fiscal year 2015, 15% of existing NASA buildings must also comply with the Guiding Principles, which requires that major renovations must result in 20% energy savings relative to the energy used by a specific building in 2003. Our interpretation of this requirement is not that 15% of NASA buildings must be retrofit to 20% less energy use, but that other elements of the Guiding Principles (e.g., water use, thermal comfort, daylighting) must be met in 15% of existing buildings. When a major renovation does occur, 20% energy savings is required. For NZER preparedness, NASA should target 30% less energy relative to an ASHRAE Standard 90.1-2010 baseline for all major renovations and net zero energy when most major building systems will be replaced including lighting, HVAC, roof, and windows. In fact, many of the net zero energy tactics discussed later in this roadmap apply equally well to retrofit projects. However, EUI targets and comprehensive best practices for achieving an NZEB in a retrofit context are outside the scope of EO 13514 and this roadmap.

2.2.1.4 Sustainable Building Operations

> "*… managing existing building systems to reduce the consumption of energy, water, and materials, and identifying alternatives to renovation that reduce existing assets' deferred maintenance costs …*" (Sec. 2. Goals for Agencies. (g)(v))

Recommended Interpretation: Successful operation of a building is valued in retrofits as well as new construction; tactics related to NZEB operation should be applied to retrofit scenarios even if a less aggressive operation goal is set.

2.2.1.5 Sustainable Procurements

> "*… advance sustainable acquisition to ensure that 95 percent of new contract actions including task and delivery orders, for products and services…are energy-efficient (Energy Star or Federal Energy Management Program (FEMP) designated), water-efficient, biobased, environmentally preferable (e.g., Electronic Product Environmental Assessment Tool (EPEAT) certified), non-ozone depleting, contain recycled content, or are non-toxic or less-toxic alternatives, where such products and services meet agency performance requirements; (i) promote electronics stewardship, in particular by: (i) ensuring procurement preference for EPEAT-registered electronic products; (ii) establishing and implementing policies to enable power management, duplex printing, and other energy-efficient or environmentally preferable features on all eligible agency electronic products; (iii) employing environmentally sound practices with respect to the agency's disposition of all agency excess or surplus electronic products; (iv) ensuring the procurement of Energy Star and FEMP designated electronic equipment; (v) implementing best management practices for energy-efficient management of servers and Federal data centers …*" (Sec. 2. Goals for Agencies. (h))

Recommended Interpretation: This section mandates the purchase of energy-efficient plug and process loads (PPLs) whenever they do not conflict with essential functionality for mission-critical needs, and the application of sustainable operating practices for electrical equipment. The procurement and operation elements of this language should be included in all NZEB project specifications. Because net zero energy is an operational goal, the success of every project will depend strongly on equipment procurement over time. Ongoing procurements will affect all projects; thus, we recommend that NASA develop an agency-wide process for taking an initial inventory of equipment in all new construction and major renovations, tracking procurements and ensuring they meet the EO 13514 requirements, and developing a mitigation plan when equipment is added instead of simply replacing old equipment. We also recommend that NASA review current agency-level policy and adjust as needed to allow efficient use (i.e., low power modes) of the procured equipment.

2.2.1.6 Sustainability Performance Reporting

> "*… develop, implement, and annually update an integrated Strategic Sustainability Performance Plan that will prioritize agency actions based on lifecycle return on investment*." (Sec. 8.)

Recommended Interpretation: This section sets forth requirements for each agency to develop an SSPP. The most recent update to the NASA SSPP was published in 2013, documenting progress toward the following sustainability goals related to buildings:

- 30% reduction in average EUI by 2015 compared to a 2003 baseline value of 216 kBtu/ft^2 (63 kWh/ft^2)
- RE generation equivalent to 7.5% of electricity use by 2013, as required by the Energy Policy Act of 2005
- 15% of all new and existing buildings, determined applicable, compliant with the Guiding Principles by 2015.

All recommended goals in this roadmap are at least on par with these goals; some are more aggressive. However, the focus is on pragmatic solutions that NASA can encourage in the near term, and that are required for all projects in the long term, ultimately leading to compliance with all statutory, executive order, and regulatory building energy requirements.

2.2.2 Net Zero Energy Building Definitions in EO 13514

There is considerable debate in the industry about the best definition of an NZEB. Although this roadmap does not aim to settle the debate, a clear definition is necessary to establish quantitative metrics that NASA will use to track progress toward program goals and demonstrate achievement of those goals. Guided by the EO 13514 goals cited in Section 2.2.1, the following subsections of the roadmap offer an interpretation of the EO 13514 NZEB definition: First, the EO language is discussed directly and clarifying points are given. Second, definitions commonly used in the building industry are presented. Third, an NZEB evaluation process is suggested as an approach to meet the intent of the EO 13514 definition. Lastly, an example is given which compares NZEB scenarios and their ability to meet the roadmap definition versus the other industry definitions and other EO 13514 goals.

2.2.2.1 NASA Net Zero Energy Building Definition

EO 13514 defines an NZEB as:

> "*… a building that is designed, constructed, and operated to require a greatly reduced quantity of energy to operate, meet the balance of energy needs from sources of energy that do not produce greenhouse gases, and therefore result in no net emissions of greenhouse gases and be economically viable*." (Sec. 19. Definitions. (o))

Because there is some ambiguity—and perhaps inconsistency—in this definition, a more specific and practical definition is required. To preface the definition, we offer the following interpretation:

- The first clause emphasizes energy efficiency and sets the energy use required by the building in annual operation as the measurement of focus. The energy use measurement is taken for all consumed utilities, including energy from central plants, after direct demand reduction tactics are applied and before RE is applied.
- The second clause states that the measurement should be met equally with nongreenhouse-gas-producing sources. To be consistent with other elements of current federal requirements such as Section 2 (a)(ii) of EO 13514, we interpret the second clause to also require that the sources be renewable, excluding nuclear energy. In addition, we interpret this clause to require the direct use or purchase of renewable energy to meet the balance of needs (versus indirectly generating demand for renewable energy by purchasing renewable energy certificates that represent environmental and other non-energy attributes of the energy).
- The third clause presents—but does not require—the intended outcome of offsetting greenhouse gas emissions. This clause may imply that the RE sources used to balance the energy needs include "no net-emitting" sources (e.g., biomass) versus "zero emitting" sources (e.g., solar) alone.

This loose interpretation appears to be corroborated by the definition of RE given in EO 13514:

> "*… energy produced by solar, wind, biomass, landfill gas, ocean (including tidal, wave, current, and thermal), geothermal, municipal solid waste, or new hydroelectric generation capacity achieved from increased efficiency or additions of new capacity at an existing hydroelectric project.*" (Sec. 19. Definitions. (j))

We recommend that the "no net-emitting" interpretation be accepted as an option but that it be prioritized after "zero emitting" RE. NASA should align policy related to biomass use with guidance such as the Federal Greenhouse Gas Accounting and Reporting Guidance Technical Support Document (CEQ 2012). The current Technical Support Document states that EO 13514 greenhouse gas reporting requirements exclude emissions due to biomass combustion from agency reduction targets because of the relatively short timescale that the associated carbon was secured and the reabsorption once released into the atmosphere through combustion. Section 203 (b)(1) of EPACT 2005 should be used as a guide for acceptable biomass sources and consideration should be given to the general sustainability and net emissions impact, such as emissions during biofuel production, when selecting a source.

2.2.2.2 Net Zero Energy Building Pathways

To extend these interpretations, a NASA NZEB evaluation process is built on the definitions developed by Torcellini et al. (2006), along with the classification grading system proposed by Pless et al. (2010), with some adaptations to align with other elements of this roadmap. One advantage of the system is that it provides substantial flexibility with respect to selecting RE generation technologies, which is important for high-risk projects. According to this system, any building can achieve NZEB status, regardless of building type, climate, geometry, or site constraints. If a building's characteristic energy use (based on building type or use) is too high or its site too restricted to achieve NZEB design within the site boundary, the options still allow for resources external to the site to be used to offset the remainder of site energy use. Importantly, though, preference is given first to energy efficiency, then to footprint-tied, zero-emitting renewables, and then to "no net-emitting" and spatially disconnected sources as a last priority.

2.2.2.2.1 General Net Zero Energy Building Classifications

An NZEB can be defined in several ways, depending on the boundary and the metric. Four commonly used accounting methods are net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions. Each definition uses the grid for net-use accounting and has different applicable RE sources. Net zero site energy is the most intuitive definition, and is the one we recommend for NASA's NZEB program.

- Net Zero Site Energy (recommended for NASA): A site NZEB produces (or purchases) at least as much RE as conventional energy it uses in a year, when accounted for at the site. RE does not necessarily have to be generated onsite, but transmission and distribution (T&D) losses should be included in the calculation of net energy use. This definition aligns with the EO 13514 language that requires the project to "meet the balance of energy needs" of the building. It also emphasizes the "designed, constructed, and operated" elements of the requirement by directly measuring building performance, and deemphasizes the complexity that can be added to the NZEB decision-making process when conversions such as changing national average site-to-source multipliers are used.
- Net Zero Source Energy: A source NZEB produces (or purchases) at least as much RE as conventional energy it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to extract, process, generate, and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers based on the utility's source energy type.
- Net Zero Emissions: A net zero emissions building produces (or purchases) enough zero-emitting RE to offset emissions from all energy used in the building annually. Carbon, nitrogen oxides, and sulfur oxides are common emissions that NZEBs offset. To calculate a building's total emissions, imported and exported energy is multiplied by the appropriate emission multipliers based on the utility's emissions and onsite generation emissions (if there are any). In a strict sense, a net zero emission goal cannot be met with "no net-emitting" sources.
- Net Zero Energy Costs: In a cost NZEB, the amount of money the utility pays the building owner for the RE the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year. The utility rate structure must be well understood and stable for this definition to be meaningful. This definition is not considered in the roadmap beyond this explanation because the roadmap tactics related to NZEB acquisition will help drive a cost-effective outcome.

2.2.2.2.2 NASA Net Zero Energy Building Evaluation Process

A series of steps based on Pless and Torcellini (2010) should be followed for all projects to encourage project teams to first use all possible cost-effective energy efficiency solutions, and then use RE sources and technologies that are located on the building. Once all possible cost-effective efficiency and onsite RE technologies have been fully exploited, offsite options should be explored if necessary. Each step should be performed in order and to the extent possible, only skipping steps when high loads, site constraints, and life cycle analysis results favor an offsite option. Criteria for meeting each RE approach are given in the step description. The criteria are based on results from an NREL analysis on NZEB feasibility (Griffith 2007) and guidance given in the Living Building Challenge Net Zero Energy Building Certification program. The process of moving through the steps ends when 100% of annual site energy use can be met by RE sources. This advantage of a process-based NZEB definition is that the system allows all* NASA building types to meet the goal using one or more of the alternative methods of accounting for RE generation.

Step 1: Reduce building energy use through demand reduction, energy efficiency, and demand-side RE building technologies (such as ground source heat pumps [GSHPs] or passive solar heating). A well-optimized NZEB should include such solutions to the point where the supply-side RE technologies become the next most cost-effective measure, which we define as "best-in-class" energy efficiency. This step is a prerequisite because maximizing energy efficiency is a fundamental quality of NZEBs.

Step 2: Maximize the use of zero-emitting RE sources within the building footprint and connected to the building's electrical or hot/chilled water distribution system. Footprint-associated RE sources are preferable to non-footprint sources because the availability of the collection area can be guaranteed over the life of the building, preventing future challenges balancing NZEB goals and land use. However, the cost of building-mounted RE could be prohibitive because of negative interactions with the building structure or interference with building functionality, which would require a heavier reliance on Step 3. Regardless, footprint-associated RE should contribute a minimum of 20% of the RE requirement.

Step 3: Maximize the use of zero-emitting RE sources at the building site and connected to the building's electrical or hot/chilled water distribution system. This step addresses RE generated on the building site when it cannot be located within the building footprint or mounted on the building. The site is typically defined as the property boundary; however, sites should represent a meaningful boundary that is functionally part of the building. LEED v4 (USGBC 2013) offers guidance on site boundary definitions. Onsite RE sources are preferable to offsite sources because they align with NASA site-based energy security and reliability objectives. Typical onsite RE approaches include parking lot photovoltaic (PV) systems mounted to shading structures, tower-based wind turbines mounted in a neighboring field, and ground-mounted solar hot water (SHW) systems connected into the building's hot water distribution system.

*At this step, 100% of the RE needs should be met for low-load buildings such as offices and support buildings. High-load buildings such as laboratories and cafeterias may use the following steps to meet the NZEB goal. Step 4 should be considered only in the scenarios mentioned when multiple benefits can be shown (e.g., a stable supply of renewable fuel exists locally and use of combined heat and power meets process load demands), and when an agency-level review is performed with respect to current federal requirements for agency greenhouse gas reduction and use of renewable fuel. In addition, if Step 4 is used, the tactical consideration regarding building-related greenhouse gas reduction must be used. Like Step 4, Step 5 should be considered only in the scenarios mentioned when multiple benefits can be shown (e.g., better wind or solar resource exists offsite and intermittent use of high equipment loads used for research does not allow for a cost-effective solution onsite). At a minimum, 20% of RE needs should be met before moving to Step 4 or Step 5 by all new buildings.

Step 4: Use RE sources that may be available offsite to generate energy onsite that can be connected directly to the building's electrical, space heating, or hot/chilled water distribution system. An example of this would be wood chips imported to heat a building. Other offsite renewables covered under this approach include waste vegetable oil, biodiesel, and ethanol. Understanding and documenting the life cycle emissions and carbon impacts of biofuels are important steps in including these types of renewables in NZEB projects. To guide this analysis and compare the offsite options to EO 13514 GHG reduction requirements, an agency-level sustainability and/or energy representative, such as a representative from the Environmental Management Division, should be directly engaged in the project preplanning and design. This connection between the defined site NZEB goal and the agency-level greenhouse gas emission is addressed at the tactical level.

If offsite RE sources are used to generate energy onsite, the non-renewable energy needed to process the fuel at the renewable central plant should be accounted for in the building energy consumption.

Step 5: Invest in or purchase newly installed (per current federal guidance) offsite RE. Preference should be given to options in which NASA can directly invest and therefore take ownership of all or part of the system. Our suggested prioritization of the offsite options is to:

1. *Use NASA-financed or NASA-owned power production.* For example, a Center could establish strict efficiency goals and negotiate with its power provider to install offsite dedicated wind turbines or PV panels at a local or regional offsite location with better solar or wind resource. In this approach, NASA might finance or own the hardware (or a portion of the system) and receive credit for the power. Preference should be given to zero-emitting sources.
2. *Purchase green power that is regionally produced.* For example, a Center could purchase green power through a third-party community choice aggregation or utility green pricing program. Purchased green power must be derived from zero-emitting sources to ensure that the fuel mix associated with the building's energy use is known. This means that purchasing biomass-derived power through a green power provider to offset natural gas use does not achieve an NZEB. Also, the purchase of RECs that are disaggregated from the purchase of power is not a pathway to an NZEB in the roadmap.

To guide the process of selecting the most appropriate offsite option, an agency-level sustainability and/or energy representative should be directly engaged in project preplanning and design, and the solution approved by NASA headquarters early in the design phase. Considerations to help guide the evaluation of offsite options include:

- RE options should be an integral part of planning and design, encouraging a focus on energy efficiency
- NASA should be directly invested in the RE sources when possible to increase the likelihood of consistent source availability over the life of the building
- RE production should be directly measured by or reported to NASA when possible so that the actual annual production can be compared to the building energy use, and so that daily production profiles can be tracked.

In all steps, care should be taken to either retire, retain, or purchase equivalent RECs, in accordance with federal guidance, as part of the design process in an attempt to comply with the EO 13514 NZEB definition intent of aiding in greenhouse gas reduction when meeting the balance of energy needs for a new building.

The site NZEB goal and steps for achieving the goal attempt to balance energy source reliability, cost, and greenhouse gas reductions, and ultimately meet the EO 13514 goal of all new construction achieving net zero energy. Reliability is addressed by the footprint, onsite, and then offsite prioritization. Cost is addressed by allowing all steps to be used when life-cycle-cost justified. Emissions are addressed in two ways: inherently through the use of the net zero site energy definition selection, which often results in net zero emissions due to direct energy used, and by engaging agency-level support for life cycle analysis of RE options if Step 4 is used. Additional NASA building-related greenhouse gas emissions that are not accounted for by the NZEB definition options are:

- Fugitive emissions from building equipment (tracked according to EO 13514 requirements)
- Production, transportation, construction, demolition, and recycling of building materials

While not considered directly though the EO 13514 NZEB requirement or NASA NZEB roadmap, these emissions should be reduced to the extent possible on each project.

2.2.2.2.3 NASA Net Zero Energy Building Evaluation Process Example

Table 2-1 gives example NZEB scenarios for which RE is sized to meet site energy use after energy efficiency solutions are applied. The impact to source energy and greenhouse gas emissions is compared qualitatively.

Although a building may be designed according to the process definition to be an NZEB, it may not actually achieve net zero energy in operation every year. For example, a well-operating building may fall short of the NZEB operation goal during abnormal weather years that have above-average heating and cooling loads, with below-average solar and wind resources. Net zero energy is therefore an operational target that requires continuous improvement to sustain. (Improper commissioning, poor maintenance practices, or incorrect operation of a building can also undermine the design intent, and prevent it from achieving net zero energy in a particular year. These variables, though, are controlled for in the NZEB operational tactics and should not be accepted as reasons for not achieving net zero energy.) The net energy use of each building should be measured, reviewed, and tracked each year with submetering.

Table 2-1 NZEB Example Comparison, Designed for Net Zero Site Energy

Example tactics: (unit energy)*	Example 1, office, mild climate, adjacent parking lot		Example 2, laboratory, cold climate, constrained site, central plant	
Step 1, energy efficiency	Daylighting, natural ventilation, etc.		Daylighting, solar hot water, etc.	
Conventional source	*Utility electricity:*	*(1)*	*Utility electricity and natural gas:*	*(3)*
Step 2, footprint RE	Roof-mounted PV:	(-0.5)	Roof-mounted PV:	(-1)
Step 3, site RE	Parking lot canopy PV:	(-0.5)	N/A	-
Step 4, offsite RE, onsite generation	N/A	-	Standalone combined heat and power fed by renewable fuel:	(-2)
Step 5, offsite RE, purchased	N/A	-	N/A	-
Net zero site energy	Yes, RE sized for whole building energy use (electricity)		Yes, RE sized for whole building energy use (electricity and natural gas), accounting for the non-renewable energy used in the central plant attributable to the building	
Net zero source energy	Yes		No	
Net zero emissions	Yes		No	
Discussion	The most straightforward scenario is when the energy carrier for demand and supply is the same, and when the RE is a zero-emitting source. In this scenario, if the building meets net zero site energy in a fiscal year then it will also meet net zero source energy and emissions in the same year.		If a project team uses Step 4, "no net-emitting" sources become an option. In this scenario, net zero site energy might not imply net zero source energy or emissions. The differential would result from the dissimilar fuel production energy use and combustion emission mix, respectively. In this scenario, the source energy use and emissions might be greatly reduced relative to a conventional energy scenario but an accounting balance might not be achieved.	

*These unit energy values are presented as an accounting exercise and are not tied to real case studies or simulation. The unit energy values in the second row indicate the annual energy needed after energy efficiency and demand reduction measures are applied. The negative values indicate renewable energy use (either by the building directly or within the utility region of the building).

2.3 Strategic Metrics To Verify Success

The NZEB goal for an individual building is achieved when allowable RE sources (in accordance with Steps 1–5 in Section 2.2.2.2.2) generate more energy than the building consumes in a fiscal year. Project teams, guided by an energy performance assurance process, should be tasked to meet this criterion in a 2-year window after building turnover, and to sustain net zero energy every year thereafter through recommissioning, maintenance, and ongoing enhancements to operational practices as building functions and occupancy levels change over time. Key members of the project team should be retained on an incentive basis during the first two years of operation to help the building operators and others assisting with energy performance assurance improve building performance based on lessons learned within the first year; this formal collaboration will increase the likelihood that NZEBs will be achieved in the first formal reporting year, which is suggested to be the second year after turnover (unless further federal guidance is issued on reporting requirements).

Ultimately, the EO 13514 NZEB requirements should be verified at the building level and the annual success of each building should be rolled up for agency reporting as the percent of NASA new construction achieving the NZEB goal. Shown in Table 2-2, this metric of building-by-building progress should be reported as a percent of new construction that begins in 2020 or later. For NASA, the official start date for a project is recommended to be when a Preliminary Engineering Report (PER) is started. The strategic-level metric is disaggregated for NZEB design and operations, and over time periods leading to the 2020 NZEB design goal and 2030 NZEB operations goal of EO 13514. The NZEB operations metric displaces the design metric in 2030 since it is assumed that all new construction must be designed for NZEB according to the roadmap tactics to achieve NZEB operations. The 2025 marker year is listed for reference to other organizational-level metrics given in the roadmap. The metrics should be evaluated annually.

In the long term, starting in 2030, the NASA SSPP should be expanded to include the annual performance of all NASA NZEBs. In the short term, once NASA commits to NZEB operations on a project, the OMB scorecard graphic shown in Figure 2-1 could be used at the project and agency level for annual tracking. For example, the scorecard could indicate whether all applicable new construction is achieving net zero energy within the fiscal year (green), net zero energy within the past two fiscal years (yellow), or failure to achieve net zero energy for all buildings within the past two fiscal years (red). NASA should incentivize and remediate progress toward the NZEB goal using mechanisms that have already been used in response to the SSPP annual results, if applicable at the Center or building level.

Table 2-2 Strategic-Level Metrics Leading to NZEBs by 2030

Metrics and minimum criteria	Pre-2020	2020	2025	2030…
NZEB planning, design, and construction for new NASA buildings				
EO 13514 metric: Percent of NASA new buildings, entering planning in 2020 and thereafter, designed to achieve net zero energy	Calculation: The number of buildings that formally set a NZEB target*, divided by the number of buildings with a PER developed in 2020 and thereafter x 100			
	N/A	100%	100%	N/A
NZEB operations for new NASA buildings				
EO 13514 metric: Percent of NASA new buildings, entering planning in 2020 and thereafter, achieving net zero energy in the fiscal year (per EO 13514)	Calculation: The number of buildings in year two of operations and thereafter that demonstrate net zero energy, through measurement of energy use and production, for the fiscal year, divided by the number of buildings with a PER developed in 2020 and thereafter x 100			
	N/A	N/A	N/A	100%
NASA metric: Percent of NASA new buildings, entering planning in 2020 and thereafter, achieving net zero energy within the past two fiscal years	Calculation: The number of buildings in year two of operations and thereafter that demonstrate net zero energy, through measurement of energy use and production in a fiscal year, during at least one of the past two fiscal years, divided by the number of buildings with a PER developed in 2020 and thereafter x 100			
	N/A	N/A	N/A	100%

*Aligning with the NZEB tactic in the roadmap, a formal NZEB target means one that is included in the project contract. If net zero energy is not required in a project contract then the project should be counted as "design to achieve net zero energy" if an aggressive EUI is included in the project contract and other NZEB tactics are being used according to the roadmap.

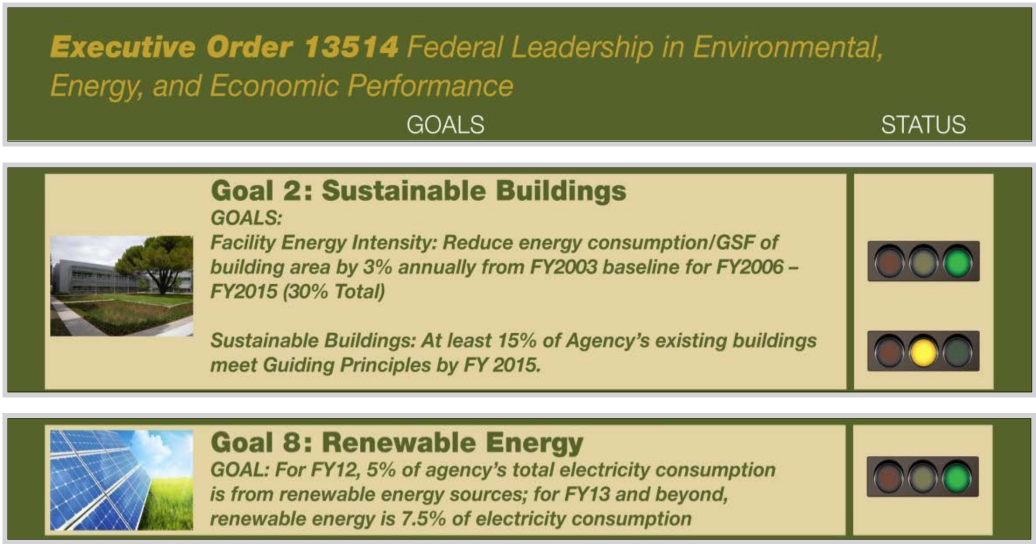

Figure 2-1 Energy-related goals in the NASA 2013 SSPP

2.4 Culture Change

NZEBs require the commitment and direct involvement of a variety of organizational stakeholders at NASA:

- Master planning
- Senior managers
- Contracting officers
- Financial managers
- Project managers
- Energy and environmental managers
- Facility engineers and managers
- O&M staff
- Procurement and property managers
- Information services
- Building occupants.

Business-as-usual practices for designing, constructing, and operating buildings will not be conducive to NZEB performance levels. We recommend that NASA:

- Continue to establish a culture of innovation and leadership in sustainable design, just as it has in aerospace technology.
- Consider energy to be an important factor for all building design tradeoffs.
- Ensure that long-term cost implications take precedence over short-term gains and short payback periods.

- Always factor nonenergy benefits, including those that can't be quantified monetarily, into the decision-making process.
- Maintain essential functionality, but eliminate unnecessary equipment and miscellaneous electric loads (MELs) when they do not contribute to the mission or to the comfort and well-being of employees.
- Mitigate project team boundary issues in favor of a more collaborative and integrated design and construction process.
- Educate occupants about how to take action to minimize wasted energy in their own work areas, and ensure that managers encourage and reward such efforts.
- Leverage and strengthen human capital at Centers to drive NZEBs agency wide.
- Engage external partners to participate in culture change using contracting mechanisms or incentives. External partners include:
    - Designers
    - Construction contractors
    - Energy modelers
    - Commissioning agents
    - Food services and vending companies
    - Contracted staff such as for custodial or security services.

This culture change may be very challenging at times, necessitating leadership and continuous reinforcement of NASA's commitment to NZEBs by senior managers. Positive incentives and buy-in from all stakeholders are likely to be the most effective methods to ensure cooperation and active support from all parties. However, a balance between incentives and policy-based motivators may be the optimal approach for securing commitments and innovation from stakeholders.

In addition to the increased emphasis and communication from NASA Headquarters to Centers about NZEB goals, and the ongoing training required to prepare all stakeholders for the organizational and tactical tasks being delegated, two specific ongoing efforts will require support from NASA Headquarters: assignment of energy performance assurance capability and formation of an occupant engagement program.

2.4.1 Net Zero Energy Building Performance Assurance Capability

In this roadmap, NZEB energy performance assurance capability is the umbrella description given to unique elements of a NZEB program relative to traditional building acquisition and operation. These elements given in action form are to:

1. First and foremost, define a NASA program that focuses on culture change within the agency and aims to address concerns, provide timely information, and share successes and lessons learned around the NZEB goal.
2. Deliver agency-wide training on NZEB organizational proficiency categories and either deliver or facilitate trainings for NZEB tactics.

3. Help to set and review project-specific EUI goals.
4. Add a checks-and-balances perspective to moving through the NZEB definitions; review project team-provided substantiation documents that justify movement through the NZEB process and steps.
5. Guide project teams toward the EUI goal by proposing NZEB tactics and reviewing substantiation documentation.
6. Communicate with project managers in a continuous and agile manner to perform energy-related substantiation reviews and RE procurement information at the time of decision-making.
7. Cut across all procurement activities to ensure coordination of the NZEB effort and that procurement contract requirements do not introduce roadblocks for NZEBs.
8. Help teams procure RE and purchase green power.
9. Track NZEB tactic lessons learned and deliver the important lessons learned to other project teams at the time of relevant decision-making.
10. Translate NZEB tactics into generic Requests for Proposals (RFPs) or specification language once NASA has demonstrated proficiency.
11. Ultimately, ensure that all new construction projects starting design in 2020 and thereafter are designed to NZEB standards, and assist in tracking and goal alignment for buildings operating to net zero site energy in 2030 and beyond.

This capability is presented in this roadmap as a Headquarters perspective for simplicity, but it could take shape in any number of ways. One of the first steps in roadmap implementation is to appropriately define this capability within NASA to align with current Center energy manager and Headquarters energy and sustainability roles, and scope depending on a specific timeline and location for new construction and major renovation projects.

2.4.2 Occupant Engagement Program

A key to sustaining long-term performance is acknowledging how building occupants influence the amount of energy consumed. Based on NREL analysis of a typical office building, occupants can control approximately 50% of the energy used in office buildings such as lighting, plug loads, and environmental system controls. Designing to a performance goal, and incorporating technology and building automation to guarantee NZEB performance in the first year are simply first steps; an energy performance assurance process will need to be developed that relies on occupants to support energy goals throughout the building life. A frustrated user can disable the most energy-efficient settings to achieve the desired results and can easily turn an NZEB from peak to poor performance. In a high performance building where every Watt counts, NASA will need to engage and enable staff members to understand their impacts on each building. The development and deployment of an occupant engagement program are critical to attain successful outcomes that build awareness, participation, and ownership.

Because all buildings have common elements, an occupant engagement program should be standardized at the Headquarters level based on collaboration with the Centers. For example, occupancy patterns should be collected in a standard way for benchmarking and use of the metrics listed in Section 2.3. Also, the POE process currently being standardized at the

Headquarters level can serve as a vehicle for collecting and disseminating NZEB lessons learned. The specific information relating to occupant engagement that should be tracked includes:

- Occupancy patterns
- Occupant-driven MELs use types and patterns
- Percent energy use that can be impacted by occupant control.
- Type of occupant engagement programs (e.g., email-based reminders to turn off personal lighting systems)
- Efficacy of occupant engagement programs for evaluation and potential use by other Centers.

Engagement in the NZEB planning, design, construction, and operation process is equally critical for facility managers and engineers. In a sense, these people are super-users and occupants because their decisions about energy system settings have impacts on annual energy use that are often much larger than a typical occupant's impact. To engage facilities team members, NASA should consider an element to the agency-wide occupant engagement program that encourages communication of all lessons learned, resulting in transparency and pride in progress toward NZEBs in incremental steps. An element of this program could include sending NASA facilities staff to industry conferences to share their specific experiences with NZEBs and to collect information from other agencies and owners that can then be shared internally. Agency-level communication, education, and advocacy for proficiency in NZEBs among NASA staff are equally important to the project-level tactics that will lead to proficiency.

3 Organizational Level Considerations

To meet the strategic objectives discussed in Section 2.0, more specific organizational and tactical objectives must be achieved. This section defines the key organizational proficiency categories necessary to ensure that NZEBs become standard expectation for new buildings by 2030 and describes organization-wide metrics that can be used to benchmark progress toward long-term goals. The premise of the organizational proficiency approach is that there is a set of categorical actions (tactics) that, when bundled appropriately based on project type and location, are unique to NZEBs. If the appropriate tactics are selected based on early project analysis and successfully implemented, an NZEB will presumably be achieved. This is not meant to imply that achieving an NZEB will be easy; successful execution of tactics will require culture and procurement process changes, extensive energy and cost modeling, and a focus on implementation and operation details.

3.1 Capstone and Organizational Proficiency Categories

Organizational proficiency (OP) categories include the experience, skills, and standard workflows necessary at the Center level to achieve the strategic goals defined in this roadmap. Table 3-1 shows four key OP categories that an organization must successfully master to standardize NZEBs for new construction. Two additional proficiency categories, called *capstone proficiencies* (CPs), initiate and carry the NZEB roadmap through 2030 and beyond. The CPs address experience, skills, and workflows needed at the agency-level. CP1 is an ongoing category that will be developed throughout the implementation of the roadmap, and CP2 is achieved by definition when NASA demonstrates proficiency in the four organizational proficiency categories. Each tactic has been adopted as standard practice.

Because it is difficult to objectively prove that these proficiencies have been accomplished, the best approach is to demonstrate proficiency through pilot projects, documentation of lessons learned, mentoring programs, and ultimately policy changes that mandate the application of the resulting best practices. The number of successful pilot projects needed to establish best practices and demonstrate proficiency with high confidence can vary greatly depending on the nature of the proficiency. Best practices for acquisition, solar integration, and operations are fairly independent of climate and building type, and may require fewer pilot projects. Energy-efficient design principles are likely to be very different depending on the site specifics, involving many tactics, and a more diverse set of pilot projects may be necessary to establish best practices that can be applied to all NASA building types at all Centers. Table 3-2 provides an example of how a series of pilot projects spanning several years can be used to develop proficiency in energy-efficient design, and provides target years for several other organizational proficiencies. See Section 4.0 for complete tactic tables.

Table 3-1 Capstone and Organizational Proficiency Categories

Capstone and Organizational Proficiency Categories	Purpose
CP1: Institutionalize NASA NZEB workflow	In 2014 and 2015, transition the NZEB roadmap into a formal NASA process that integrates into current project planning, execution, and review processes.
OP1: Establish NZEB acquisition process	In a step-by-step approach, integrate elements of an energy performance-based acquisition process into current NASA acquisition processes by the end of 2017; starting in 2018, all projects begin with a project structure that is conducive to achieving NZEBs.
OP2: Establish EE system best practices	A base level of energy efficiency is required by all new projects. Key system elements and performance requirements are identified that have been shown to be roadblocks to NZEBs in low energy building case studies. Each new construction project should select at least two system-level tactics that will result in a set of lessons learned that will ensure success on future projects.
OP3: Establish RE system integration process	In line with the NZEB definition and steps identified in this roadmap, RE systems can be time phased and emphasized second to energy efficiency. Once NASA has started to demonstrate proficiency in the energy efficiency categories of envelope, lighting, HVAC, and MELs, project resources should be directed toward integrating RE systems.
OP4: Establish NZEB operations plan	NZEB operation requires efforts that are not common in standard practice. The tactics identify efforts related to submetering, O&M practices, and occupant engagement.
CP2: Achieve NZEBs	As a capstone category, these tactics define agency-level metrics for tracking progress toward the EO 13514 NZEB goal.

Table 3-2 Example Time-Phased Approach To Developing Organizational Proficiencies

Organizational Proficiency Categories	Tactics	2015	2020	2025	2030
OP1: NZEB acquisition process	OP1 tactics, left blank intentionally for the example				
OP2: EE system best practices	Procure an advanced lighting control system	Pilot and develop spec language			
	Require air barrier testing	Pilot and develop spec language			
	Account for and control MELs	Pilot and develop spec language			
	Remaining OP2 tactics, left blank intentionally				
OP3: RE system integration process	OP3 tactics, left blank intentionally for the example				
OP4: NZEB operations plan	OP4 tactics, left blank intentionally for the example				

3.2 Organizational Metrics

Metrics used to track organizational objectives must be practical to assess and realistic to achieve, culminating in successful accomplishment of all strategic objectives. The metric recommended for this purpose is the percent of tactics successfully piloted (i.e., results lead to new master specification language). This metric is presented in Table 3-3 along with suggested multiyear targets, which are based on the suggested start year for each tactic and an assumption of approximately three new construction projects per year between 2016 and 2025.

Table 3-3 Organizational-Level Metric Leading to NZEBs by 2030

Metrics and minimum criteria	2020	2025	2030
NZEB tactics for NASA new and major renovation projects			
NASA metric: Minimum percent of OP tactics successfully piloted in new construction and major retrofit projects	Calculation: The number of tactics that have been translated into NASA general specification language or requirements, divided by the total number of tactics in the most current version of the roadmap* x 100		
	30%	90%	100%

*The roadmap identifies 46 tactics within the organizational proficiency categories (57 tactics including the capstone categories) that collectively differentiate NZEBs from typical practice. All tactics are not required for each project to achieve an NZEB but most will be used on every NZEB project entering planning in 2020 and thereafter. To ensure that tactic implementation is tracked on multiple projects for informal trends analysis among successes and lessons learned, each project starting in 2015 should select a minimum of 10 tactics to formally pilot. The number of tactics used but not necessarily piloted (e.g., tracked) should gradually increase based on project start year to approximately 35 tactics used for projects entering planning in 2020. This will give the pilot iteration time needed to turn most tactic pilots into specification language by 2025.

Figure 3-1 shows the distribution of tactic implementation (might not correlate directly to project start date) relative to the marker years identified by EO 13514 and the strategic metrics given in Section 2.3. This figure is meant to give a general picture of when NASA activity related to pilot implementation and tracking will be greatest and when tactics from each proficiency category should be phased in to planning discussions. More specific pilot time periods for each tactic, which conclude with the development of specification and requirement language, are given in Section 4.0.

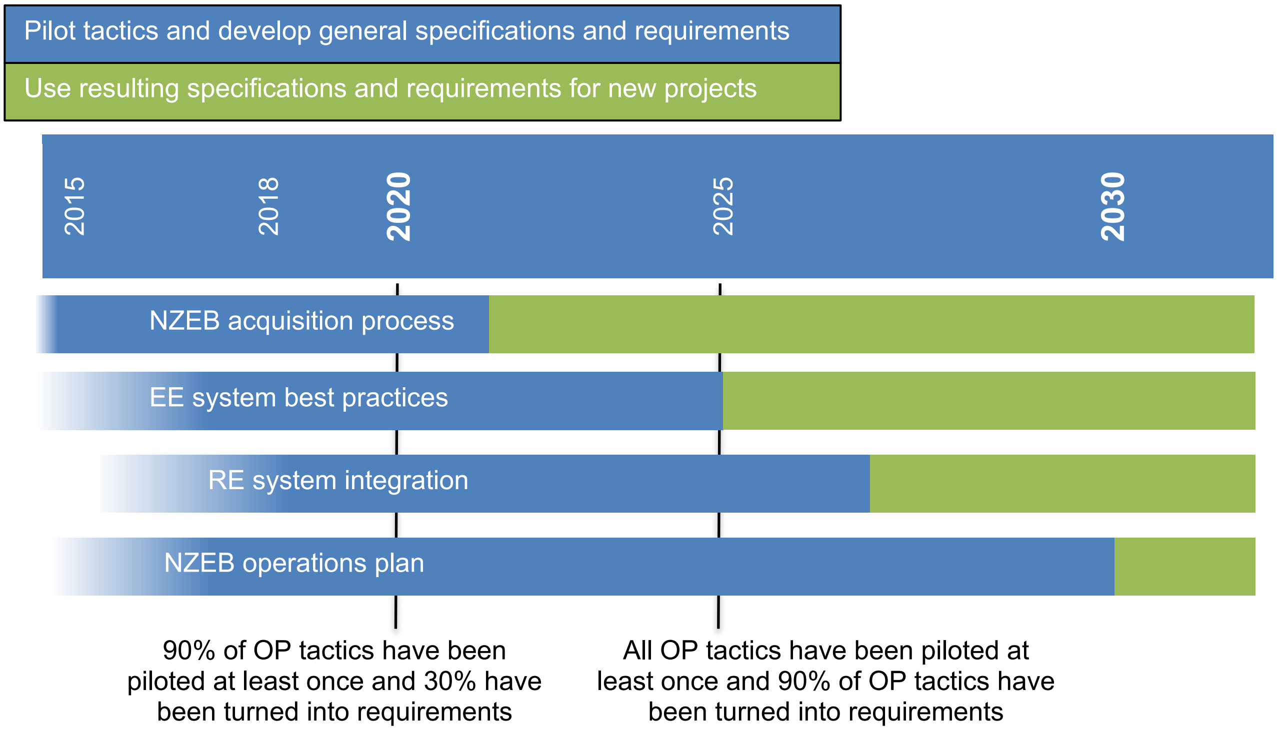

Figure 3-1 Strategic and organizational metric overlay

3.3 Project-Specific Metrics

Project-specific metrics in the will be helpful to connect the tactics (primarily those in OP2 and OP3) to the NZEB steps presented in 2.2.2.1. As discussed, it is important to ensure that NZEBs meet a threshold level of energy efficiency before RE is added. Because it is difficult to demonstrate that the energy efficiency requirements of Step 1 have been met for a particular building, we recommend simplifying the process for project teams by establishing a series of EUI targets for each major building type NASA constructs. Each EUI target should correspond to the NZER point on the optimal life cycle cost curve for the relevant building type (see Figure 3-2), which defines the most cost-effective efficiency package at each level of energy savings. This curve may vary significantly depending on the building type and climate region. The EUI targets will include all energy uses in the building, including MELs. EUI targets may change over time, and NASA should revisit changes in technology, measure costs, and energy prices as necessary to determine if lower EUI targets are justified. Terms used in Figure 3-2 are defined below:

- **Total life cycle cost** (TLCC)
    - Inputs. Analysis period, discount rate, measure costs, measure lifetimes
    - Incorporates. Capital costs, O&M costs, energy costs, replacement and salvage costs, tax implications, impact on resale value.
- **Optimal life cycle cost curve**. A series of points, approximated by a curve, representing packages that achieve a specific level of energy savings at the lowest TLCC.

- **Baseline**. The efficiency level consistent with NASA's current practice and the Guiding Principles.
- **Cost minimum**. An efficiency package that minimizes TLCC; maximum return on investment.
- **Cost neutral**. An efficiency package with the same TLCC as the baseline; maximum efficiency level that can be achieved cost effectively.
- **NZER**. An efficiency package that includes all the efficiency measures that are more cost effective than RE, consistent with Step 1 of the NZEB definition.
- **NZE**. Adding RE generation to an NZER efficiency package as needed to achieve annual site NZE.

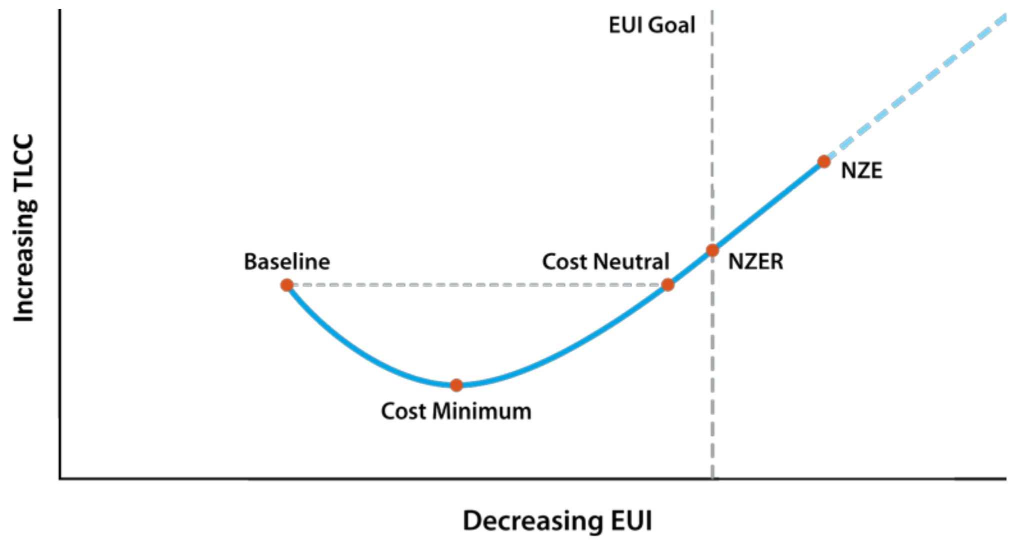

Figure 3-2 NZER in context of optimal life cycle cost curve

As a starting point for project teams, Table 3-4 gives EUI targets by typical building type and climate zone that applies to NASA Centers. The values given are based on a study performed by NREL (Griffith 2007) to determine the "max tech" scenario, or the energy performance possible when all appropriate and available energy efficiency solutions are applied to a specific building type in a specific climate. The targets do not necessarily represent the best possible EUI that can be achieved; rather, they represent an aggressive yet achievable target for a project that begins design once the roadmap is implemented. These EUIs are not as aggressive as the 50% reduction versus ASHRAE Standard 90.1-2010 that should be targeted starting in 2020.

Table 3-4 Reference EUI Targets by Climate and Building Type (in kBtu/ft^2/yr [kWh/ft^2/yr])

Climate Zone	2	3	4	5
NASA Centers and Component Facilities	JSC, MAF, SSC, KSC	ARC, AFRC, JPL, GDSCC, WSTF, MSFC	GSFC, HQ, WFF, LaRC	GRC, PBS
Assembly/public	36 (11)	38 (11)	27 (8)	29 (8)
Food services	298 (87)	334 (98)	305 (89)	316 (93)
Laboratory	319 (93)	319 (93)	227 (67)	286 (84)
Office	36 (11)	30 (9)	34 (10)	33 (10)
Service	42 (12)	32 (9)	38 (11)	40 (12)
Training/classroom	27 (8)	22 (6)	26 (8)	22 (6)
Warehouse	13 (4)	15 (4)	17 (5)	19 (6)

This roadmap recommends that these values be used for reference only, to familiarize a project planning team with a ballpark goal. Each project lead should evaluate the mix of space types that will be included in each project, and then use references such as the U.S. Environmental Protection Agency's ENERGY STAR Target Finder and Labs21® tools to refine the target before schematic design, and preferably during preplanning so that the target can be included in the contract. Target setting should be applied to all new construction projects whether or not an NZEB is being pursued. New construction projects that enter design in 2020 and thereafter should use the TLCC evaluation process outlined earlier in this section. The project team for a building seeking NZEB status must first identify a plausible path or technology package for achieving an NZEB for the specific climate and building type mix, within an estimated project budget. This will help set the EUI goal for the design and construction team. Then, the project team can identify the actual technology package in design that meets the EUI goal in the most cost-effective way using real-time cost information and more detailed TLCC information about the systems being considered. Just like integrated project design, goal setting is an iterative process:

1. NASA starts with ballpark goals.
2. NASA and an energy analyst use TLCC to refine the goals.
    a. Consider using tiered goals if a design competition is used.
    b. Consider normalizing the goals for uncertain design elements such as occupancy or data center capacity.
3. The integrated project team achieves the goals in design, construction, and early operation.
4. NASA and the integrated project team assess the goals at project conclusion for feedback to future, similar projects.

Site EUI targets should be informed by lower level metrics based on the types of activities conducted in each building. These lower level metrics can be much easier to estimate, and can be combined to create higher level EUI metrics for mixed-use buildings, such as laboratory buildings that also include office space or a cafeteria. Table 3-5 lists some of the common energy use metrics used for various building and space types.

Table 3-5 Common Metrics Used in Various Building Space Categories

Metric	Application
Btu/ft^2 (Wh/ft^2)	Any building
Btu/employee (Wh/employee)	Office building
Btu/unit of product (Wh/unit)	Assembly/manufacturing
kWh/ft^2	Lighting
kW/ton	Chilled water efficiency
W/ft^3 airflow/min	HVAC systems

Other methods for establishing intermediate goals, such as percent savings relative to NASA current practice or percent of energy use met by renewables, are less practical in the context of setting targets for performance-based design and construction contracts.

Sustainable or “green” buildings may require additional metrics, including water use intensity, embodied energy, percent recycled content, and other metrics, to demonstrate minimized environmental impact. However, this roadmap focuses on the metrics related to energy efficiency, and does not establish other important sustainability metrics.

4 Tactical Level Considerations

The third and most actionable series of objectives is tactical. This section describes the essential tactics associated with NZEB design and construction based on lessons learned from NREL's experience designing and operating NZEBs as well as numerous high performance buildings documented in a recent study by NBI (NBI 2012). These tactics cover the spectrum from building acquisition processes to operation practices. A large cross-section of stakeholders must be involved in the execution of these tactics for NZEBs to be a consistent outcome of NASA's new construction projects. As outlined in Section 2.4.1, an energy performance assurance process should be developed to guide tactic implementation as described in the following sections.

4.1 Tactical Objectives

Each CP and OP category includes a number of tactics, each of which must be successfully implemented through a series of pilot projects. Many tactics have been executed by other organizations, including NASA, and can be straightforward to implement with minimal risk and disruption to current workflows. Others will require innovative approaches that may replace the current building acquisition processes and design methodologies applied by NASA for new construction projects. Table 4-1 through Table 4-6 summarize the tactics associated with each proficiency category. In addition to tactic description and numbering the tables present information under the following headings.

- *Tactic priority:* From one to five, this value suggests the prioritization of all tactics across proficiency categories.
- *Resources:* If available, specific resources are listed that have further information about the tactic purpose or implementation approach. General resource types are also listed for more commonly implemented tactics.
- *Metrics for success*: The metrics are guides for assessing the level of success of each pilot (the elements of a successful pilot should be translated into draft specification language and the elements of an unsuccessful pilot should be fed into other pilots as lessons learned).
- *Climate and building type*: This is a placeholder for identifying if the tactic applies primarily or only to specific climates or building types. Most tactics apply to all projects.
- *Tactic pairs*: While there is synergy among all tactics, this placeholder highlights other tactics that must be used or considered when the listed tactic is piloted. The paired tactics do not necessarily have to be formally piloted (e.g., tracked for comparison to the metric for success) on the project. The tactic pair notes in the roadmap are not exhaustive, but rather they are meant to bring attention to key connections.
- *Pilot years*: This is the approximate timeframe for which the tactic should be piloted, on numerous projects if necessary. The tactic should be turned into NASA specification language or requirements by the end year. Once a tactic has been transitioned to a requirement, it should still be used on projects but its success does not necessarily need to be tracked and reported with the same rigor as piloted tactics (unless tracking and reporting the success is part of the final requirement).

Table 4-1 Tactics for CP1 (Institutionalize NASA NZEB Workflow)

CP1 Purpose: Transition the NZEB roadmap into a formal NASA process that integrates into current project planning, execution, and review processes.

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
1	CP 1.1	Define NZEB energy performance assurance capability	Determine the appropriate breadth of scope and roles required to execute the roadmap	N/A	Annual tracking and progress toward NASA organizational NZEB goal	N/A	N/A	2014
1	CP 1.2	Establish a process for selecting tactics for each project	Adjust the selection approach proposed in the roadmap as information is collected about future project size, location, and siting	N/A	Each new project pilots a minimum of ten tactics from each proficiency category	N/A	N/A	2014
1	CP 1.3	Establish a pilot lessons learned dissemination approach	Enhance the existing POE process to ensure that tactic-specific lessons learned are transferred as preliminary design guidance to projects using relevant tactics	N/A	A second pilot is successfully implemented based on a first pilot lessons learned	N/A	N/A	2014
2	CP 1.4	Establish a process for distilling lessons learned from pilot POEs into generic RFP, specification, or policy language	Develop a tracking tool to monitor the success of each piloted tactic. On success, identify key components of the tactic that can be turned into specification language or policy	N/A	Tracking tool and specification or policy language template	N/A	N/A	2014-2015
2	CP 1.5	Establish a process for identifying technology/process gaps and addressing high-risk buildings such as labs or buildings in humid climates	Set criteria to determine if unsuccessful piloted tactics should be persisted, replaced, or escalated for further research/resources	N/A	A second pilot results in success or unique lessons learned compared to a previous pilot project	N/A	N/A	2014-2015

CP1 Purpose: Transition the NZEB roadmap into a formal NASA process that integrates into current project planning, execution, and review processes.

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
2	CP 1.6	Perform a benchmarking effort of existing NASA high performance buildings	Establish references for metrics for success (examples given in Section 2.3) to be used for project planning and early energy models, and then updated with each project and used for verification in operations	N/A	A set of NASA-specific metrics for success, focused on subsystems, that can be normalized based on occupancy, space density, etc.	N/A	N/A	2014-2015
2	CP 1.7	Hold an NZEB team kickoff meeting	Upon agency acceptance of an NZEB roadmap, brief project managers, energy managers, and the first pilot project team	N/A	A first set of tactics is selected by a project team (tactic selection should be guided by a team member who has energy performance assurance capability)	N/A	N/A	2014-2015
3	CP 1.8	Refine OP3 tactics based on known Center barriers to RE implementation	Review the most recent RE assessment site summaries, if more recent than the 2011 report, and add RE tactics as needed for each Center, with emphasis on high-risk sites such as those that are land constrained	N/A	OP3 tactics are refined to address Center-level challenges	N/A	N/A	2015-2020
3	CP 1.9	Develop a strategic-level performance assurance review process for NZEBs	Based on other CP1 tactic outcomes, assign Center or Headquarters level oversight of the NZEB design and operations process, as well as performance measurement, reporting, and comparison to EUI and NZEB goals	N/A	A fiscal year reporting process is established that allows project teams to communicate the past year energy use and RE production for each project planned as an NZEB, to the Centers and Headquarters	N/A	N/A	2016-2020

Table 4-2 Tactics for OP1 (Establish NZEB Acquisition Process)

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
OP1 Purpose: In a step-by-step approach, integrate elements of an energy performance-based acquisition process into current NASA acquisition processes; by 2018, all projects begin with a project structure that is conducive to achieving NZEBs.								
1	OP 1.1	Use an integrated project delivery process focused on energy	Evaluate options for integrated project delivery and select a team structure that supports project energy objectives. Clearly define energy objectives (e.g., require that all Leadership in Energy and Environmental Design [LEED] energy credits be achieved)	http://www.aia.org/contractdocs/aias077630	Execute project on time and on budget, while meeting energy objectives. Energy (and water) objectives are met before nonenergy-related LEED credits are met	All	N/A	2014-2017
1	OP 1.2	Assemble a NASA project team to take training using a performance-based acquisition approach	If design-build is appropriate for the project, use Design-Build Institute of America (DBIA) training. Otherwise, select an acquisition approach that allows for early contractor involvement for at-risk cost estimating, inclusion of energy goals in the contract, and performance incentive structures	DBIA training modules	A DBIA-issued record of training or other equivalent documentation of training or experience in performance-based acquisition with an emphasis on energy performance	All	N/A	2014-2017
2	OP 1.3	Include an EUI goal and a NZEB goal in the project contract	Select an EUI goal, starting with the reference values given in the organizational section of the roadmap, and require that this goal be met in the project contract	DBIA training modules	Design team substantiated goal in energy modeling coincident with the design phases. The final energy model shows the building is on track to meet the goal	All	N/A	2014-2017
2	OP 1.4	Define energy goal substantiation requirements	Create an energy appendix in the project contract or request for proposals that shows how NASA expects the energy calculations to be performed and presented, allowing for equal comparisons across proposing teams and easier internal review of energy calculations	NREL how-to guide, http://buildingdata.energy.gov/cbrd/energy_based_acquisition/	Energy calculation appendix is developed by NASA, with the help of internal or external energy analysts, and is followed by the design team	All	OP 1.3	2014-2017

OP1 Purpose: In a step-by-step approach, integrate elements of an energy performance-based acquisition process into current NASA acquisition processes; by 2018, all projects begin with a project structure that is conducive to achieving NZEBs.

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
2	OP 1.5	Include owner representation from all building systems on the integrated project team	Review each potential building system (e.g., security systems, laboratory setup) at project kickoff and ensure there is representation to define system needs early in the design	NREL how-to guide, http://buildingdata.energy.gov/cbrd/energy_based_acquisition/	All loads are well defined in the energy appendix; no general load types are added after the energy appendix is released to the design team	All	OP 1.3	2014-2017
2	OP 1.6	Include internal system experts on the integrated project team	Identify internal system experts for HVAC, lighting, envelope, miscellaneous loads, and/or data centers. Experts relevant to the selected energy efficiency tactics for a project should attend project meetings, review substantiation documents, and participate in project acceptance	N/A	The energy efficiency tactics are successful or are not noted as unsuccessful due to lack of NASA guidance and input	OP2	N/A	2014-2018
2	OP 1.7	Use performance incentives that are tied to an EUI goal	Select an aggressive EUI goal that is on target for net zero energy and include in the project contract. Set aside 1%-2% of the project budget as an award fee if the team substantiated the energy goal in design and then in operations. The award fee comes out of the project budget but goes back in to the project in the form of scope, quality, and performance either through the project team or through later, direct use by NASA	DBIA training modules	Project energy goal is achieved on time and on budget, and more than 75% of the award fee is awarded to the team based on NASA expectations for energy performance being met or exceeded	All	N/A	2015-2018

OP1 Purpose: In a step-by-step approach, integrate elements of an energy performance-based acquisition process into current NASA acquisition processes; by 2018, all projects begin with a project structure that is conducive to achieving NZEBs.

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
3	OP 1.8	Use a competitive team selection process that gives substantial selection weight to proposed energy efficiency	Use a best-value project team selection process in which part of the value is based on a full project proposal, including preliminary energy calculations, that shows how a NASA-specified EUI will be met or exceeded	DBIA training modules	The selected team meets or exceeds the NASA-specified energy goal in design and in operations	All	N/A	2015-2018
4	OP 1.9	Require an early cost and energy optimization model for building system selection	Use internal or external energy analysts to create a NZER building by determining the efficiency package that is most cost effective before renewables become the next most cost-effective measure. Establish this solution set in early design. Internal energy analyst involvement is encouraged for internal ownership and continued updating of the model	http://openstudio.nrel.gov (classes to be offered by NREL-authorized trainers)	The optimization model gives clear direction to the team on building design features that can be referenced by the final design specifications	All, emphasize hot and humid	N/A	2016-2019
4	OP 1.10	Use a NZEB project kickoff process	Engage a team member who has energy performance assurance capability to implement the processes established in OP1. An NZEB kickoff process might also include early energy modeling as well as evaluation of relevant POE lessons learned and successful tactics for inclusion in the project RFP	N/A	List solutions to the POE issues identified and use project members with experience on other site buildings if possible, and reach out to Centers in similar climates for early design feedback	All	N/A	2016-2019
4	OP 1.11	Require that NASA hold an NZEB commissioning contract	Enhance traditional or LEED defined commissioning to be defined and contracted as an owner's representative role	USGBC	Commissioning practices support NZEB operation during the first year of building operation	All	N/A	2018-2021

OP1 Purpose: In a step-by-step approach, integrate elements of an energy performance-based acquisition process into current NASA acquisition processes; by 2018, all projects begin with a project structure that is conducive to achieving NZEBs.

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
4	OP 1.12	Evaluate contract requirements for energy efficiency system training at project turnover	Require or negotiate enhanced training for high-risk systems or systems that NASA or the Center is using for the first time. Preferably, require condition-based maintenance and training for multiple seasonal cycles.	N/A	Through an iterative process of O&M cycles and retraining, NASA O&M staff is able to service energy efficiency system equipment without additional service calls to the manufacturer	All	N/A	2018-2021

Table 4-3 Tactics for OP2 (Establish Energy Efficiency System Best Practices)

OP2 Purpose: A base level of energy efficiency is required by all new projects. Additionally, key system elements and performance requirements are identified that have been shown as roadblocks to NZEBs in low energy building case studies. Each new construction project should select at least one system-level tactic to address in a resource-focused manner with the result being a set of lessons learned that will ensure success on future projects.

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
1	OP 2.1	Use passive design solutions	Use the following design solutions to the extent possible: east-west building orientation, less than 70-foot floor plate depth, passive solar design, high-performance building envelope (detailed consideration of glazing, insulation, and thermal breaks), consideration of static building elements and landscape elements to assist in solar shading and natural ventilation, rectilinear form with modular elements	ASHRAE Advanced Energy Design Guides	A checklist noting design team discussion and modeling regarding each approach. Verify that added geometry or complexity serves an energy purpose	All	N/A	2014-2017
1	OP 2.2	Use efficient active systems	Use the following design solutions to the extent possible: lighting system installed power less than 0.8 W/ft^2, ENERGY STAR approved or FEMP designated equipment, energy recovery to preheat or cool ventilation air, size the HVAC system to meet only the load not met by the passive systems ("right-size" the HVAC system), automatic shading, dynamic glass, automated windows, natural ventilation circulating fans	ASHRAE Advanced Energy Design Guides	Use industry-developed guidance such as the Advanced Energy Design Guides to design and specify low energy building systems required to meet the loads not addressed through passive design	All	OP 2.1	2014-2017

OP2 Purpose: A base level of energy efficiency is required by all new projects. Additionally, key system elements and performance requirements are identified that have been shown as roadblocks to NZEBs in low energy building case studies. Each new construction project should select at least one system-level tactic to address in a resource-focused manner with the result being a set of lessons learned that will ensure success on future projects.								
Envelope								
2	OP 2.3	Procure an optimized envelope	Go beyond best practices suggested in OP 2.1 and compare envelope alternatives using an energy model to refine window-to-wall ratio, roof and wall insulation level, glazing properties, and at minimum meet ASHRAE Standard 189 recommendations	ASHRAE Standard 189	ASHRAE Standard 189 envelope requirements or better are shown in design documents	All	OP 2.1	2015-2022
2	OP 2.4	Require air barrier testing	Ensure proper implementation of OP 2.3 by requiring field air barrier testing as part of the commissioning process	ASHRAE Standard 189	ASHRAE standard 189 (ASTM E2357) air barrier testing requirements are performed	All	OP 2.3	2015-2022
2	OP 2.5	Incorporate an aggressive daylighting design	Use a daylighting model to drive the building footprint and envelope in early design and verify the effectiveness of at least three different daylighting options. Allow interior spaces to “borrow” daylight from perimeter spaces even if the daylight saturation does not meet the complete lighting need of the space	ASHRAE Standard 189	Glare free daylighting at 25 fc average for 75% of the building is measured and verified	All, with less emphasis in cold	OP 2.1	2015-2022
2	OP 2.6	Use natural ventilation	Use an airflow model to verify expected results due to wind resource and internal pressure. Consider both cross and stack ventilation options	ASHRAE Standard 189	Eliminate the need for an active air conditioning system	Mild	OP 2.1	2015-2022
Lighting								
1	OP 2.7	Use vacancy sensors in all daylit areas	Employ a design philosophy that requires occupants to "opt-in" when they want more light than is provided by daylight	Case studies	Verify that no lights in daylit areas turn on automatically. Occupants must manually turn lights	All	OP 2.2	2015-2022

OP2 Purpose: A base level of energy efficiency is required by all new projects. Additionally, key system elements and performance requirements are identified that have been shown as roadblocks to NZEBs in low energy building case studies. Each new construction project should select at least one system-level tactic to address in a resource-focused manner with the result being a set of lessons learned that will ensure success on future projects.

					on			
2	OP 2.8	Use a task/ambient or personal lighting control system	Provide layers of electric light to address different occupant type and task needs	Case studies	Verify that lighting energy use varies on an hourly basis in non-daylit spaces (or during non-daylit hours), in parallel with an assumption of occupancy and task diversity in those spaces	All	OP 2.2	2015-2022
3	OP 2.9	Procure an advanced lighting control system	Combine lighting control solutions for daylighting, occupant type, task type, and has capability for demand control. Auto-commissioning features should be considered	Case studies	Greater than 50% lighting energy use reduction versus an ASHRAE 90.1 2010 baseline is measured and verified	All	OP 2.2, 2.7, 2.8	2015-2022
HVAC								
2	OP 2.10	Use a dedicated outside air system	Separate ventilation air from the heating and cooling systems. Employ energy recovery to pretreat the air	Case studies	Design for, and measure and verify 50% system energy savings versus a 90.1-2010 baseline	All	OP 2.1, 2.2	2015-2022
2	OP 2.11	Use a hydronic system for heating	Consider pairing with GSHP or central plant systems	Case studies	Design for, and measure and verify 50% system energy savings versus a 90.1-2010 baseline	All, except hot	OP 2.1, 2.2	2015-2022
2	OP 2.12	Use a hydronic system for cooling	Consider pairing with GSHP or central plant systems	Case studies	Design for, and measure and verify 50% system energy savings versus a 90.1-2010 baseline	All, except cold	OP 2.1, 2.2	2015-2022
3	OP 2.13	Use a GSHP	Use rigorous ground sampling, and expert design, modeling, and	Case studies	Energy model predictions match operations in the	All	OP 2.1,	2015-2022

OP2 Purpose: A base level of energy efficiency is required by all new projects. Additionally, key system elements and performance requirements are identified that have been shown as roadblocks to NZEBs in low energy building case studies. Each new construction project should select at least one system-level tactic to address in a resource-focused manner with the result being a set of lessons learned that will ensure success on future projects.

			commissioning to ensure the system provides expected energy savings		first year of operation		2.2, 2.11, 2.12	
3	OP 2.14	Use aggressive heat recovery methods	Consider methods such as energy recovery wheels, transpired solar collectors, and data center heat recovery	Case studies	Require no active preheating/cooling of ventilation air	All	OP 2.1, 2.2	2015-2022
3	OP 2.15	Use passive dehumidification methods	Consider methods such as membranes or sea water cooling	Case studies	Require only pump and fan energy for dehumidification	Hot and humid	OP 2.1, 2.2	2015-2022
4	OP 2.16	Use a layered HVAC system where there is a base load for general comfort with tuning for varied occupant comfort	Fine-tune HVAC system design to provide heating, cooling, and/or ventilation only to occupants who need space conditioning at a given point in time, accounting for heating/cooling system latency	Case studies	Design for, and measure and verify 75% system energy savings versus a 90.1-2010 baseline	All	OP 2.1, 2.2	2015-2022
Miscellaneous								
1	OP 2.17	Require that a written sequence of operations be developed for each system and subsystem	The plan must describe function for all variations in operations: occupancy type, time of day, season, and must include reference to other systems that interact with the system of interest (e.g., shade operation must reference operable windows)	Case studies	Written sequence of operations in project specifications and in commissioning functional test plans	All	N/A	2014-2016
2	OP 2.18	Account and control for MELs	In preplanning or early design, take an inventory of all MELs that are likely to be in the building based on other similar buildings or expert advice. Develop a solution to control the plug loads throughout the life of the building	NREL MELs workflow, ACES current work implementing a computer	Verification that 75% of a building's computers go to sleep after 15 minutes is shown through an equipment survey and submetering results	All	N/A	2014-2020

OP2 Purpose: A base level of energy efficiency is required by all new projects. Additionally, key system elements and performance requirements are identified that have been shown as roadblocks to NZEBs in low energy building case studies. Each new construction project should select at least one system-level tactic to address in a resource-focused manner with the result being a set of lessons learned that will ensure success on future projects.								
				sleep program				
4	OP 2.19	Use a control system that integrates HVAC, lighting, and plug loads	Provide central control of all building systems to allow for demand control and adaptation to occupant preferences over time. The control system should allow for collection and analysis of system performance data	N/A	O&M use and acceptance of integrated control system	All	OP 2.9, 2.16	2014-2022
5	OP 2.20	Deploy an occupant feedback system	Develop or specify an occupant feedback system that gives occupants actionable information about when and how to control their personal control systems. Consider actuating control systems based on occupant preferences to allow for preference-based load reduction in lighting and HVAC systems	NREL case study; NASA internal efficiency research	Energy model assumptions and predictions match occupant behavior	All	OP 2.19	2020-2025

Table 4-4 Tactics for OP3 (Establish RE System Integration Process)

OP3 Purpose: In line with the NZEB definition and steps identified in this roadmap, RE systems are time phased and emphasized second to energy efficiency. Once NASA has started to demonstrate proficiency in the energy efficiency categories of envelope, lighting, HVAC, and MELs, project resources should be directed toward integrating RE systems.

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
2	OP 3.1	Apply the NZEB evaluation process	Ensure each project starts with a focus on energy efficiency in design and operations, and then evaluates the options for RE procurement	NASA NZEB Roadmap	Demonstrate that an implemented RE system follows the classification system steps from 1 to 5 (as listed in the roadmap)	All	CP 1.7, 1.8	2016-2022
2	OP 3.2	Perform a RE assessment for the project	Evaluate onsite options for renewables, focusing on zero-emitting sources such as PV, wind, and SHW (SHW is considered a demand reduction solution in the NZEB process definition). Coordinate the RE assessment with the most current Center Master Plan.	NREL resources	Project team provides an assessment report to a NASA team member with energy performance assurance capability	All	OP 3.1	2016-2022
3	OP 3.3	Procure a solar hot water system	Design and procure a solar hot water system that meets the typical demand of a building	NREL resources	Demonstrate a properly sized system that meets 75% of hot water needs	All	OP 3.2	2020-2023
4	OP 3.4	Procure a renewables-ready building	Once an energy-cost optimization is performed for a project and the "best in class" efficiency package is specified, include additional design considerations such as structural integrity, electrical sleeving, piping, switches and valves, and structural attachment points for future RE systems	NREL resources	Provide a future RE integration plan for the building that requires no new construction and diagrams the integration process for ease of future installation	All	OP 3.1, 3.2	2016-2022

OP3 Purpose: In line with the NZEB definition and steps identified in this roadmap, RE systems are time phased and emphasized second to energy efficiency. Once NASA has started to demonstrate proficiency in the energy efficiency categories of envelope, lighting, HVAC, and MELs, project resources should be directed toward integrating RE systems.								
	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
5	OP 3.5	Use a third-party owned RE system integrated into an NZEB	Evaluate local and national guidelines for power purchase agreements and execute an agreement within a project scope. Evaluate the success and lessons learned about the contract and RE system annually	NREL resources	Demonstrate a successful RE power purchase agreement model. Provide annual lessons learned reports to a NASA team member who has energy performance assurance capability	All	OP 3.1, 3.2	2020-2026
5	OP 3.6	Evaluate the cost and greenhouse gas emission impact of offsite renewables	If Step 4 of the NZEB process definition is discussed as a potential option in the NZEB kickoff meeting, engage an agency-level sustainability representative to support a life cycle assessment of offsite RE options and coordinate decision making with current federal requirements related to greenhouse gas reduction.	N/A	If Step 4 is used in the acquisition of an NZEB, the offsite RE is shown to have at least two benefits aside from net zero energy, and be more life cycle cost effective than other RE options. A greenhouse gas mitigation plan is formed for emissions related to offsite source production and T&D.	All, emphasis on high-load buildings	OP 3.1, 3.2	2020-2026

Table 4-5 Tactics for OP4 (Establish NZEB Operations Plan)

OP4 Purpose: NZEB operation requires efforts unique to standard practice. The tactics identify efforts related to submetering, O&M practices, and occupant engagement.

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
1	OP 4.1	Require submetering for all building end uses	Include a submetering requirement in the project contract and ensure that the electric and gas system design and installation disaggregate all end uses. Require that the meters be integrated into the building control system	Case studies	All end use system energy use can be viewed via the building control system	All	N/A	2014-2017
2	OP 4.2	Use a change management approach to prepare occupants for NZEBs	Create training materials, develop lunch-and-learn modules, or set up example systems and tours to prepare incoming occupants for the changes in NZEB operations such as lower workstation walls, slower temperature change, personal control systems, and their roles in energy use	NREL resources, forthcoming FY14	Demonstrate an approach for communicating with and collecting occupant feedback about building features. Provide change management materials for use by other projects	All	N/A	2016-2020
2	OP 4.3	Implement an NZEB occupant move-in process	Mandate a 30-day moratorium on all building changes (not maintenance-related issues) that are related to occupant preference to prevent reactive building operation practice and allow occupants time to find personalized solutions to environmental changes compared to previous working environments. Also, evaluate all building changes with respect to impact on energy use and choose a solution that balances comfort and energy	NREL resources, forthcoming FY14	A written policy addressing the move-in process for building operations staff and training materials for occupants that give suggestions for addressing common concerns related to NZEB systems	All	N/A	2016-2020

OP4 Purpose: NZEB operation requires efforts unique to standard practice. The tactics identify efforts related to submetering, O&M practices, and occupant engagement.

	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
2	OP 4.4	Develop a building or Center-level performance assurance review process for NZEB operations	Measure energy use and report the actual energy use relative to the energy use goal. Use submeter data and an as-built model to normalize the design-predicted EUI, and establish trend analysis for the expected annual operating EUI. Measure and report energy use and production in a format compatible with the reporting process determined in CP 1.9, but report and review at a higher frequency than used for CP 1.9 strategic-level review	NREL resources, forthcoming FY14	A process is established that enables digital reporting (maximum resolution of 15 minutes) of the measured EUI compared to the normalized contract EUI, for each building designed with an energy goal. A written review plan is developed that includes a quarterly or higher frequency evaluation of energy performance	All	CP 1.9	2017-2023
3	OP 4.5	Develop or procure a standard NASA NZEB feedback display	Standardize a NASA display that is deployed at the building or Center level to clearly present the information made available for each building in OP 4.5. The display should give ranges. This tactic requires display design, determination of acceptable operating ranges, and addressing data access gaps and barriers for transferring submetered data to a display form	NREL resources, forthcoming FY14	A facilities team uses the display to determine the seasonal operating performance of a building relative to its energy goal and identifies the area for corrective action if the building is not meeting the goal	All	OP 4.4	2017-2023
3	OP 4.6	Manage the procurement of PPLs over the life of the building	Assign a building or Center plug load champion to take part in PPL procurement and operation over the life of the building	NREL resources, forthcoming FY14	PPL submetering shows alignment with the acceptable operating ranges identified in OP 4.5	All	OP 4.5, 4.6	2017-2023

OP4 Purpose: NZEB operation requires efforts unique to standard practice. The tactics identify efforts related to submetering, O&M practices, and occupant engagement.								
	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
4	OP 4.7	Balance O&M tasks related to NZEBs	Identify tradeoffs in O&M tasks for energy efficiency systems. Add new tasks for things such as PV cleaning but remove tasks for reduced maintenance such as lamp replacement	N/A	Provide NZEB O&M task list and show balanced time and cost	All	N/A	2020-2023
5	OP 4.8	Develop a remediation plan for buildings not achieving NZE	Although some buildings may not achieve an NZEB goal in one fiscal year because of unusual operating conditions, develop a remediation plan for buildings that have not yet achieved net zero energy or do not achieve the goal for two consecutive years	NREL resources, forthcoming FY14	Demonstrate that a building not achieving the NZEB goal in operations is corrected to align with the project goal	All	OP 4.4	2025-2030

Table 4-6 Tactics for CP2 (Achieve NZE)

CP2 Purpose: As a capstone category, these tactics define agency-level metrics for tracking progress toward NZE.									
	Tactic		Description	Resources	Metric for success	Climate and building type	Tactic pairs	
4	*CP 2.1*	Incorporate a subset of tactics to achieve NZEB design	OP1 and OP2; 100% of tactics have been successfully piloted	N/A	A NZER building is designed and constructed	All	N/A	2020-2025
5	*CP 2.2*	Incorporate all applicable tactics to achieve NZEBs	OP1 through OP4; 100% of tactics have been successfully piloted	N/A	An NZEB is designed, constructed, and operated to the goal for 1 year	All	N/A	2025-2030

4.2 Application of Tactics to Achieve Organizational Proficiency

To focus on continuous improvement of NASA processes without placing excessive burdens on any individual project, every new construction and major renovation project should be required to pilot a subset of the tactics presented in Section 4.1. Piloting tactics differs from casual implementation in that third-party experts should be included to guide the NASA team in tactic implementation, and the metrics for success will be monitored using an energy performance assurance process to understand the parameters for success and any barriers that need to be turned into new tactics. The tactic selection should be a collaborative effort between the project planning team, guided by an energy performance assurance process (to be defined as a NASA role in CP1), ensuring that the project team has some level of comfort, if not expertise, with the tactics selected.

1. Tactics in the energy efficiency proficiency category may be selected in schematic design, once the design and construction team has been selected.
2. An energy consultant should be part of this team to develop cost optimization energy models to refine energy efficiency tactic selection that might have been highlighted as options through early, internal energy analysis (if performed).
3. Third-party training should be provided to help the NASA project team develop the skills to address each tactic successfully.
4. Upon completion of each project, significant lessons learned should be shared with other NASA stakeholders, especially those planning new projects, through a knowledge database or formal mentoring program.
5. Finally, knowledge gained from each project should be used to refine best practice documents and standard protocols within NASA, and shared with other agencies that may be facing similar challenges. As best practices are solidified from multiple pilots of a tactic, and NASA develops confidence with new techniques, specific tactics can be checked off the list of candidate options for pilot projects, and instead be required for all future projects. A summary of the overall process is shown in Figure 4-1.

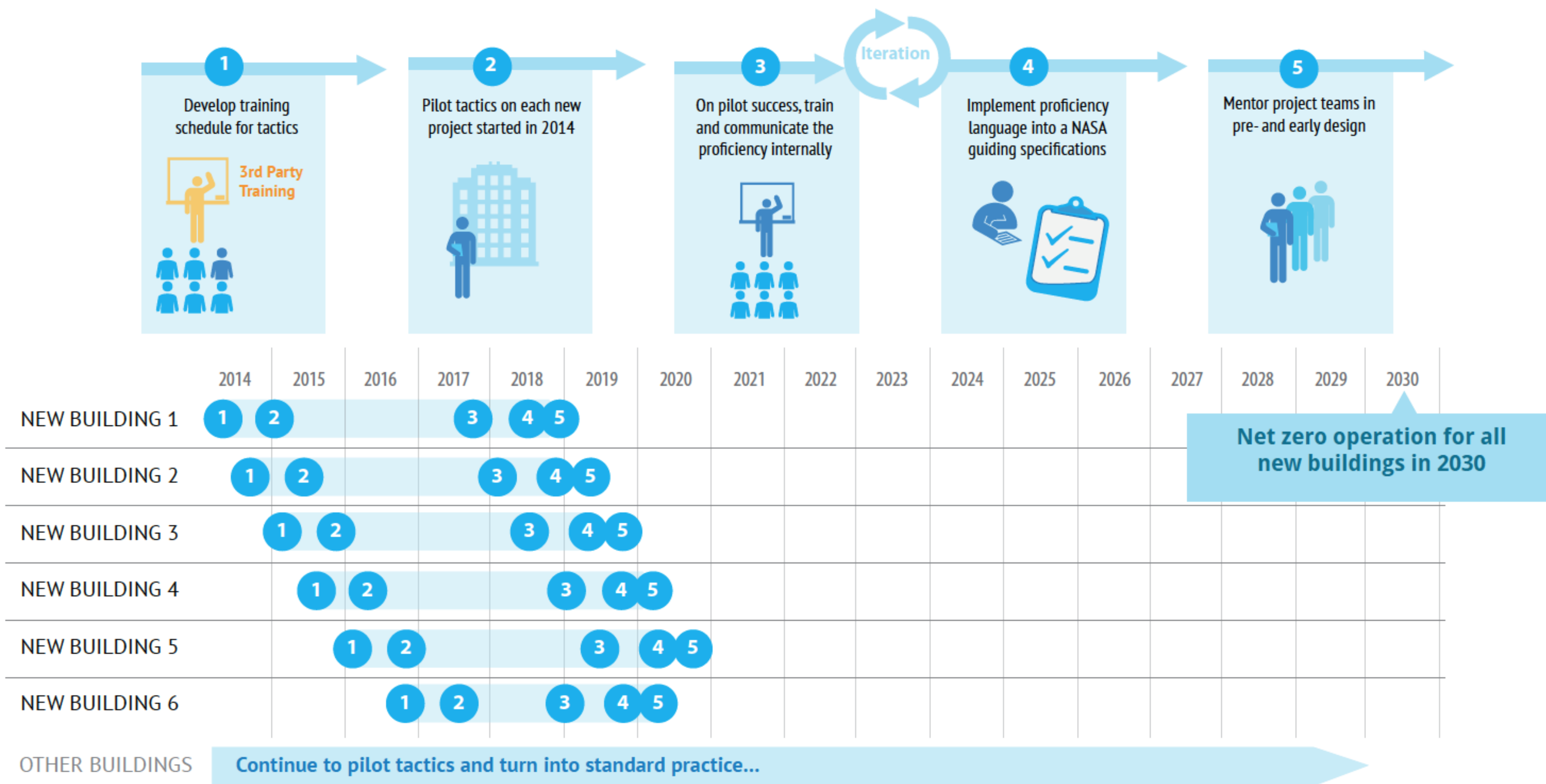

Figure 4-1 Time-phased approach to demonstrating organizational proficiency using individual tactics

For tracking purposes, progress toward proficiency should include three important milestones: (1) completion of the first pilot project; (2) completion of enough pilot projects that application issues are well understood; and (3) documentation of lessons learned and best practices in NASA specifications or policy language. Occasionally, execution of pilot projects may reveal unexpected challenges that require the application of new tactics to overcome.

5 Risks

Execution of this roadmap is predicated on the identification and mitigation of potential risks. These include the following, among others that may be revealed as the first steps are taken on the path to NZEBs:

- Current NASA process gaps must be filled, such as that for NZEB performance assurance at the agency and/or Center level.
- Humid climates and load-intensive laboratories may present significant design challenges and require exceptions to the EUI targets or a longer time frame between project completion and NZEB operating status.
- Changes in management processes, which may require solicitation of volunteers, and rewards for early adopters.
- Large-scale construction of NZEBs that rely heavily on RE may have a significant impact on the electricity grid, which may require the use of load management techniques that are developed in partnership with utilities and researchers.
- Additional budget may be needed to cover additional time and resources needed to implement the roadmap and pilot tactics, including possible costs for training, planning, subcontracting, submetering, tracking, documentation, and O&M. These costs are expected to subside once NZEB construction becomes standard NASA practice.
- Changes in occupancy and building function may cause a well-designed NZEB to fall short in operation, requiring ongoing commissioning or retrofit measures to sustain NZEB performance.

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